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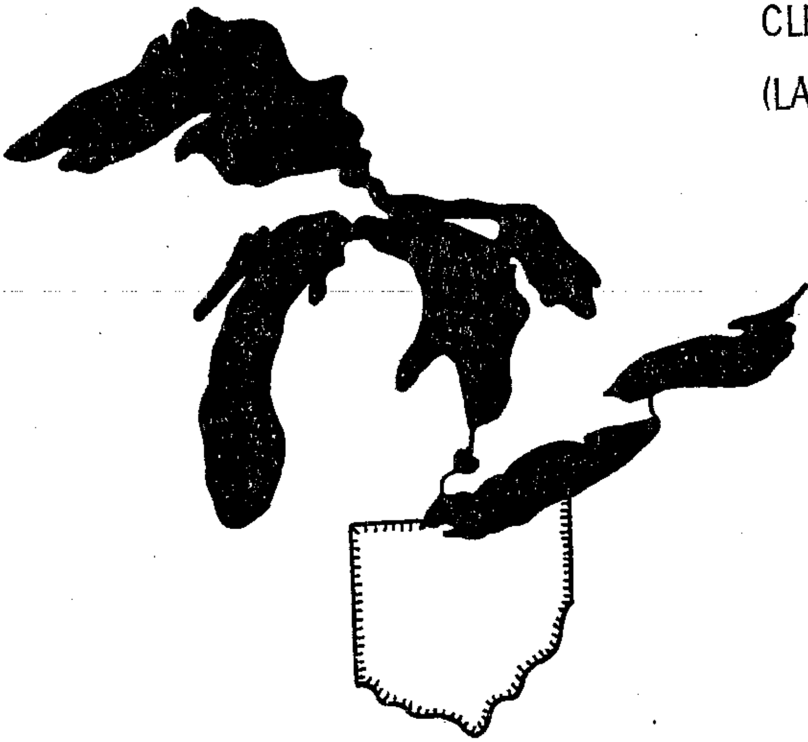

LAKE ERIE INTENSIVE STUDY: NUTRIENT LOADING TO LAKE ERIE AND ITS EFFECT ON LAKE BIOTA

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INTRODUCTION

It is widely known that the Lake Erie aquatic ecosystem has been seriously degraded due to human activities over the past century. Nutrients from agricultural fertilizers, domestic detergents, municipal sewage and industrial wastes have greatly changed the water quality and the aquatic ecosystem. Plankton abundance has increased and fish species and populations have changed. Total dissolved solids have also increased. Detritus in sediments has accelerated the benthic oxygen depletion and development of an anoxic hypolimnion. The eutrophication of Lake Erie has threatened the availability of this vast freshwater resource and the status of the aquatic ecosystem.

Many researchers have addressed the causes of the aging phenomenon and the strategies for reversing the eutrophication process. Also, many efforts have been made to protect the Lake Erie water resource and aquatic ecosystem. However, the current levels of understanding and control are not enough. The eutrophication process of Lake Erie has slowed down due to pollution abatement efforts, but the goal of reversing eutrophication is still distant.

LITERATURE REVIEW

Many studies of Lake Erie's water quality and aquatic ecosystem have sought to develop reliable aquatic chemical and biological data and realistic models or theories which describe the mechanisms operating within the aquatic ecosystem. The literature review conducted here summarizes these studies.

With respect to water quality data, the Great Lakes Water Quality Board (GLWQB) of the International Joint Commission (IJC) Annual Reports (1974, 1975, 1976, 1977, 1978, 1979, 1981) with its Appendices, is the most important source. These reports provide an annual estimation of nutrient loadings from tributaries, direct municipal, direct industrial, atmospheric and upstream sources into Lake Erie for the years 1972 and 1974-1980. The IJC Reference Group on Great Lakes Pollution from Land Use Activity (PLUARG 1978, 1979, 1980) also has reported annual tributary nutrient loadings into Lake Erie for the years 1975-1978. Furthermore, GLWQB (1979) and PLUARG (1978) have estimated short term and long term total phosphorus loadings due to shoreline erosion. Burns, William, Jaquet, Lam and Kemp (1976) have estimated a total phosphorus budget for Lake Erie for 1970, including total phosphorus from tributary sediment transport and shoreline erosion. Fraser and Wilson (CCIW, 1981) have estimated loadings for several chemical variables into Lake Erie for 1967-1976. Fay and Herdendorf (CLEAR, 1981) have estimated trends covering the years 1970 and 1973-1980 for water level, temperature, DO, nutrients, transparency, chlorophyll and total dissolved solids. The GLWQB (1969) report to the International Joint Commission (1979) has nutrient estimations for 1966 and 1967. Rathke (1979) has estimated nutrient distributions in western and central basins for 1975.

There are sufficient total phosphorus loading data but data of total inlake phosphorus are missing for eastern basin for 1970 to 1975. Nitrogen loading data for 1977-1980 are yet to be collected. Nitrogen inlake data are insufficient because data of 1968-1972 and 1976-1980 are missing and yet to be collected.

On the biological availability of phosphorus, in terms of a percentage of the total phosphorus loading into Lake Erie, there are many reports. Both PLUARG (1979) and the Lake Erie Waste Water Management Study (1979) have reported on tributary available phosphorus, and the U.S. Environmental Protection Agency (EPA, 1980) and PLUARG (1979) have reported on direct municipal phosphorus which is nearly all available. No study on the availability of atmospheric phosphorus for Lake Erie has been done. However, EPA's publication on the atmospheric phosphorus input to Lake Michigan (1980) and Peter's report (1977) on the available atmospheric phosphorus for the Montreal area can be used as guides. Both PLUARG (1978, 1979) and William, Murphy and Mayer (1976) have reported on the availability of phosphorus from shoreline erosion. Finally, the biologically available phosphorus output to downstream of Lake Erie can be estimated from data in Lake Erie Nutrient Control: Effectiveness Regarding Assessment in Eastern Basin (1980) published by EPA. The availability of total phosphorus (TP) and nitrogen (N) in tributary, direct municipal, direct industrial, upstream input and output to downstream may be calculated from Fraser and Wilson's (1981) Lake Erie loading estimations for 1967-1976.

Herdendorf (1980) has published chlorophyll *a* data for the western, central and eastern basins of Lake Erie for 1967-1974, and Rathke (1979) has estimated corrected chlorophyll *a* for the western and central basins, for 1975. Fay and Herdendorf (1981) have published chlorophyll data for the western, central and eastern basins for 1970 and 1973-1980, and Gregor and Ongley (PLUARG, 1978) have estimated the chlorophyll *a* concentration for the Canadian nearshore of the western, central and eastern basin for 1967-1973. The GLWQB (1969) report to IJC has phytoplankton estimates for each basin of Lake Erie for 1963-1964 and 1967-1968. Rathke (1979) has reported central basin phytoplankton for 1975. Munawar and Munawar (1976) have estimated the phytoplankton for the western, central and eastern basins for 1970. Central basin zooplankton counts for 1975 have been reported by Rathke (1979). Lake average zooplankton data for 1970 has been reported by Watson and Carpenter (1974). Bacteria data for 1967 and 1970 have been reported by Rao and Burnison (1976). American nearshore bacteria data are available for 1967-1969 (FWPCA, 1969) and Canadian nearshore coliform data for 1967-1973 are available (1978). Commercial fishery data for 1967-1979 have been reported by Baldwin, Saalfield, Ross and Buettner (GLFC, 1979).

Data of phytoplankton for 1965, 1969, 1971-1974 are unavailable right now, and no data for years after 1975 are published. Data on zooplankton are available only for 1970 and 1975 and hence are insufficient. Bacteria data are available for 1967 and 1970 only. Nearshore phytoplankton, zooplankton and bacteria data are fractional and incomplete. In conclusion, data for phytoplankton, zooplankton and bacteria are seriously inadequate and waiting to be collected.

Central basin hypolimnion thickness and temperature data for 1973-1980 are available from Fay and Herdendorf (1981). Central basin hypolimnion oxygen depletion rates for 1930-1977 are available from U.S. Army Corps of Engineers (1979); the data for 1978-1979 are available from Fay and Herdendorf (1981). Secchi disk transparency data for the eastern and central basins for 1960-1963 and 1967 are available from Reference (1969). Secchi disk transparency data for the western, central and eastern basins for 1973-1980 are also available from Fay and Herdendorf (1981). Central basin hypolimnion nutrient data for 1970, 1973-1974 and 1975 are available from DiToro and Connolly (1980). Central basin hypolimnion chlorophyll data for 1973-1974 and 1975 are also available from EPA (1980). Lake wide sediment phosphorus data for 1971 are available from William, Jaquet and Thomas (1976). Central and western basins sediment bacteria data for 1972 are available from Dutka, Bell and Liu (1974).

A summary table for those aforementioned available data, so far, are presented in Table 1.

With respect to theories and models dealing with aquatic ecosystems, Sykes (1973, 1974, 1976) has established criteria for identifying single or multiple limiting nutrients. Smith (1969), Vollenweider (1968), Thomas (1969), Hutchinson (1970) and Steele (1962, 1978) have published papers concerning nutrients as limiting factors in aquatic ecosystems, and Smith (1936), Steele (1962, 1978), Vollenweider (1969) have proposed theories or models concerning light as a limiting factor. Schaefer (1968) and Beverton and Holt (1957) have proposed models for fish catches. Steele (1962, 1978) has also discussed the critical depth for algae and the determination of the limiting factor. Gause (1934), Lotka (1925), Volterra (1926) and MacArthur (1955, 1972) models are all for biomass coexistence. The Manhattan College Group (1971, 1974, 1975) have worked on the interactions between phytoplankton, zooplankton and nutrients. These models simulate the dynamics of phytoplankton chlorophyll, zooplankton carbon, and various forms of nitrogen and phosphorus. Chen and Orlob's Ecological Model (1968, 1970, 1975) also simulates ecological processes in water resource systems. The Snow-Thompson Model (1968) compares the saturation of hydroxy-apatite and plankton concentrations in Lake Erie and notes their inter-dependences. The Chen and Orlob Model is for nearshore, while Manhattan College Group Models and Snow-Thompson Model are for the open lake.

NUTRIENT LOADS

To understand how Lake Erie's water quality changed during the past decade, the phosphorus loads from different sources (namely, tributary, direct municipal, direct industrial, atmospheric, upstream input, shoreline erosion and output to downstream) have been studied. Annual phosphorus loads for each source for the period 1970 through 1980, were collected from published reports or estimated from reliable data. These phosphorus loads were then studied to see if any trends existed. The results are presented as Table 2 and Figure 1. The trend of phosphorus load from each individual tributary was also studied for the purpose of assessing the effectiveness of nutrient control programs. USGS tributary surface water and chemical data were collected for linear or nonlinear regressional model analyses. The results for Maumee, Sandusky, Huron, Portage, and Cuyahoga Rivers are presented in Table 3 and Figures 2-6. Supporting data are found in the Appendix.

PROPOSED INVESTIGATION ON LIMITING NUTRIENTS AND FACTORS

Objectives

The objectives of this research are: (1) to identify the limiting nutrients/factors, and (2) to determine the optimum nutrient input loads for Lake Erie. The most likely limiting factors are nitrogen, phosphorus, light and temperature.

Availability

The purposes of studying the availability of nutrients are to see whether biomass, hypolimnetic oxygen depletion rate and fishery yields correlate with the total amounts of nutrients or the available amounts of nutrients.

The research on availability of nutrients will be based on published reports and will consider tributary, direct municipal, direct industrial, atmospheric, upstream input, output to downstream, and shoreline erosion. A summary of preliminary results is shown in Table 4. Nutrient availability for nearshore and open lake areas will be studied separately to see if there is any difference between these two regions. Besides, the relation between chemically defined and biologically defined availability for each category will be studied and discussed.

Limiting Nutrients/Factors

For the case of pure cultures in chemostats, the relationship between nutrient variation and biomass have been shown to be as follows (Sykes, 1973, 1974):

TABLE 5

EFFECT OF INCREASING THE INFLUENT CONCENTRATION OF ONE SPECIFIED NUTRIENT (AFTER SYKES, 1973, 1974)

	Limiting		Nonlimiting	
Culture Concentrations	Single Limiting Nutrient Case	Multiple Limiting Nutrient Case	Single Limiting Nutrient Case	Multiple Limiting Nutrient Case
Specified nutrient	No change	Increase	Increase	Increase
Biomass	Increase	Increase	No change	No change
Other limiting nutrients	NA	Decrease	No change	No change
Other nonlimiting nutrients	Decrease	Decrease	No change	No change

However, for the cases of pure cultures in batch systems and mixed cultures, the corresponding relationships between nutrient variation and biomass are not yet known. These will require further development. It is believed that graph theory is applicable to this problem. As indicated by Levins (1968), if the structure of the Lake Erie ecosystem can be graphed, it should be possible to predict the responses of each component of the ecosystem to changes in the inputs of limiting factors and nutrients. Thus a table of expected responses can be constructed for each of the supposed limiting factors or nutrients. Since the different factors and nutrients enter the ecosystem graph at different points, the overall pattern of responses for each factor or nutrient should be different, even though some components (e.g., fishery yields) may respond the same way to increases in any limiting factor or nutrient.

In order to determine the actual correlations between limiting nutrients and factors and the various components of the Lake Erie system, a regression analysis will be performed upon the available data summarized in literature review. The time series for total phosphorus loading, inlake total phosphorus concentration, chlorophyll _a_, fishery yields, and hypolimnion oxygen depletion rates are shown in Figure 7. Those for Secchi disk transparency, hypolimnion thickness and hypolimnion temperatures are shown in Figure 8. The correlations determined from the regression analyses of the field data will be compared to the tables of responses predicted by ecosystem theory. This comparison will permit identification of the limiting factors and nutrients.

Optimum Loading and Inland Nutrient Levels

There are several criteria for establishing the optimum nutrient input rates, but in this study the yields of desirable fish species will be used. This will be done for two reasons: (1) fish species, especially commercial fish, are sensitive indicators of overall water quality, integrating many environmental factors over the several years of their life cycles, and (2) the fish themselves are of major economic importance to the Lake Erie basin. It is expected that if the historical data on nutrient inputs covers a wide enough range, the correlation between fish yields and nutrient input rates ought to show an optimum directly. If not, it may be possible to deduce an optimum from the ecosystem graph. This, however, would require numerical estimates of the mass fluxes between components of the graph, which may not be currently available. In this case, the available data will be collected and organized, and the needed data will be identified.

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TABLES

TABLE 1
LIST OF AVAILABLE DATA FOR NUTRIENT LOADS

TP Loading: Lake Total ('70-'79) (25); Lake Total ('67-'76) (26); Lake Total ('66-'67) (47)

TP in Lake: WB, CB, EB ('70, '73-'80) (25); WB ('58,'59,'62,'63) (47); WB, CB ('70-'75) (44); WB, CB ('70-'77), EB ('73-'76) (49)

N Loading: Lake Total ('67-'76) (26); WB, CB ('75) (67); Lake Total ('66-'67) (47)

N in Lake: WB, CB, EB ('63-'65 & '73-'75) (44); WB, CB ('75) (67); WB, CB, EB ('63-'64 & '67) (47); WB, CB, EB ('69-'71) (19)

Temperature: CB ('73'-80) (25)

Turbidity: CB, EB ('80) (25)

POC in Lake: WB, CB, EB ('73,'74,'75) (44)

Chlorophyll a: WB, CB, EB ('67-'74) (44); WB, CB ('75) (67); WB, CB, EB ('70, '73-'80) (25); WB, CB, EB (Nearshore of Canada) ('67-'73) (61); EB (Nearshore) ('78) (73)

Phytoplankton: WB, CB, EB ('63-'64 & '67 & '68) (47); Lake Avg. ('70) (90); WB, CB, EB ('70) (4); CB ('75) (67); Nearshore of Ohio ('68-'72) (68); EB (Nearshore) ('78) (73)

Zooplankton: Lake Avg. ('70) (90); CB ('75) (67); Nearshore of CB (crustacean) ('78, '79) (41); EB (Nearshore) ('78) (73); WB (Nearshore) ('77); WB, CB, EB ('67) (47); WB, CB, EB ('74) (44)

Water Level: Cleveland (monthly, '60-'80); Lake Avg. (1860-1968) (47)

Bacteria: WB, CB, EB ('67, '70) (4); Ohio Nearshore ('68-'72) (68); WB, CB, EB (Canada Nearshore) (Coliform only) ('67-'73) (61); WB (Nearshore) ('78, '79) (14); WB (Canada Nearshore) (Coliform) ('67-'68) (CCIW Data); America Nearshore ('67, '68, '69) (13); Ohio Nearshore ('78) (43); EB (Nearshore) ('78) (73)

Fishery (commercial): Lake Wide ('67-'79) (2)

Hypo Bacteria: CB ('70) (3)

Hypo Thickness: CB ('73-'80) (25)

TABLE 1 CONT.

Hypo Temperature: CB ('73-'80) (25); CB ('70) (3)

Hypo Oxygen Depletion Rate: CB ('30-'77) (49); CB ('78, '79, '80) (25)

Hypo Area: CB ('30-'74) (44)

Secchi Disk Transparency: EB, CB ('60-'63, '67) (47); WB, CB, EB ('73-'80) (25)

Hypo TP: CB ('70, '73-'74), '75) (15)

Hypo Nitrate: CB ('70, '73-'74, '75) (15)

Hypo Chlorophyll: CB ('73-'74, '75) (15)

Sediment Phosphorus: Lake Wide ('71) (4)

Sediment Bacteria: CB, WB ('72) (20)

Sediment Phytoplankton: CB ('70) (3)

Total Phosphorus as P (MT/yr)	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Tributary (+ unmonitored)		(29) 5125		(30) 5030	(30) 8161	(31) 4903	(66) 5553 (+1658)	(33) 5285 (+1260)	(35) 10070 (+2804)	(c) 6266 (+1566)	
Direct Municipal		(29) 8539		(30) 10493	(30) 6977	(31) 6632	(66) 5731	(33) 5681	(35) 4440	(37) 2958	
Direct Industrial		(29) 263		(30) 281	(30) 126	(31) 68	(66) 275	(33) 135	(35) 191	(12) 186	
Atmosphere		(a) 1119		(a) 1119	(a) 1119	(a) 1119	(66) 1119	(33) 1119	(35) 879	(12) 774	
Upstream Lake Input		(29) 2987		(a) 2987	(a) 1080	(a) 1080	(66) 1080	(33) 1080	(35) 1080	(a) 1080	
Sub-total	(25) 23500	18033	(25) 22000	19910	18263	13802	15416	14560	19464	12830	
Shore Line Erosion	(5) 14800	(b) 13379	(b) 11957	(36) 10536	(b) 9336	(b) 8136	(62) 6936				
Output to Downstream	(26) 7016	(26) 3421	(26) 3554	(26) 5141	(26) 5262	(26) 3806	(26) 5071				
Net Total	45316	34833	37511	35587	32861	25744	27423				

Note: a= assumed
b= by interpolation
c= calculated by linear/nonlinear regressional analyses and watershed factor, details shown in this report

Table 2: IJC GLWQB Data for Total Phosphorus Loading into Lake Erie, 1970-1980

Calculated Total Phosphorus Load to Lake Erie from Major Tributaries (MT/yr)

Tributary	Maumee	Sandusky	Huron	Portage	Cuyahoga
'70	2434.0	389.8	84.1	—	—
'71	2139.4	584.5	65.5	—	—
'72	2475.1	253.4	116	—	—
'73	—	—	—	—	—
'74	4793.9	1332.5	481.7	132.3	483.5
'75	2628	595	136	156	788
'76	2960	362	95	86	420
'77	1700	244	111	110	357
'78	3298	494.4	—	—	374
'79	1870.4	444.3	240.8	87.1	396
'80					

Tabe 3: Total Phosphorus Loading into Lake Erie from Tributaries

Table 4: Availability of Phosphorus from Different Sources Loading into Lake Erie

Source of Phosphorus Loading		Ratio of Phosphorus Categories	Range (%)	Average (%)	Reference Number
Tributary	Flow	NAP/TP	14-40		36
		OP/TP	4-58	31	49
		SRP/TP	60-30	decreasing	26
				50	64
	Sediment	NAP/TP	43-89	66	49
Direct Municipal		TBAP/TP	58-88	72	12
		SRP/TP	51-65	55	26
			32-80	56	64
Direct Industrial		SRP/TP	52-58	55	26
Atmospheric		TSP/TP	28-50	40	21 59
Upstream Lake Input		TSP/TP	54-60	56	19 , 62
		SRP/TP	20-57	29	26
Shoreline erosion		NAP/TP	5-14	10	92 65 64
Output to Downstream		TSP/TP	14-30	24	74
		SRP/TP	65-20	decreasing	26

Notes:

TSP=Total soluable phosphorus = SRP+SOP (Soluable reactive P+Soluable organic P)

NAP=Non-apatite phosphorus

TP =Total phosphorus

OP =Orthophosphate

TBAP=Total bioligical available phosphorus; TBAP x 0.95=TSP, (47) for Direct Municipal.

FIGURES

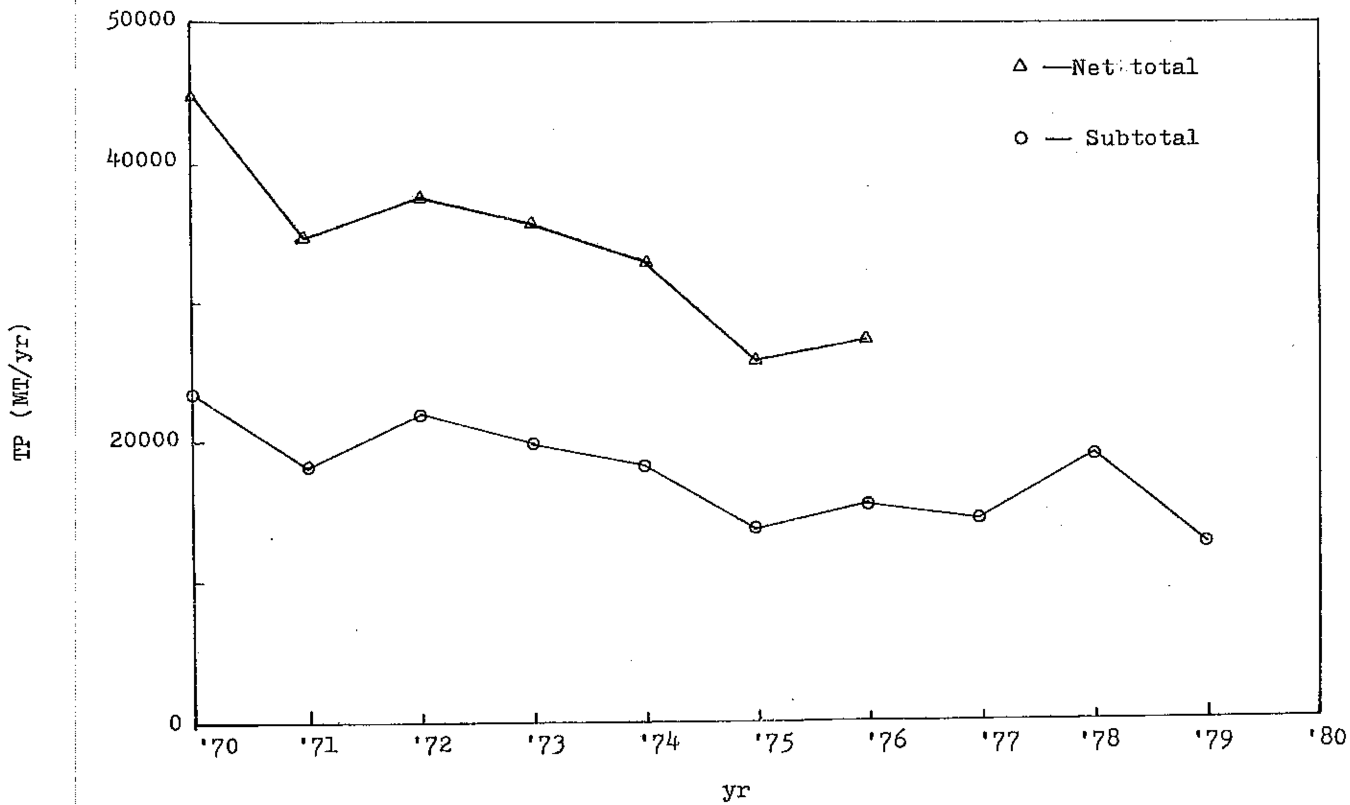


Fig. 1: Total Phosphorus Loading into Lake Erie, '70-'80

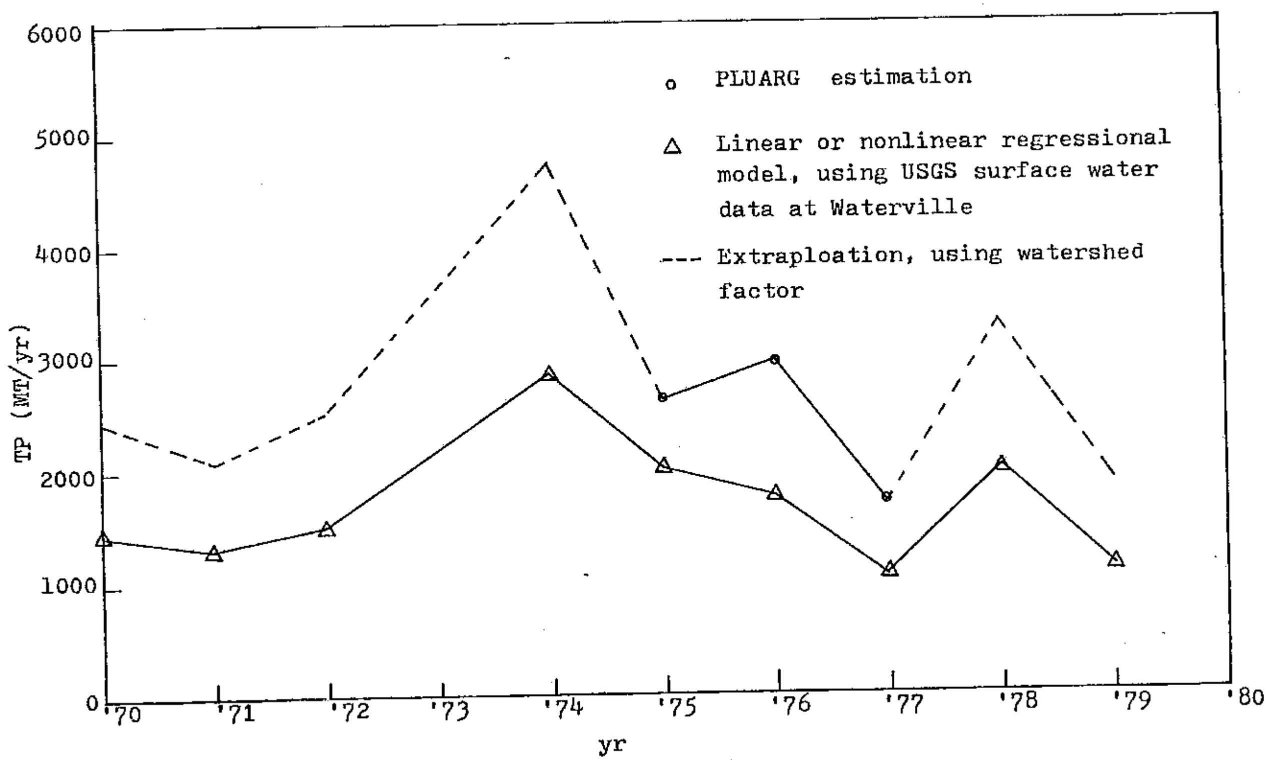


Fig. 2 : Total Phosphorus Load of Maumee River into Lake Erie

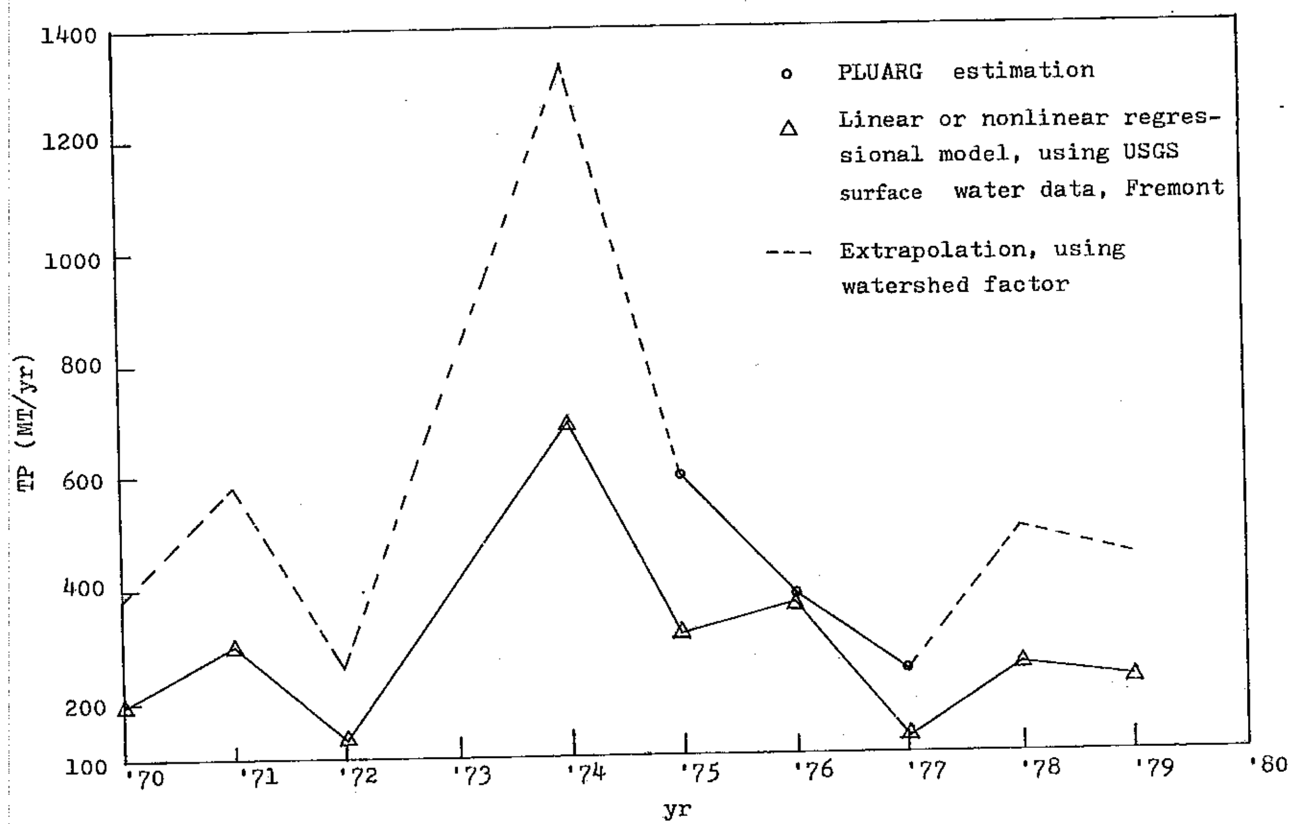


Fig. 3 : Total Phosphorus Load of Sandusky River into Lake Erie

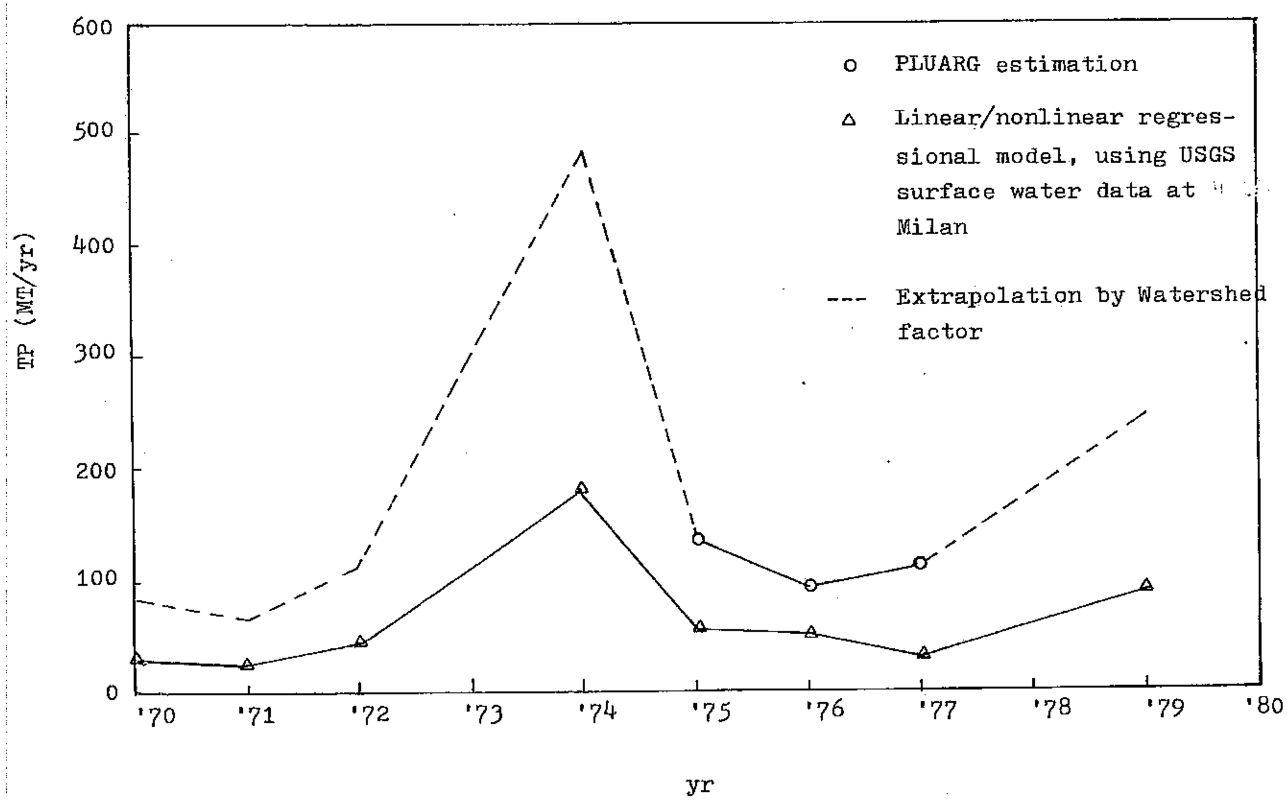


Fig. 4: Total Phosphorus Load of Huron River into Lake Erie

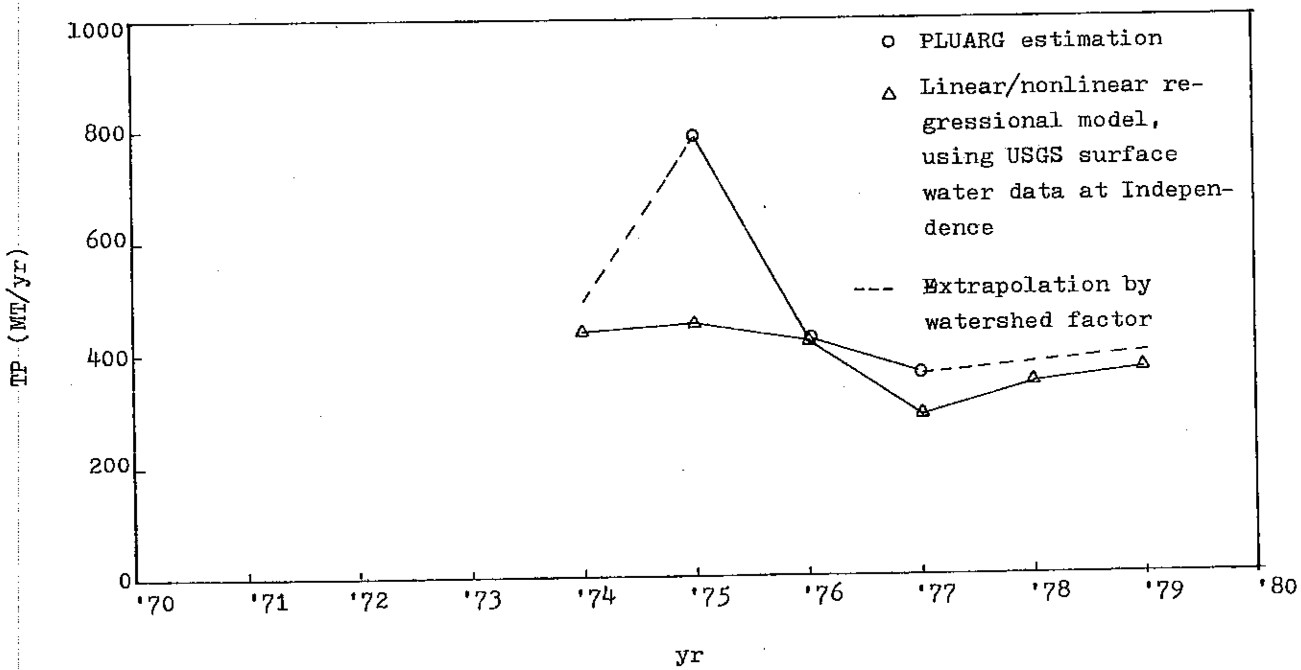


Fig. 5: Total Phosphorus Load of Cuyahoga River into Lake Erie

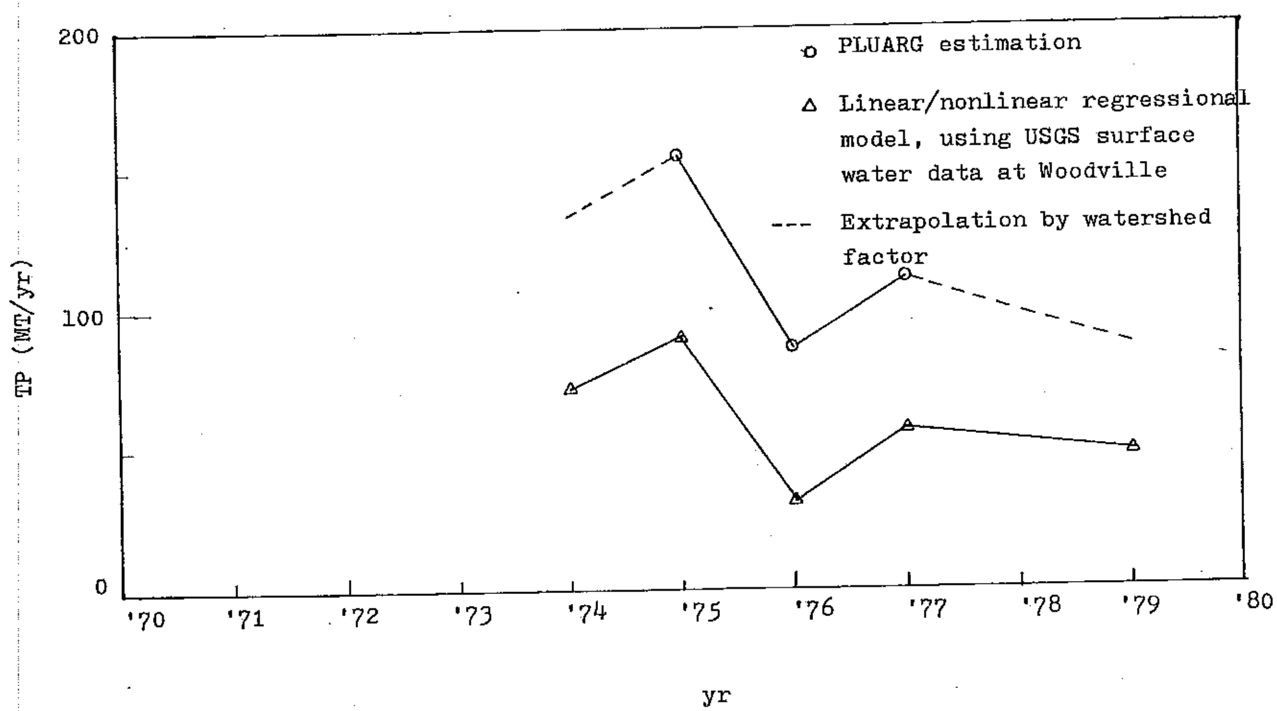


Fig. 6: Total Phosphorus Load of Portage River into Lake Erie

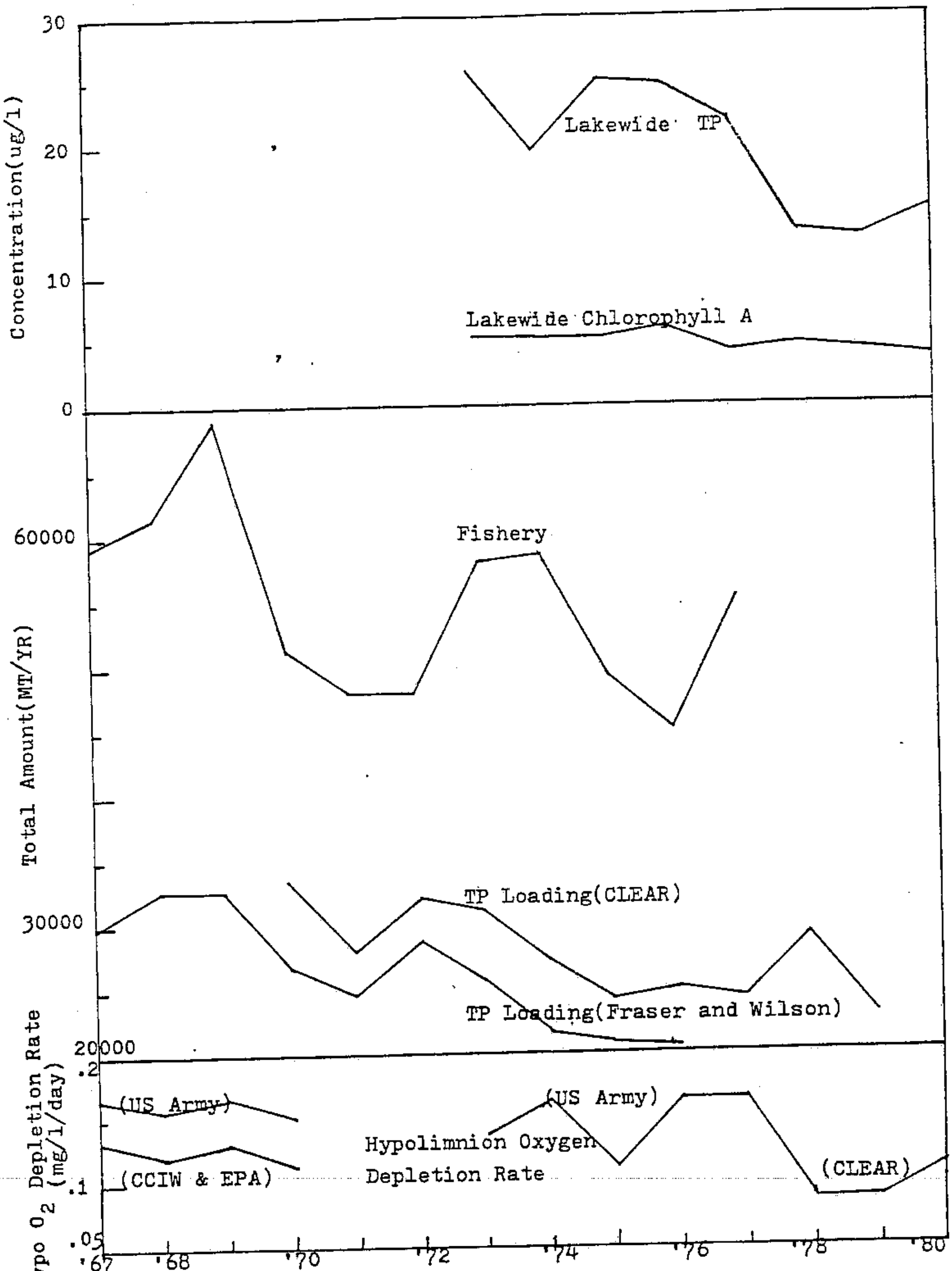


Fig. 7 Correlation between nutrients, fishery, chlorophyll a and hypolimnion oxygen depletion rate for Lake Erie

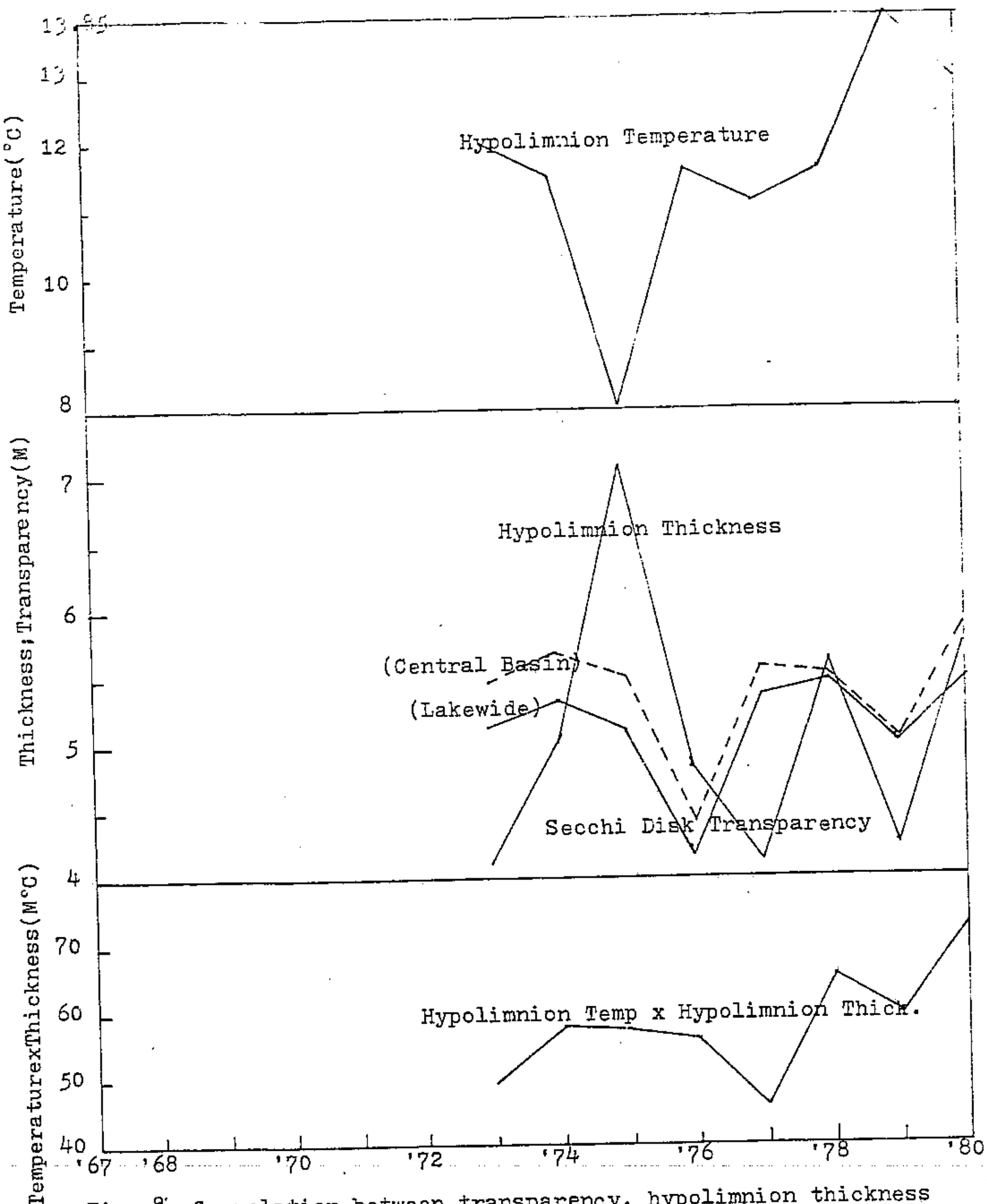


Fig. 8: Correlation between transparency, hypolimnion thickness and hypolimnion temperature

APPENDIX

APPENDIX A

CALCULATION OF TOTAL PHOSPHORUS LOAD TO LAKE ERIE FROM TRIBUTARIES

CALCULATION OF THE TRIBUTARY TP LOAD, 1979

PLUARG: (63) & (78)

1975 $\Sigma$of 5 Rivers/ $\Sigma$of US = 4301/8639 = 49.8%

1976 $\Sigma$of 5 Rivers/ $\Sigma$of US = 3917/7732 = 50.7%

1977 $\Sigma$of 5 Rivers/ $\Sigma$of US = 2521/5130 = 49.1%

Avg. = 49.9%

for '76 (66)

PLUARG: Σ US/Σ Lake Erie = 7732/9643 = 80.2%

Task Group III: = 7732/10276= 75.2%

GLWQB: = 5603/7211 = 77.7%

Avg. = 77.7%

$\Sigma$of 5 Rivers (PLUARG)/Σ of Lake Erie (GLWQB)=0.499x0.777=38.8%

USGS data, and watershed factor)	1978	1979
Maumee River	3298	1870.4
Huron River	180.0	241.0
Portage River	95.7	87.1
Sandusky River	494.4	444.3
Cuyahoga River	374.0	396.0
	4442.1	3038.8
Total Tributary =	4442.1/0.388	3038.8/0.388
	= 11465	= 7832
	(=9172+2293)	(=6266+1566)

LAKE ERIE 1976 PHOSPHORUS LOAD (66)
(metric tons)

Source	PLUARG			TASK GROUP III			WATER QUALITY BOARD		
	U.S.	Cdn.	Total	U.S.	Cdn.	Total	U.S.	Cdn.	Total
Direct Municipal	5588	70	5658	6846	81	6927	5661	70	5731
Direct Industrial	111	164	275	111	164	275	111	164	275
Tributary Total	7732	1911	9643	7732	2544	10,276	5603	1608	7211
Atmospheric	-	-	774	-	-	1119	-	-	1119
Load from Upstream Lake	-	-	1080	-	-	1080	-	-	1080
Other: Urban Direct			44	-	-	-	-	-	-
TOTAL			17,474			19,677			15,415

ESTIMATION OF TRIBUTARY PHOSPHORUS
LOADING INTO LAKE ERIE, 1975-1978.

Tributary Phosphorus Loading (MT/yr)	PLUARG			GLWQB		
	U.S.A.	Canada	Total	Monitored	Unmonitored	Total
1975	(78) 8639		8639*	(31) 4903		4903**
1976	(66) 7732	1911*** (±265)	9643	(32) 5553 (±357)	(66) 1658 (±265)	7211 (±622)
1977	(78) 5130	1830*** (±211)	6960	(33) 5285 (±533)	(33) 1260 (±132)	6550 (±665)
1978	(78) 9100	1877*** (±203)	10977	(35) 10070 (±899)	(35) 2804 (±396)	12874 (±1295)

* Incomplete ** Underestimation

*** Data Source: Ontario Ministry of Environment

CALCULATION OF INDIVIDUAL TRIBUTARY TP LOAD
BY EXTRAPOLATION WITH A WATERSHED FACTOR

MAUMEE RIVER

1975		2628/2004 = 1.31 *
1976		2960/1742 = 1.70
1977		1700/10428 = 1.63
	Watershed Factor	Average = 1.67
1978		1981 x 1.67 = 3298(MT/yr)
1979		1120.7 x 1.67 =1870.4(MT/yr)
1970		1457.5 x 1.67 =2434.0(MT/yr)
1971		1281.1 x 1.67 =2139.4(MT/yr)
1972		1482.1 x 1.67 =2475.1(MT/yr)
1974		2870.6 x 1.67 =4793.9(MT/yr)

SANDUSKY RIVER

1975		595/318.5 = 1.87
1976		362/370 = 1.00 *
1977		244/123.6 = 1.97
	Watershed Factor	Average = 1.92
1978		257.5 x 1.92 = 494.4(MT/yr)
1979		231.4 x 1.92 = 444.3(MT/yr)
1970		203 x 1.92 = 389.8(MT/yr)
1971		304.4 x 1.92 = 584.5(MT/yr)
1972		132 x 1.92 = 253.4(MT/yr)
1974		694 x 1.92 =1332.5(MT/yr)

* Not used for Average Watershed Factor Calculation.

Cuyahoga River

1975	788/448=1.8*
1976	420/424=1.0
1977	357/287=1.2

Watershed Factor (Avg.) =1.1

1974	439.5 x 1.1=483.5	(MT/yr)
1978	340 x 1.1 =374	(MT/yr)
1979	360 x 1.1 =369	(MT/yr)

Portage River

1975	156/90 =1.73
1976	86/31 =2.77*
1977	110/57 =1.93

Watershed Factor (Avg.) = 1.83

1974	72.3 x 1.83=132.3	(MT/yr)
1979	47.6 x 1.83=87.1	(MT/yr)

Huron River

1975	136/52 =2.6
1976	95 /52.2=1.8
1977	111/30 =3.7

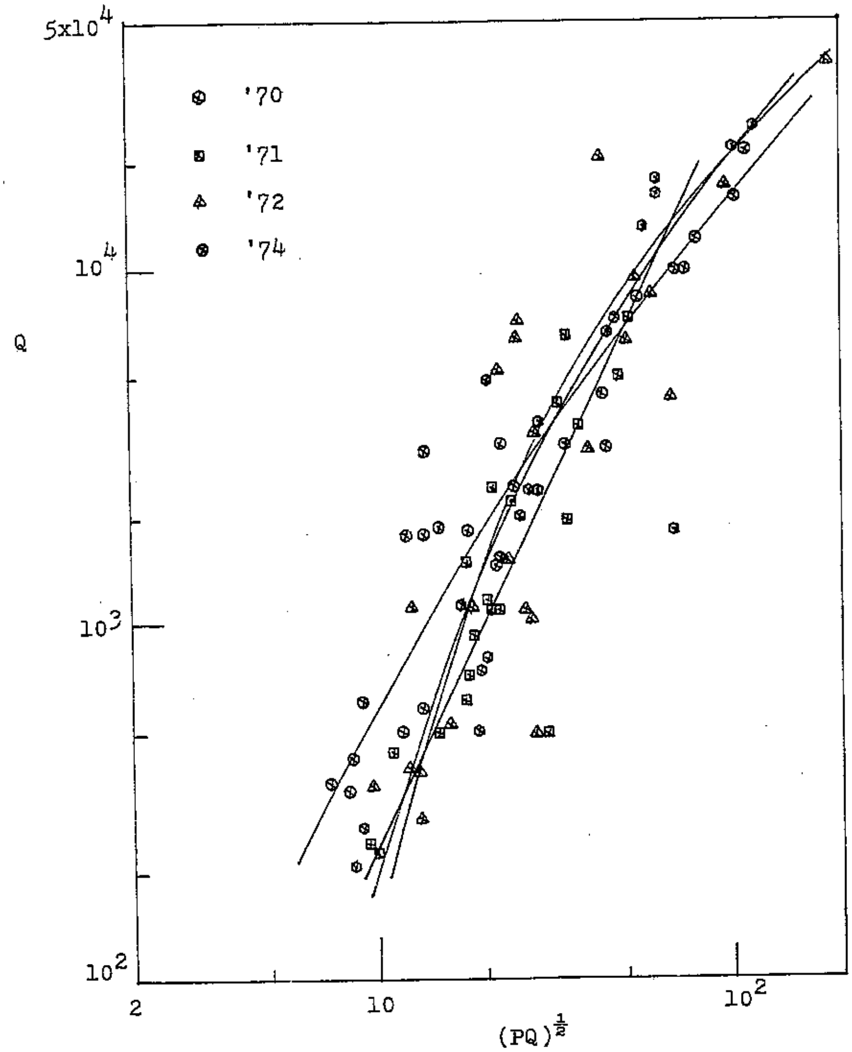
Watershed Factor (Avg)=2.7

1970	31.1 x 2.7	= 84.1 (MT/yr)
1971	24.2 x 2.7	= 65.5(MT/yr)
1972	43.0 x 2.7	= 116 (MT/yr)
1974	178.4 x 2.7	= 481.7(MT/yr)
1979	89.2 x 2.7	= 240.8(MT/yr)

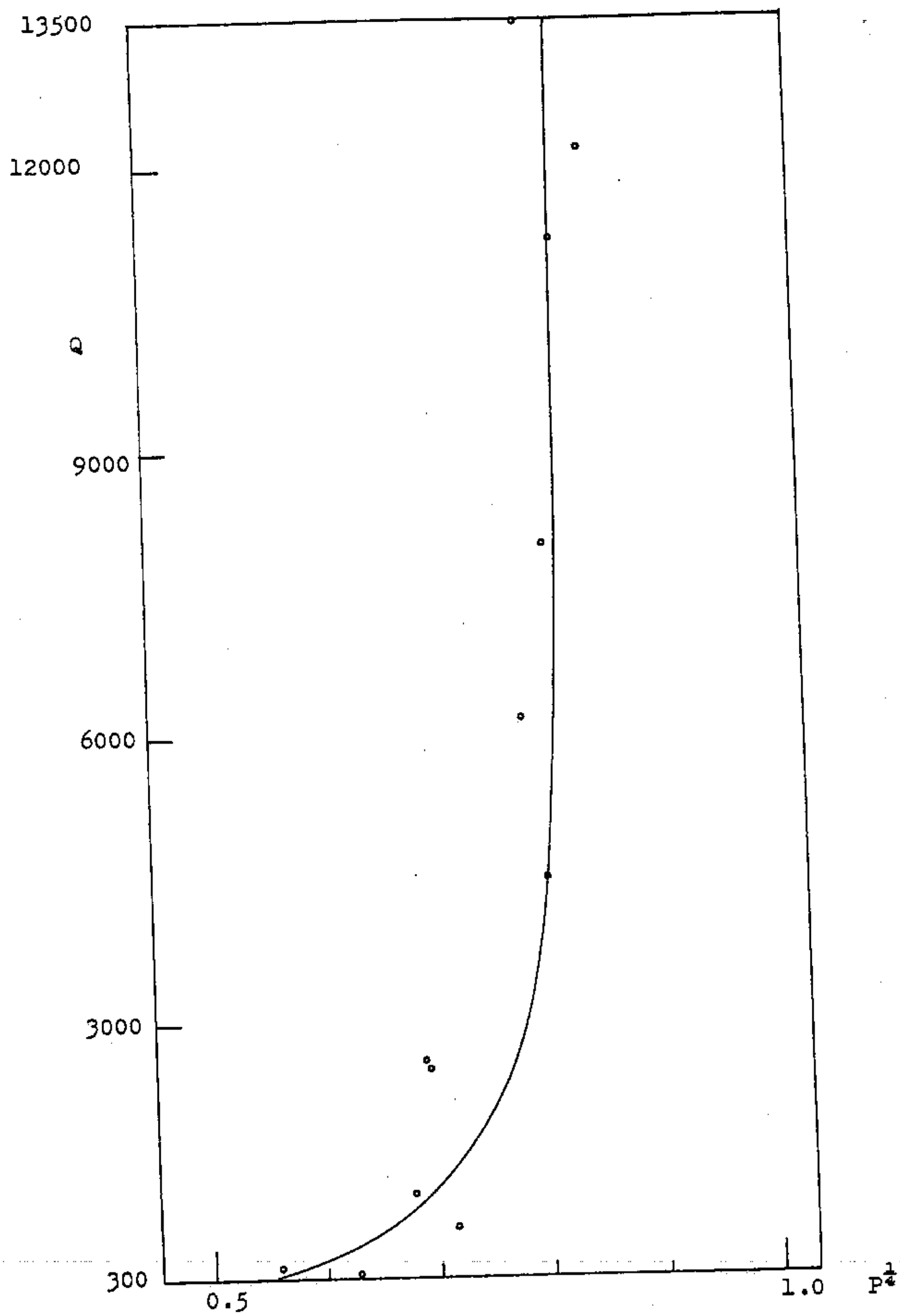
* Not used for Average Watershed Calculations.

APPENDIX B

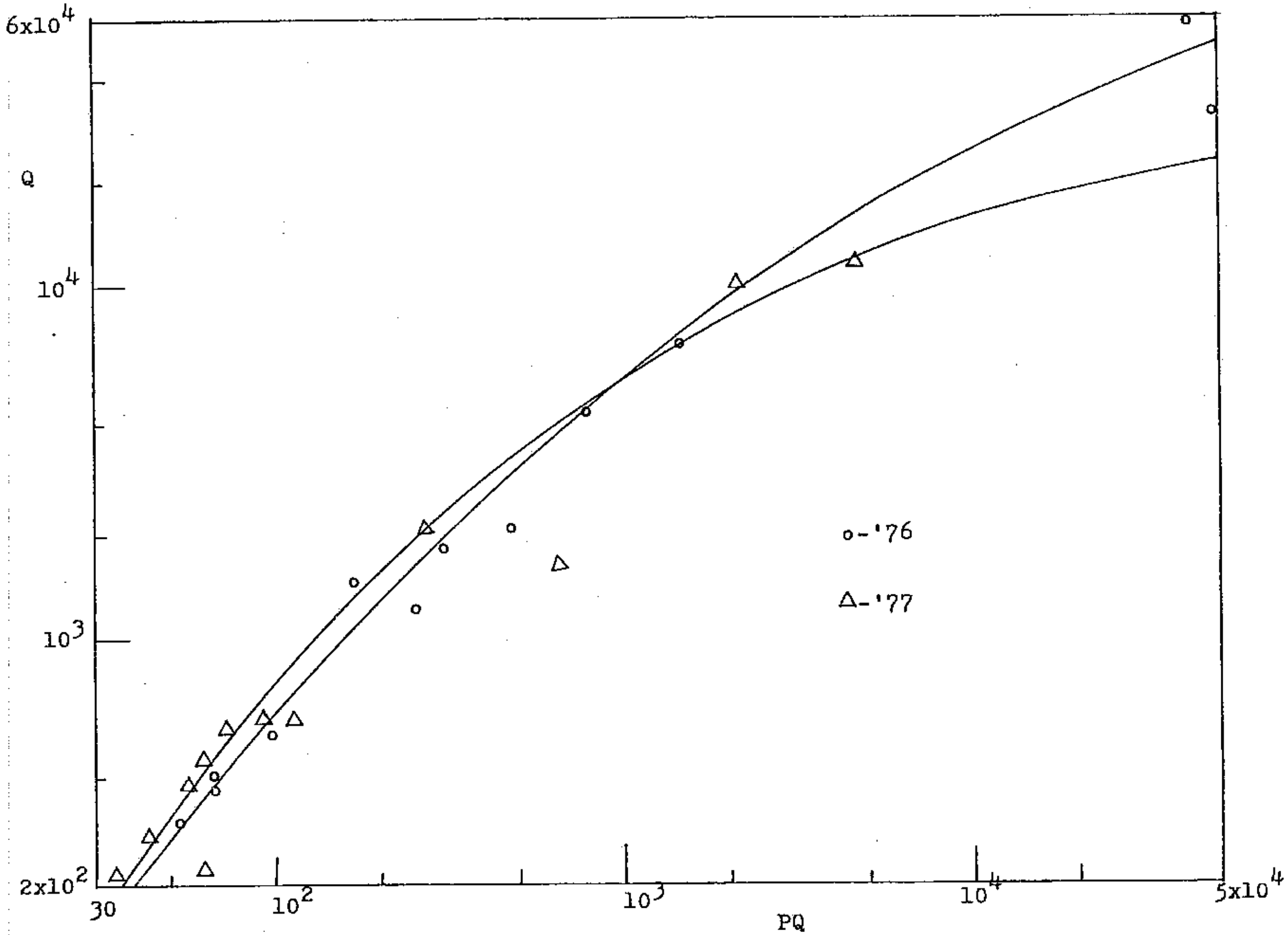
MAUMEE RIVER LOADING DATA



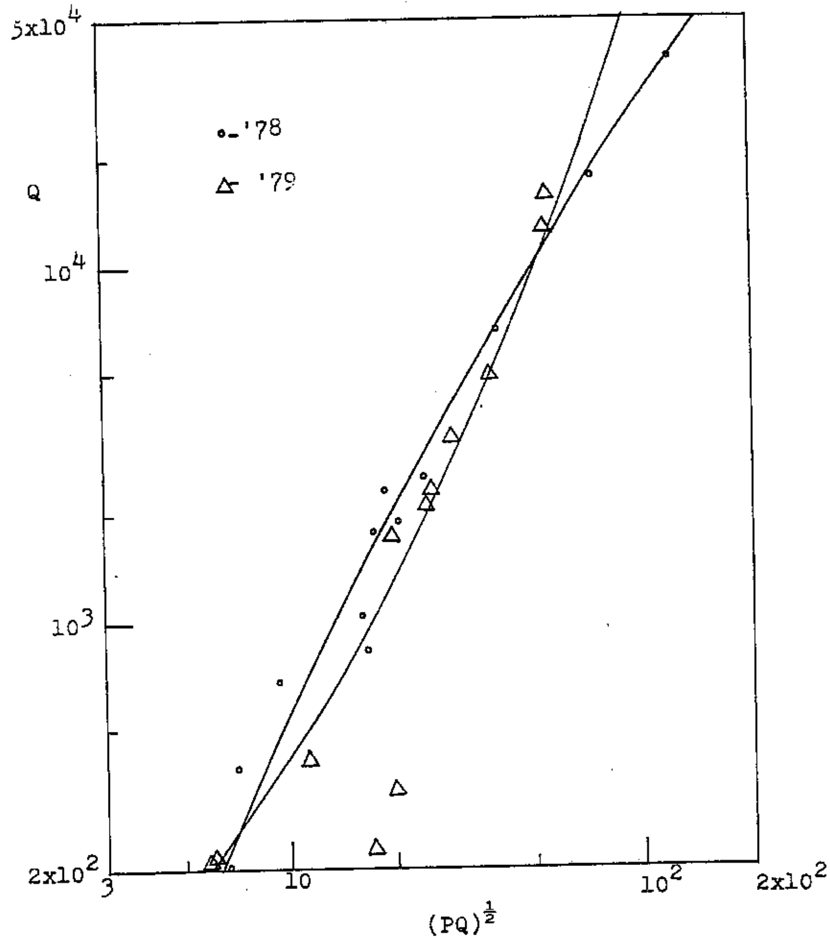
MAUMEE RIVER AT WATERVILLE, 1970-1974



MAUMEE RIVER AT WATERVILLE, 1975



MAUMEE RIVER AT WATERVILLE, 1976 and 1977.



MAUMEE RIVER AT WATERVILLE, 1978 and 1979.

MAUMEE RIVER AT WATERVILLE, 1970

Date	$(PQ)^{\frac{1}{2}}$	Q	P
Oct./20	22.4	1520	0.33
Nov./17	19.9	493	0.8
/24	60.4	16600	0.22
Dec./1	28.6	3720	0.22
/15	37.7	2850	0.50
Jan./5	19.4	750	0.50
/23	19.1	500	0.73
Feb./1	101.7	22000	0.47
/2	115.1	25000	0.53
Mar./12	33.9	6760	0.17
/23	46.2	7360	0.29
April/15	56.1	13100	0.24
/27	59.1	18400	0.19
May/11	25.3	2050	0.313
/18	60.3	18200	0.20
June/10	27.3	2490	0.30
/24	17.4	1170	0.26
July/20	45.1	6560	0.31
/27	69.2	1840	0.26
Aug./4	27.4	2420	0.31
/25	9.1	265	0.31
Sept./7	8.8	208	0.37
/30	20.7	811	0.53

	$\bar{Q}$	$\bar{P}$
Oct.	1310	424.4
Nov.	6953	2116
Dec.	2109	625
Jan.	1487	470.9
Feb.	8978	2809
Mar.	9312	2970.3
April	14610	5625
May	8665	2704
June	2146	650.3
July	2374	702.3
Aug.	833	292.4
Sept.	512	196

$$(\Sigma PQ) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 1457.5 \text{ MT/yr}$$

MAUMEE RIVER AT WATERVILLE, 1971.

Date	$(PQ)^{\frac{1}{2}}$	Q	P
Oct./12	18.2	627	0.53
/28	18.6	737	0.47
Nov./2	19.4	942	0.40
/6	21.0	1190	0.37
Dec./9	25.1	2250	0.28
/18	35.6	3420	0.37
Jan./14	23.5	1100	0.5
Feb./12	50	5000	0.5
Mar./11	33.6	4350	0.26
/24	35.5	6640	0.19
April/1	21.6	2460	0.19
/28	18.3	1520	0.22
May/6	30.1	3360	0.27
/12	53.5	7160	0.4
June/9	39.2	3570	0.43
/30	29.7	2200	0.40
July/9	11.3	440	0.29
/21	21.7	1100	0.43
Aug./3	15.3	500	0.47
/10	9.4	240	0.37
Sept./1	10.2	220	0.47
/30	32.9	1900	0.57

	$\bar{Q}$	$\bar{P}$	$\bar{P}\bar{Q}$
Oct.	875	0.40	361
Nov.	1701	0.40	702.3
Dec.	3982	0.35	1600
Jan.	1205	0.5	484
Feb.	13960	0.3	5256.3
Mar.	8848	0.3	3364
April	1909	0.20	784
May	6390	0.40	2500
June	3376	0.40	1332.3
July	1000	0.40	420.3
Aug.	342	0.40	148.8
Sept.	630	0.50	262.4

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 1281.1 \text{ MT/yr}$$

MAUMEE RIVER AT WATERVILLE, 1972.

date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./15	392	0.39	12.4
/20	347	0.28	9.6
Nov./2	385	0.46	13.1
/24	277	0.63	13.2
Dec./8	3220	0.52	40.9
/15	8540	0.45	62.0
Jan./12	7320	0.09	25.7
/26	5200	0.10	22.8
Feb./14	520	0.50	16.1
/23	1110	0.65	26.9
Mar./1	1060	0.76	28.4
/15	21500	0.09	44.6
April/5	4240	0.11	68.4
/24	39400	0.90	188.3
May/10	6420	0.10	25.3
/22	3160	0.25	28.1
June/14	1110	0.15	12.9
/21	1100	0.32	18.8
July/6	1520	0.37	23.7
/21	6410	0.42	51.9
Aug./2	479	0.34	12.8
/30	478	0.36	13.1
Sept./14	17200	0.56	98.1
/21	9560	0.32	55.3

	$\bar{Q}$	$\bar{PQ}$
Oct.	604	272.3
Nov.	310	182.3
Dec.	4544	1369
Jan.	4299	1332.3
Feb.	975	380.3
Mar.	8356	2916
April	16910	7656.4
May	4271	1369
June	2114	681.2
July	2912	900
Aug.	889	357.2
Sept.	7283	2500

$$(\Sigma \bar{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 1482.1 \text{ MT/yr}$$

MAUMEE RIVER AT WATERVILLE, 1974.

Date	$(PQ)^{\frac{1}{2}}$	Q	P
Oct./1	8.6	410	0.18
/30	7.4	343	0.16
Nov./23	11.65	485	0.28
/30	74.4	9890	0.57
Dec./3	41.7	4450	0.39
/5	34.5	3130	0.38
Jan./8	13.4	3000	0.06
Feb./12	44.2	3100	0.63
/12	22.3		0.16
Mar./13	107.7	20700	0.56
/14	104.2	16200	0.67
April/2	55.0	7970	0.38
/2	49.7		0.31
/25	24.2	2340	0.25
May/6	18.3	1850	0.18
/6	14.9		0.12
/21	79.1	11800	0.53
June/5	11.9	1760	0.08
/5	13.3		0.10
/19	21.7	1430	0.33
July/10	10.7	603	0.19
Aug./5	8.3	314	0.22
Sept./11	13.2	560	0.31

	$\bar{Q}$	$\overline{PQ}$
Oct.	422	85
Nov.	1420	400
Dec.	7049	3200
Jan.	19670	11500
Feb.	10760	5600
Mar.	14500	8400
April	9742	5000
May	7299	3400
June	2094	675
July	553	119
Aug.	460	95
Sept.	485	101

$$(\Sigma \overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 2870.6 \text{MT/yr}$$

MAUMEE RIVER AT WATERVILLE, 1975.

Date	Q(cfs)	P (mg/l)	$P^{1/4}$
Oct/17	351	0.16	0.632
Nov/13	844	0.26	0.714
Dec/18	11200	0.45	0.819
Jan./15	12200	0.50	0.841
Feb./11	25000	0.23	0.693
March/5	6220	0.37	0.780
April/2	8050	0.42	0.805
May/7	13500	0.39	0.790
June/3	4520	0.42	0.805
July/17	1230	0.21	0.677
Aug./14	442	0.10	0.562
Sept./4	2630	0.23	0.693

	$\bar{Q}$	$\bar{P}$
Oct.	266	0.110
Nov.	757	0.190
Dec.	4769	0.411
Jan.	9400	0.441
Feb.	13490	0.463
Mar.	7954	0.441
April	6164	0.410
May	7110	0.420
June	7321	0.420
July	2127	0.284
Aug.	2271	0.284
Sept.	3017	0.334

$$(\Sigma \bar{P}\bar{Q}) \times 24 \times 3600 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 2004 \text{MT/yr}$$

(River Mouth Estimation 2628 MT/yr)

MUAMEE RIVER AT WATERVILLE, 1976.

Date	Q(cfs)	P	PQ
Oct./16	526	0.18	94.7
Nov./19	1180	0.22	259.6
Dec./17	29200	1.9	55480
Jan./14	2000	0.24	480
Feb./17	62600	0.66	41316
Mar./15	6780	0.21	1423.8
Apr./12	1430	0.12	171.6
May/11	4390	0.18	790.2
June/8	1810	0.17	307.7
July/20	418	0.18	75.24
Aug./24	351	0.22	77.22
Sept/22	280	0.23	64.4

	$\bar{Q}$	$\bar{P}$
Oct.	1479	0.178
Nov.	1530	0.178
Dec.	8288	0.249
Jan.	4909	0.205
Feb.	30000	0.689
March	12810	0.322
April	3026	0.185
May	2805	0.182
June	1793	0.178
July	1069	0.178
Aug.	542	0.178
Sept.	288	0.178

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 1742.1 \text{ MT/yr}$$

(River Mouth Estimation 2960 MT/yr)

MAUMEE RIVER AT WATERVILLE, 1977.

Date	Q(cfs)	Q	PQ
Oct./	363	0.16	58.08
Nov./	277	0.15	41.55
Dec./	200	0.18	36.
Jan./	230	0.28	64.4
Feb./	1300	0.59	767.
Mar./	9430	0.23	2169.
April/	2080	0.13	270.4
May/	889	0.04	35.56
June/	579	0.16	92.64
July/	515	0.14	72.1
Aug./	603	0.81	114.57
Sept./	10550	0.44	4542.

	$\bar{Q}$	$\overline{PQ}$
Oct.	512	72.5
Nov.	357	56.
Dec.	504	71.
Jan.	319	51.
Feb.	1588	215.
March	13880	6700.
April	11900	4400.
May	4778	800.
June	656	90.
July	1934	270.
Aug.	1384	185.
Sept.	3113	450.

$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{360}{365} \times (3.048)^3 \times 10^{-9} = 1042.8 \text{ MT/yr}$$

(River Mouth Estimation 1700 MT/yr)

MAUMEE RIVER AT WATERVILLE, 1978.

Date	Q(cfs)	P	$(PQ)^{\frac{1}{2}}$
Oct./25	638	0.12	9.1
Nov./ 21	1990	0.23	21.4
Dec./15	17000	0.32	73.8
Jan./24	1000	0.27	16.4
Feb./21	820	0.35	16.9
Mar./17	37300	0.39	120.6
April/19	6600	0.23	39.0
May/9	2430	0.14	18.4
June/12	1700	0.17	17.0
July/11	2570	0.24	24.8
Aug./1	382	0.12	6.8
Sept./13	197	0.23	6.7

	$\bar{Q}$	$\overline{PQ}$
Oct.	1168	210.3
Nov.	1377	249.6
Dec.	18870	5625.
Jan.	1810	342.3
Feb.	854	148.8
March	29000	10000.
April	19050	8100
May	3942	841.
June	2149	420.3
July	2988	625.
Aug.	550	100.
Sept.	351	64.

$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times 365/360 \times (3.048)^3 \times 10^{-9} = 1981 \text{ MT/yr}$$

MAUMEE RIVER AT WATERVILLE, 1979.

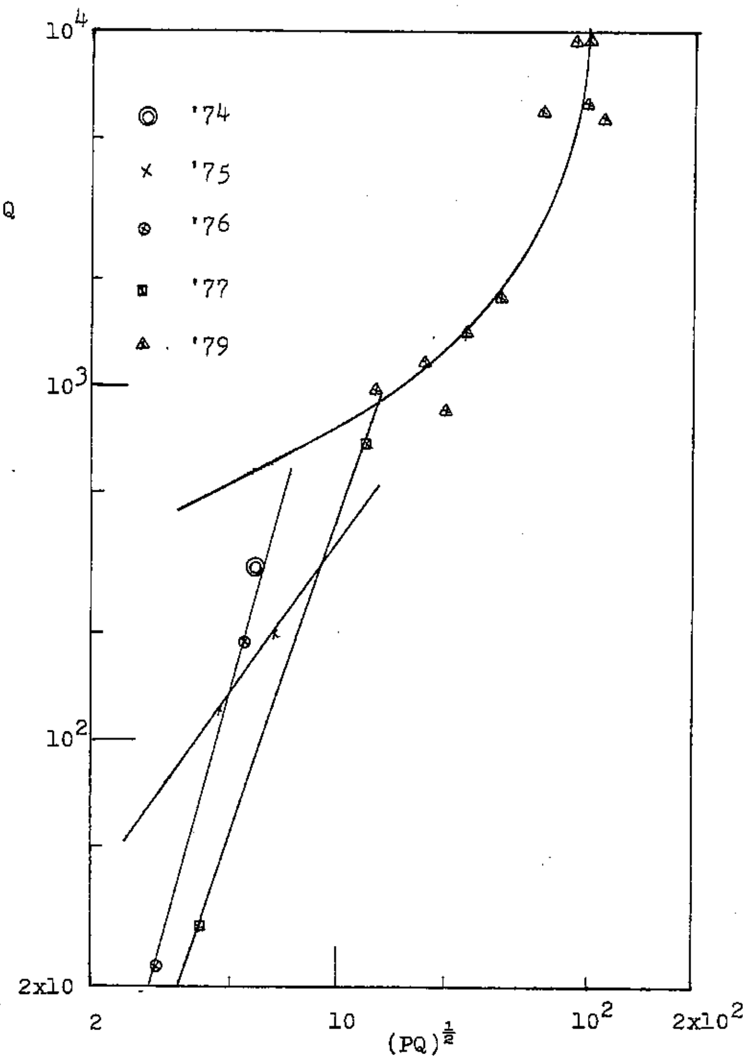
Date	Q(cfs)	P	$(PQ)^{\frac{1}{2}}$
Oct./11	205	0.17	5.9
Nov./7	197	0.16	5.6
Dec./7	3320	0.26	29.3
Jan./10	2400	0.27	25.5
Feb./13	400	0.33	11.5
Mar./12	1590	0.25	63.0
April/3	12400	0.25	55.7
May/9	3250	0.13	20.6
June/5	2240	0.13	17.1
July/2	5000	0.29	38.1
Aug./1	1800	0.22	19.9
Sept./5	2110	0.30	25.2

	$\bar{Q}$	$\bar{PQ}$
Oct.	260	49.
Nov.	491	121.
Dec.	1533	506.3
Jan.	2669	870.3
Feb.	2296	961
March	15380	3906.3
April	12830	3364.
May	5084	1592
June	2254	702.3
July	3078	961.
Aug.	4889	1521.
Sept.	1558	506.3

$$(\Sigma \bar{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 1120.7 \text{MT/yr}$$

APPENDIX C

PORTAGE RIVER LOADING DATA



PORTAGE RIVER AT WOODVILLE, 1974-1979.

PORTAGE RIVER AT WOODVILLE, 1974.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Aug./21	32	1.1	5.9

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	27.8	15.2
Nov.	73.1	30.3
Dec.	428	100
Jan.	1117	196
Feb.	561	121
March	1234	225
April	562	121
May	244	88.1
June	107	39.1
July	11.2	8.1
Aug.	30.6	16
Sept.	17.6	11.6

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 72.3\text{MT/yr}$$

PORTAGE RIVER AT WOODVILLE, 1975.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Feb./6	190	0.24	6.75
Sept./10	123	0.19	4.8

	$\bar{Q}$	$\overline{PQ}$
Oct.	13.6	1.1
Nov.	35.3	4.
Dec.	344	95.1
Jan.	626	210.3
Feb.	837	316.8
March	356	100
April	177	36
May	568	182.3
June	229	49.4
July	40.6	4.8
Aug.	245	60.1
Sept.	461	144

$$(\Sigma \overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 89.6 \text{MT/yr}$$

(River Mouth Estimation - 156 MT/yr)

PORTAGE RIVER AT WOODVILLE, 1976.

Date	Q	P	$(PQ)^{\frac{1}{2}}$		$\bar{Q}$	$\bar{P}\bar{Q}$
				Oct.	220	31.4
				N v.	66.3	16.8
				Dce.	506	49
				Jan.	635	56.3
				Feb.	1793	100
March/15	187	0.16	5.5	March	668	56.3
				April	199	30.3
				May	183	28.1
June/30	23	o.43	3.1	June	60.5	16
				July	40.7	13.
				Aug.	36.1	12.3
				Sept.	19.9	9

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 31.1\,\mathrm{MT/yr}$$

(River Mouth Estimation - 86 MT/yr)

PORTAGE RIVER AT WOODVILLE, 1977.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
March/9	696	0.21	12.1
June/14	30	0.55	4.1

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	15.4	9.61
Nov.	17.2	9.9
Dec.	10.8	8.1
Jan.	9.4	7
Feb.	231	65.6
March	1185	210.3
April	694	144
May	270	76.6
June	30.8	16.8
July	171	52.6
Aug.	50.2	23.1
Sept.	562	121

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 55.4 \text{MT/yr}$$

(River Mouth Estiamtion - 110 MT/yr)

PORTAGE RIVER AT WOODVILLE, 1979.

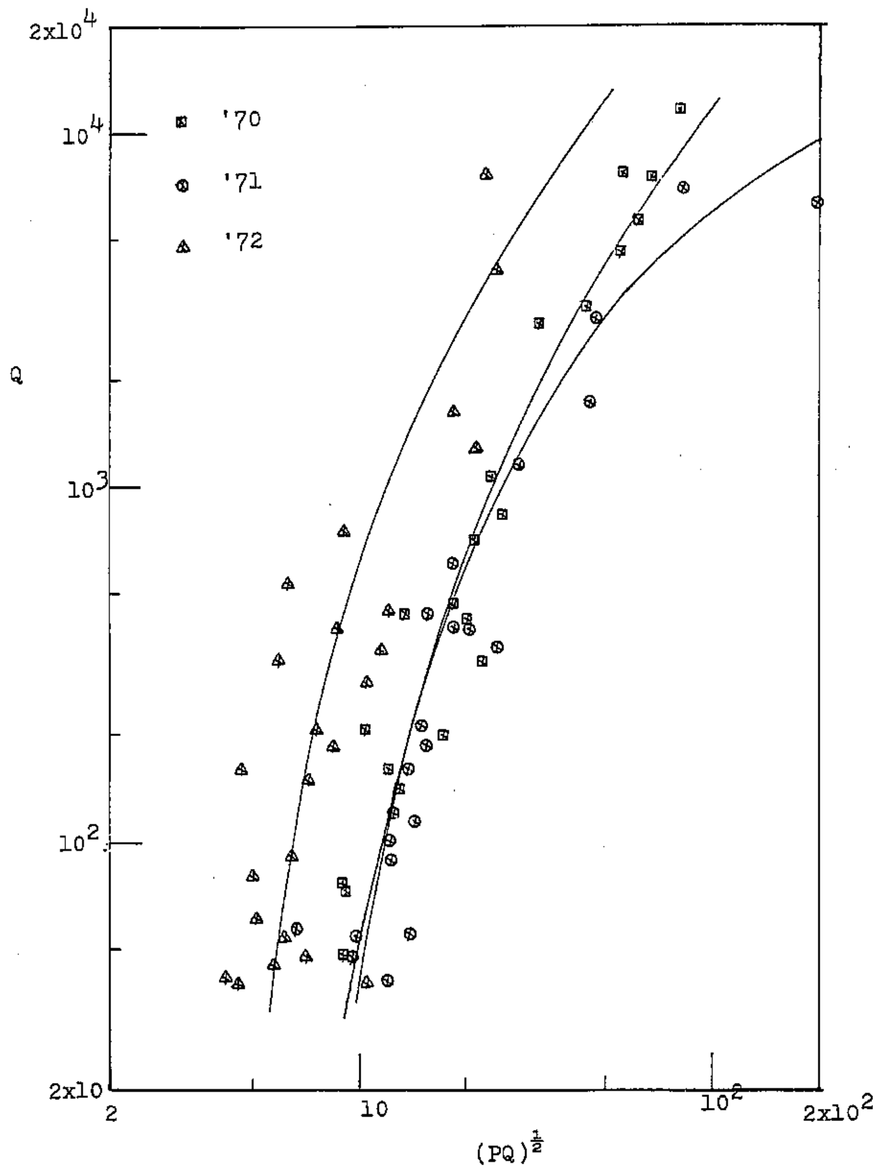
Date	Q	P	$(PQ)^{\frac{1}{2}}$
June/29		0.37	
	860	0.33	9.5
		0.62	
June/30		0.57	
		0.49	
	6250	0.40	49.4
		0.34	
		0.29	
		0.26	
July/1	9830	0.25	49.6
/2	9200	0.23	46
Aug./1	1800	0.35	28.5
		0.54	
/2		0.65	
		0.63	
	5800	0.60	55.4
		0.56	
		0.22	
/24	5910	0.23	36.9
Sept./15		0.25	
		0.19	
		0.25	
		0.29	
		0.29	
	1130	0.27	17.1
		0.26	
		0.26	
		0.28	
		0.29	
/16	1460	0.31	22.3
		0.37	
/21	999	0.16	12.6

	$\bar{Q}$	$\overline{PQ}$
Oct.	16.5	0.01
Nov.	28.6	0.01
Dec.	58.7	0.01
Jan.	163	0.49
Feb.	179	0.504
March	843	121
April	1382	441
May	489	20.3
June	119	0.04
July	371	7.84
Aug.	635	49
Sept.	144	0.09

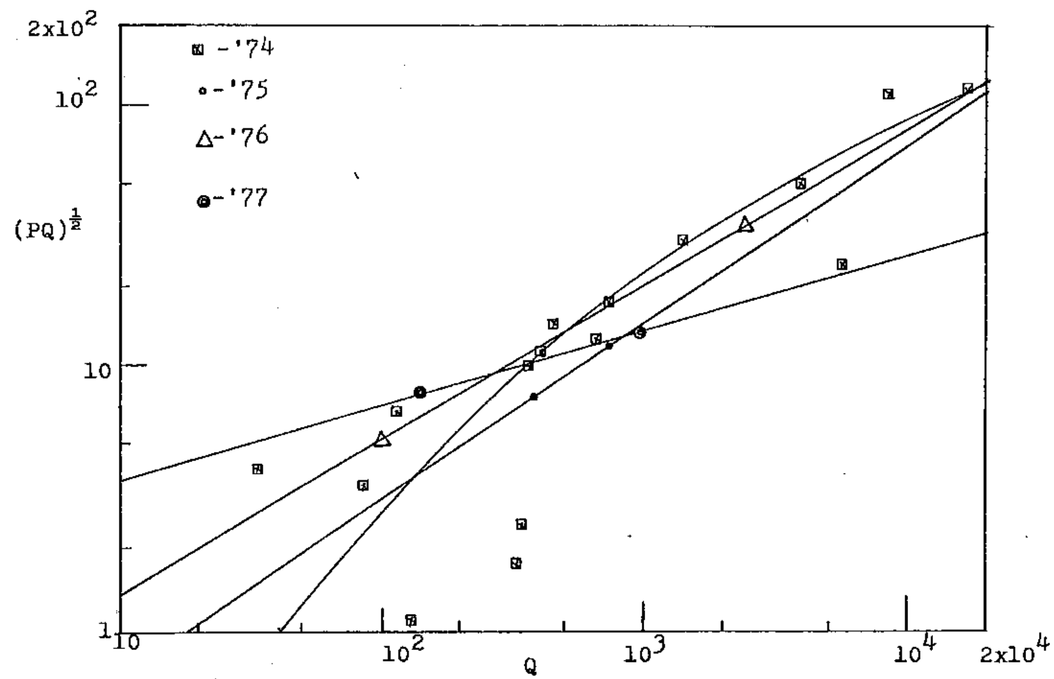
$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 47.6 \text{ (MT/yr)}$$

APPENDIX D

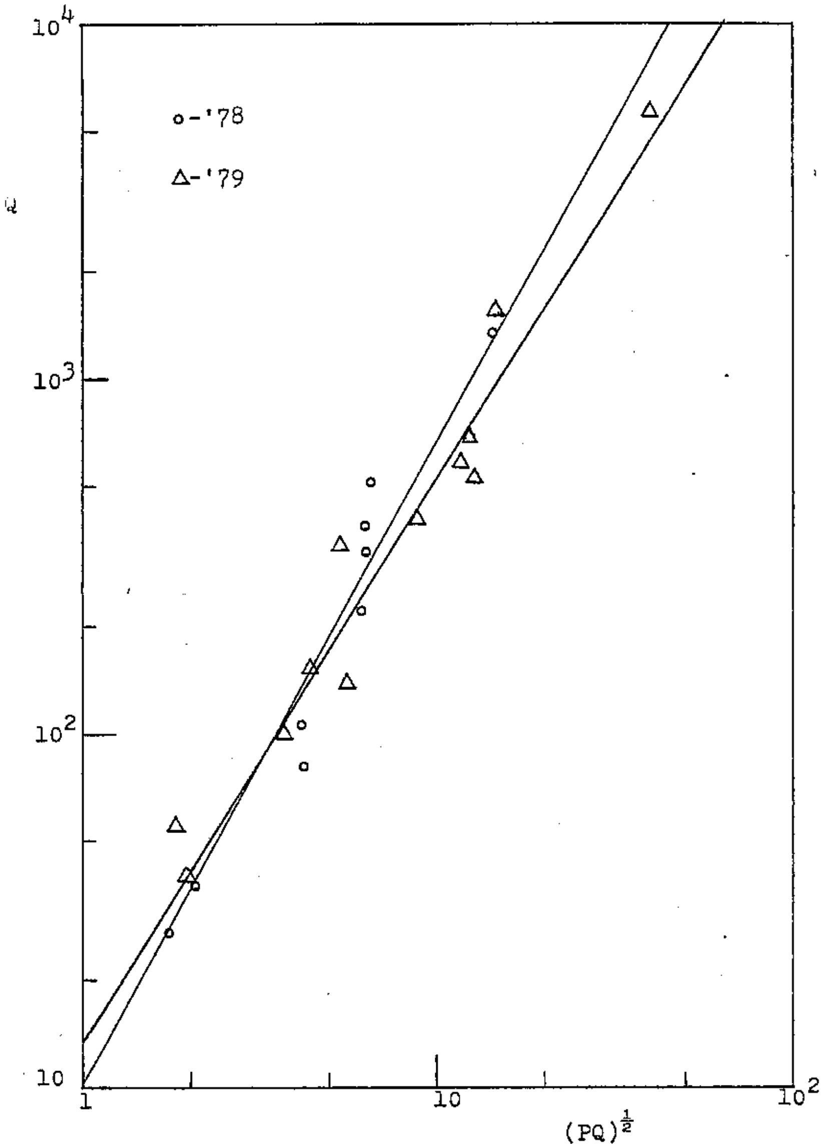
SANDUSKY RIVER LOADING DATA



SANDUSKY RIVER NEAR AND BELOW FREMONT, 1970-1972.



SANDUSKY RIVER NEAR AND BELOW FREMONT, 1975-1977.



SANDUSKY RIVER NEAR AND BELOW FREMONT, 1978 and 1979.

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1970

Date	$(PQ)^{\frac{1}{2}}$	Q	P (as PO_4)
Oct./2	12.2	159	0.93
/23	9.2	71	1.20
Nov./5	22.2	309	1.6
Dec./18	13.4	440	0.41
/29	10.7	210	0.55
Jan./26	13.0	140	1.2
/31	68.6	7600	0.62
Feb./5	45.6	3200	0.65
/20	21.3	700	0.65
Mar./6	81.6	11100	0.60
/19	20.5	422	1.0
April/4	57.4	7840	0.42
/18	23.9	1060	0.54
May/12	18.4	464	0.73
/16	56.3	4600	0.69
June/6	25.2	833	0.76
/20	31.2	2870	0.34
July/18	9.4	73	1.2
/31	63.6	5610	0.72
Aug./1	45.5	3090	0.67
/29	9.3	46	1.9
Sept./1	10.7	38	3.0
/30	17.6	193	1.6

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	88.4	132.3
Nov.	1029	600.3
Dec.	454	306.3
Jan.	845	506.3
Feb.	2203	1036.8
March	2390	1892.3
April	3368	1722.3
May	1272	729
June	1056	625
July	430	306.3
Aug.	256	213.2
Sept.	56.5	113.4

$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 609$ MT/yr/3= 203MT/yr

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1971.

Date	Q	P(as PO_4)	$(PQ)^{\frac{1}{2}}$
Oct./12	53	2.3	10.0
/23	86	1.5	11.4
Nov./9	113	1.9	14.7
/26	100	1.5	12.2
Dec./16	1150	0.72	28.8
Jan./11	400	0.88	18.8
/29	160	1.2	13.9
Feb./3	120	1.3	12.5
/19	7000	1.0	83.7
Mar./1	3020	0.45	36.9
29	610	0.55	18.3
April/1	440	0.57	15.8
28	182	1.30	15.4
May/3	210	1.5	17.7
/26	6490	6.4	203.8
June/4	399	1.1	20.95
/7	1730	1.2	45.60
July/14	345	1.8	24.9
/19	86	1.8	12.4
Aug./4	57	0.76	6.6
/28	40	3.60	12.
Sept./25	54	3.7	14.1
/30	47	1.9	9.45

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	100	132.3
Nov.	123	148.8
Dec.	753	529
Jan.	355	289.
Feb.	5652	7744
March	1798	1296
April	284	243.4
May	1653	1190.3
June	451	342.3
July	113	114
Aug.	52.5	110.3
Sept.	44.1	104.0

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 913.\text{MT}/3 = 203\text{MT/yr}$$

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1972.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./1	41	0.44	4.2
/26	47	1.10	7.2
Nov./1	39	0.54	4.6
/24	45	0.76	5.8
Dec./4	55	0.70	6.2
/23	161	0.14	4.7
Jan./5	520	0.08	6.4
/22	400	0.20	8.9
Feb./15	340	0.38	11.4
/23	280	0.39	10.4
Mar./15	7620	0.07	23.1
/29	761	0.11	9.1
April/8	1790	0.04	8.5
/22	12300	0.04	22.2
May/8	316	0.11	5.9
/18	4150	0.16	25.8
June/16	1610	0.22	18.8
28	150	0.36	7.3
July/10	392	0.30	10.8
/19	440	0.34	12.2
Aug./10	80	0.36	5.4
/27	209	0.36	8.7
Sept./5	89	0.47	6.5
/15	59	0.46	5.2

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	41	59
Nov.	43	36
Dec.	218	56.28
Jan.	697	110.3
Feb.	349	72.3
March	2478	324
April	3703	529
May	1678	256
June	438	81
July	455	82.8
Aug.	113	43.6
Sept.	769	123.2

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 132\text{MT/yr}$$

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1972.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./5	333	0.02	2.6
/16	85	0.15	3.6
Nov./1	212	0.00	0
/8	128	0.01	1.1
Dec./25	320	0.01	1.8
/29	5750	0.11	25.1
Jan./15	400	0.32	11.3
/22	17400	0.72	111.9
Feb./24	3920	0.65	50.5
Mar./26	661	0.25	12.9
April/ 4	8560	1.40	109.5
/24	465	0.51	15.4
May/11	433	0.37	12.7
/31	1430	0.68	31.2
June/2	849	0.46	19.8
/14	120	0.42	7.1
July/25	34	0.52	4.2
Aug.			
Sept.			

	$\bar{Q}$	$\overline{PQ}$
Oct.	117	12.3
Nov.	398	123.2
Dec.	1488	900
Jan.	4326	3364
Feb.	1578	1024
March	3041	2256.3
April	1992	1296.
May	604	256
June	256	60.8
July	59.7	2.56
Aug.	104	9.61
Sept.	148	18.5

$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 694 MT/yr$$

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1975.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Feb./6	904.	0.21	13.8
Sept./9	493	0.18	9.4
	$\bar{Q}$		$\bar{P}\bar{Q}$
Oct.	49.5		4.
Nov.	400.		64.
Dec.	2372		729
Jan.	2594		841
Feb.	4029		1521
March	2017		576
April	580		106.1
May	685		132.3
June	430		96
July	88		6.8
Aug.	106		9.6
Sept.	685		132.3

$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times 365/360 \times (3.048)^3 \times 10^{-9} = 318.5$ MT/yr

(River Mouth Estiamtion – 595 MT/yr)

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1976.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Mar./23	2530	0.52	36.3
June/16	100	0.28	5.3
	$\bar{Q}$		$\bar{P}\bar{Q}$
Oct.	289		100
Nov.	152		49
Dec.	865		361
Jan.	2025		992.3
Feb.	3550		1936
March	1769		900
April	383		144
May	361		132.3
June	469		182.3
July	339		125.4
Aug.	141		43.6
Sept.	65.4		17.6

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times 365/360 \times (3.048)^3 \times 10^{-9} = 370 \text{ MT/yr}$$

(River Mouth Estimation - 352 MT/yr)

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1977.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
March/3	963	0.21	14.2
June/20	145	0.44	8.0
	$\bar{Q}$		$\overline{PQ}$
Oct.	72.3		43.6
Nov.	77.5		46.2
Dec.	66.6		41.0
Jan.	54.2		49.
Feb.	2310		324
Maech	2164		306.3
April	1595		259.2
May	788		169.
June	114		57.8
July	519		134.6
Aug.	182		74.
Sept.	652		156.3

$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times 356/360 \times (3.048)^3 \times 10^{-9} \cong 123.6$ MT/yr

(River Mouth Estimation- 264MT/yr)

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1978.

Date	Q(cfs)	P	$(PQ)^{\frac{1}{2}}$
Jan./5	380	0.10	6.2
Feb./15	320	0.12	6.2
Mar./7	220	0.16	5.9
April/11	1320	0.16	14.5
May/1	516	0.08	6.4
June/21	87	0.19	4.1
July/17	41	0.19	2.8
Aug./15	106	0.14	3.9
Sept./6	28	0.11	2.0

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	159	19.4
Nov.	192	24.0
Dec.	4034	729
Jan.	1194	190.4
Feb.	528	76.6
Mar.	8261	1764
April	2851	484
May	654	95.1
June	307	39.7
July	122	14.5
Aug.	165	20.3
Sept.	33.8	2.7

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 257.5 \text{ MT/yr}$$

SANDUSKY RIVER NEAR AND BELOW FREMONT, 1979.

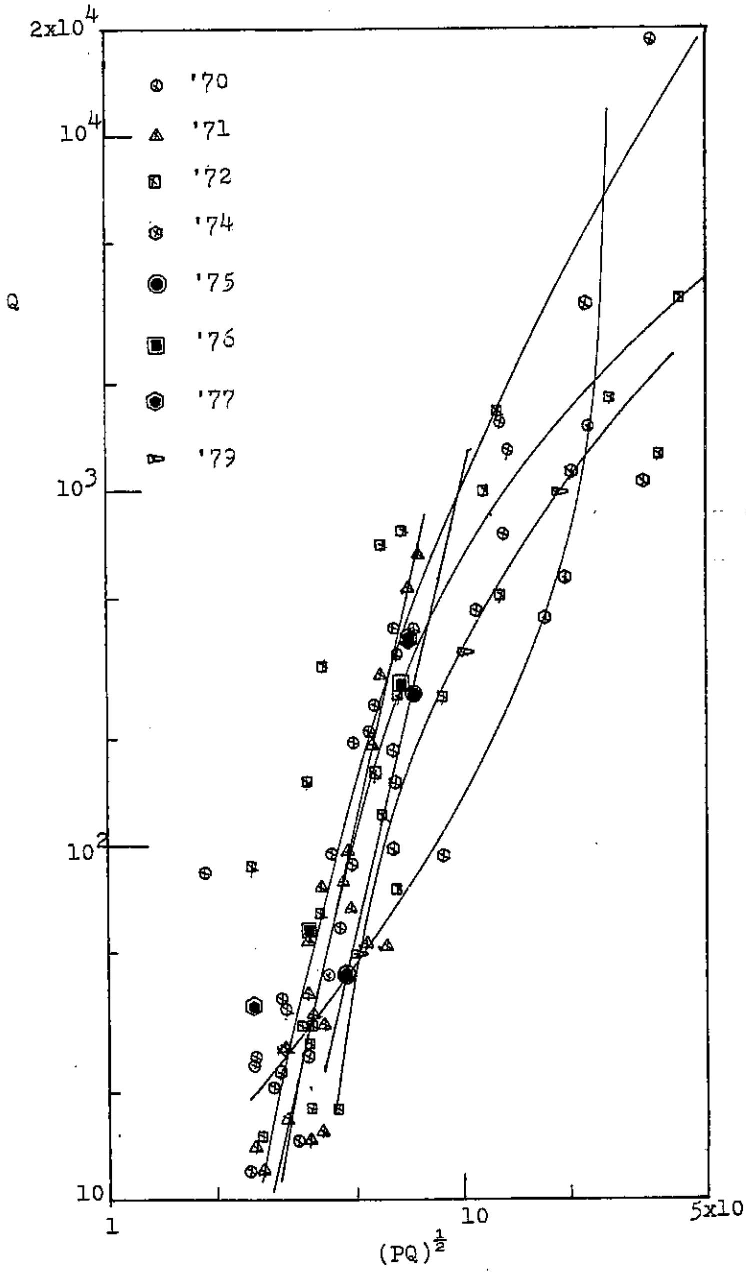
Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./12	40	0.09	1.9
Nov./7	57	0.06	1.8
Dec./12	706	0.23	12.7
Jan./15	155	0.12	4.7
Feb./13	98	0.14	3.7
Mar./13	1560	0.14	14.8
April/10	5690	0.27	39.2
May/1	346	0.08	5.3
June/13	534	0.35	13.7
July/3	404	0.20	9.0
Aug./8	137	0.23	5.6
Sept./5	578	0.24	11.8

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	56.9	5.8
Nov.	76.	8.1
Dec.	463	72.3
Jan.	734	132.3
Feb.	1409	272.3
March	4062	954.8
April	3716	912
May	1125	210.3
June	711	121
July	415	64
Aug.	1275	256
Sept.	596	100

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 231.4 \text{ MT/yr}$$

APPENDIX E

HURON RIVER LOADING DATA



HURON RIVER AT MILAN, 1970-1979.

HURON RIVER AT, AND BELOW MILAN, 1970.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./11	37	0.74/3	3.02
/29	41	1.4/3	4.4
Nov./1	43	1.2 /3	4.1
/29	192	0.38/3	4.9
Dec./10	250	0.36/3	5.5
/30	90	0.76/3	4.8
Jan./19	85	0.11/3	1.8
/29	736	0.34/3	10.3
Feb./2	1500	0.33/3	12.8
/20	360	0.34/3	6.4
Mar./7	1300	0.40/3	13.2
/12	210	0.40/3	5.3
April/2	1580	0.30/3	12.6
/14	417	0.29/3	6.3
May/9	96	0.56/3	4.2
/13	19000	0.19/3	34.7
June/11	59	0.93/3	4.3
/22	402	0.40/3	7.3
July/8	35	0.81/3	3.1
/17	26	0.81/3	2.6
Aug./5	25	0.84/3	2.6
/31	12	1.5/3	2.4
Sept./11	15	2.3/3	3.4
/23	21	1.2/3	2.9

	$\overline{Q}$	$\overline{PQ}$
Oct.	43.8	12.3
NOv.	270	34.8
Dec.	175	26.
Jan.	506	51.8
Feb.	699	66.4
March	598	59.3
April	616	60.8
May	383	42.4
June	178	27.
July	114	19.4
Aug.	21.9	9.
Sept.	22.7	9.1

$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 31.1\,\mathrm{MT/yr}$$

HURON RIVER BELOW MILAN, 1971.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./13	52	2.1/3	6.0
/29	27	2.1/3	3.1
Nov./3	99	0.98/3	5.7
/12	31	1.6/3	4.1
Dec./1	284	0.36/3	5.8
/30	80	0,76/3	4.5
Jan./5	535	0.26/3	6.8
/30	34	1.2/3	3.7
Feb./2	32	1.3/3	3.7
Mar./17	652	0.26/3	7.5
/28	195	0.48/3	5.6
April/10	76	0.58/3	3.8
/26	55	0.72/3	3.6
May/4	53	1.6/3	5.3
/11	95	0.7/3	4.7
June/8	65	1.0/3	4.7
/29	17	1.7/3	3.1
July/6	14	1.3/3	2.5
/13	38	0.96/3	3.5
Aug./18	12	1.7/3	2.6
/31	9.1	1.7/3	2.3
Sept./22	16	2.8/3	3.9
/28	15	2.5/3	3.5

	$\bar{Q}$	$\overline{PQ}$
Oct.	42.4	16.8
Nov.	74.1	21..2
Dec.	261	36
Jan.	105	25
Feb.	1090	72.3
March	457	46.9
April	86	23
May	212	33.6
June	45.6	17.6
July	29.7	14.4
Aug.	11.7	9.6
Sept	11.4	9.4

$$(\Sigma \overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 24.2\text{MT/yr}$$

HURON RIVER BELOW MILAN, 1972.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./12	18	1.1	4.4
/18	15	0.48	2.7
Nov./2	28	0.52	3.8
/4	18	0.81	3.8
Dec./7	75	0.54	6.4
/15	263	0.16	6.5
Jan./11	700	0.05	5.9
/18	65	0.24	3.9
Feb./9	32	0.46	3,8
/18	260	0.29	8.7
Mar./11	158	0.20	5.6
/14	3460	0.54	4. 3
April/4	152	0.08	3.5
/18	760	0.06	6.8
May/9	1630	0.1	
/26	88	0.07	2. 5
June/13	1000	0.13	11.4
/27	320	0.05	4
July/7	121	0.28	5.8
/19	1250	1.1	37
Aug./17	503	0.32	12.7
/23	739	0.28	14.4
Sept./12	33	0.39	3.6
/18	1770	0139	26.3

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	16.6	11.2
Nov.	20.7	11.6
Dec.	120	23.
Jan.	183	31.4
Feb.	128	25.
March	756	121
April	566	85.6
May	339	52. 6
June	349	53.3
July	201	33.6
Aug.	240	39.1
Sept.	573	89.9

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 43.0 \text{ MT/yr}$$

HURON RIVER BELOW MILAN, 1974.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./13	23	0.38	3.0
/31	93	0.81	8.7
Nov./22	41	0.01	0.64
/29	976	0.04	6.2
Dec./21	295	0.0	0
/26	3400	0.15	22.6
Mar./19	439	o.67	17.2
/26	494	0.21	10.2
April/6	1110	0.37	20.3
/30	154	0.26	6.3
May/10	188	.019	6.0
/30	1040	1.1	33.8
June/20	657	0.65	19.2
Aug./22	28	0.48	3.7

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	42.5	19.4
Nov.	140	106.1
Dec.	462	278.9
Jan.	1119	420.3
Feb.	405	256
March	972	400
April	636	327.6
May	254	182.3
June	169	130
July	55	30.3
Aug.	44.2	21.2
Sept.	32.6	22.5

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 178.4\,\mathrm{MT/yr}$$

HURON RIVER BELOW MILAN, 1975.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Feb./4	269	0.20	7.32
July/22	41	0.51	4.57

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	23.9	16.8
Nov.	97.9	31.4
Dec.	841	77.4
Jan.	710	72.3
Feb.	926	81
March	651	68.9
April	166	38.4
May	227	44.9
June	222	44.9
July	35.8	20.3
Aug.	51.9	23.
Sept.	191	41.

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.028)^3 \times 10^{-9} = 52.\ \text{MT/yr}$$

(River Mouth Estimation 136 MT/yr)

HURON RIVER AT MILAN, 1976

Date	Q	P	$(PQ)^{\frac{1}{2}}$
March/11	279	0.16	6.7
June/29	56	0.23	3.6

	$\bar{Q}$	$\overline{PQ}$
Oct.	120	23
Nov.	56.7	16
Dec.	265	42.3
Jan.	743	121
Feb.	1407	289
March	549	82.8
April	136	36
May	79.4	23.0
June	78	18.5
July	44.8	14.4
Aug.	88.7	19.4
Sept.	55.8	16

$$(\Sigma\overline{PQ}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 52.2\text{MT/yr}$$

(River Mouth Estimation 95MT/yr)

HURON RIVER AT MILAN, 1977

Date	Q	P	$(PQ)^{\frac{1}{2}}$
March/1	388	0.18	7.1
June/16	36	0.17	2.5

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	54.8	13
Nov.	46.8	12.3
Dec.	33	10.9
Jan.	27.1	9
Feb.	496	50.4
March	862	72.3
April	476	50.4
May	211	29.2
June	143	23.
July	716	65.6
Aug.	148	23
Sept.	204	29.2

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 29.\ \text{MT/yr}$$

(River Mouth Estiamtion 111 MT/yr)

HURON RIVER AT MILAN, 1979.

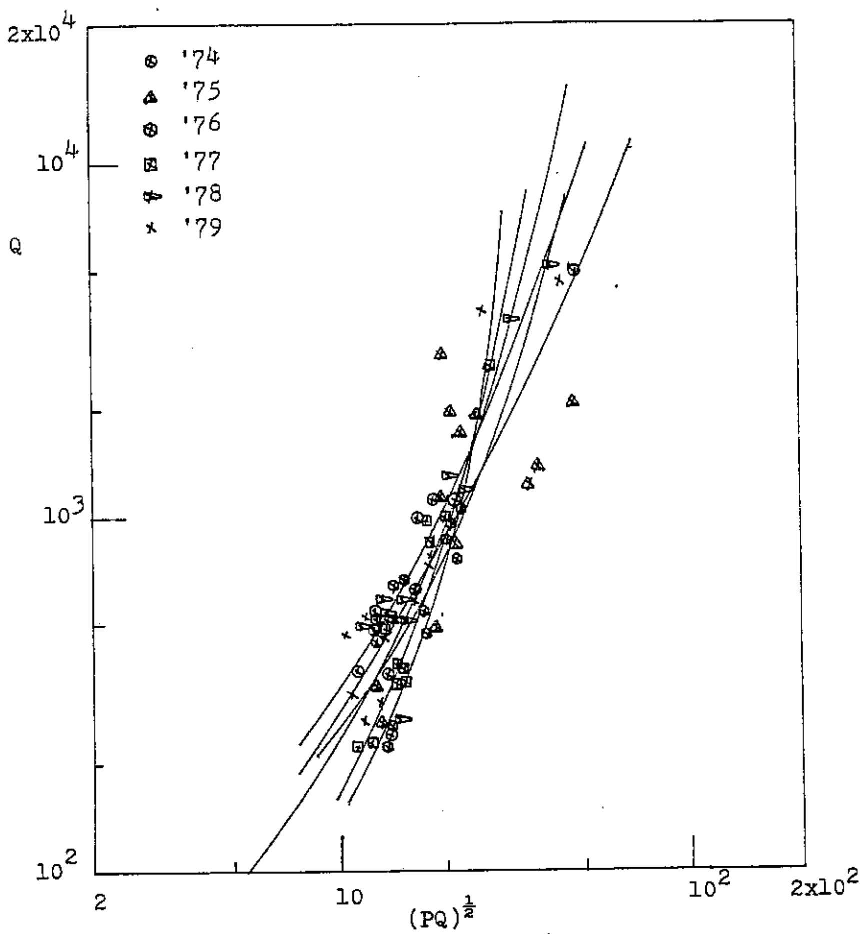
Date	Q	P	$(PQ)^{\frac{1}{2}}$
Sept./15		0.44	
		0.38	
	960	0.37	18.8
		0.36	
		0.34	
		0.32	
Sept./16		0.32	
		0.31	
	349	0.31	10.2
		0.29	
		0.28	
		0.27	
Sepr./20	50	0.56	5.3

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	24.9	4.4
Nov.	26.5	4.5
Dec.	99.9	5.9
Jan.	278	8.5
Feb.	514	11.5
March	1039	18
April	1041	18
May	410	10.1
June	219	7.7
July	154	6.7
Aug.	84.8	5.6
Sept.	98.1	5.9

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 89.2 \text{MT/yr}$$

APPENDIX F

CUYAHOGA RIVER LOADING DATA



CUYAHOGA RIVER AT INDEPENENCE, 1974-1979.

CUYAHOGA RIVER AT INDEPENDENCE, 1974.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Jan./10	453	0.34	12.4
Feb./6	487	0.30	12.1
/13	618	0.42	16.11
Mar./12	1120	0.28	17.7
April/3	4950	0.47	48.2
May/8	1020	0.26	16.3
June/4	555	0.27	12.2
July/9	367	0.37	11.7
Aug./6	246	0.81	14.1
Sepr./11	351	0.52	13.5

	$\bar{Q}$	$\overline{PQ}$
Oct.	504	196
Nov.	906	420.3
Dec.	1055	506.3
Jan.	1621	784
Feb.	756	324
March	2096	1024
April	1862	900
May	1681	812.2
June	629	306.3
July	460	182.3
Aug.	581	240.3
Sept.	514	210.3

$$(\Sigma\overline{PQ})\times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 439.5 \text{ MT/yr}$$

CUYAHOGA RIVER AT INDEPENDENCE, 1975.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./15	486	0.76	19.1
Nov./13	1400	0.38	37.4
Dec./18	1970	0.22	20.8
Jan./15	1720	0.29	22.3
Feb./11	840	0.51	20.7
Mar./25	2220	0.30	47.1
Apr./1	1110	0.34	19.4
May/7	1260	0.40	35.5
June/4	1870	0.33	24.8
July/10	258	0.67	13.1
Aug./5	312	0.51	12.6
Sept./2	2850	0.13	19.2

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	370	240.3
Nov.	1460	552.3
Dec.	2060	650.3
Jan.	2166	650.5
Feb.	2390	676
Mar.	2400	676
Apr.	774	400
May	1142	492.8
June	1619	576
July	358	231.0
Aug.	608	331.2
Sept.	1456	538.2

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 447.6\text{MT/yr}$$

(River Mouth Estimation - 788 MT/yr)

CUYAHOGA RIVER AT INDEPENDENCE, 1976.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./1	655	0.36	15.4
Nov./11	745	0.62	21.5
Dec./10	986	0.42	20.3
Jan./13	835	0.49	20.2
Feb./3	1000	0.45	21.2
Mar./16	1080	0.37	20.
Apr./14	650	0.32	14.4
May/11	490	0.68	18.3
June/8	358	0.46	12.8
July/1	554	0.53	17.1
Aug./9	522	0.31	12.7
Sept./9	219	0.70	12.4

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	605	289
Nov.	508	240.3
Dec.	1199	576.
Jan.	1487	676
Feb..	3108	1024
Mar.	1787	784
Apr.	995	484
May	460	225
June	462	225
July	1332	625
Aug.	492	256
Sept.	610	292

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 423.8 \text{MT/yr}$$

(River Mouth Estimation- 420 MT/yr)

CUYAHOGA RIVER AT INDEPENDENCE, 1977.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./6	368	0.52	13.8
Nov./3	489	0.44	14.7
Dec./1	325	0.59	13.8
Jan./5	318	0.68	14.7
Feb./1	260	0.56	12.1
Mar./1	2570	0.29	27.3
Apr./13	985	0.31	17.5
May/11	493	0.34	12.9
June/8	224	0.55	11.1
July/19	1020	0.42	20.7
Aug./16	858	0.37	17.8
Sept./13	335	0.70	15.3

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	453	225
Nov.	411	225
Dec.	415	225
Jan.	272	156.3
Feb.	1333	506.3
Mar.	2335	625
Apr.	1541	529
May	488	259
June	342	196
July	496	256
Aug.	774	361
Sept.	558	289

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 286.7 \text{MT/yr}$$

(River Mouth Estimation- 357 MT/yr)

CUYAHOGA RIVER AT INDEPENDENCE, 1978.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./12	588	0.38	14.9
Nov./10	1170	0.44	22.7
Dec./13	1300	0.31	20.1
Jan./4	537	0.34	13.5
Feb./16	529	0.34	13.4
Mar./16	5240	0.31	40.3
Apr./5	3630	0.27	31.3
May/8	493	0.27	11.5
June/7	485	0.39	13.8
July/5	593	0.28	12.9
Aug./9	500	0.47	15.3
Sept./20	255	0.80	14.3

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	481	156.3
Nov.	1077	400
Dec.	2889	930.3
Jan.	1203	441
Feb.	613	207.4
Mar.	2621	852.6
Apr.	1620	576
May	1278	442
June	509	160
July	564	196
Aug.	374	115.6
Sept.	246	64

$$(\Sigma \bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 339.9 \text{MT/yr}$$

CUYAHOGA RIVER AT INDEPENDENCE, 1979.

Date	Q	P	$(PQ)^{\frac{1}{2}}$
Oct./18	484	0.32	12.4
Nov./14	260	0.53	11.7
Dec./6	731	0.43	17.7
Jan./11	461	0.35	12.7
Feb./1	560	0.44	15.7
Mar./6	4600	0.38	41.8
Apr./9	3770	0.18	26.0
May/8	503	0.29	12.1
June/14	465	0.25	10.8
July/18	302	0.39	10.9
Aug./1	723	0.43	17.6
Sept./11	299	0.57	13.1

	$\bar{Q}$	$\bar{P}\bar{Q}$
Oct.	501	255
Nov.	294	130
Dec.	728	306.3
Jan.	927	400
Feb.	1040	400
Mar.	2437	784
Apr.	1915	676
May	1246	506
June	585	256
July	526	228
Aug.	715	292.4
Sept.	1865	676

$$(\Sigma\bar{P}\bar{Q}) \times 3600 \times 24 \times 30 \times \frac{365}{360} \times (3.048)^3 \times 10^{-9} = 484 \text{MT/yr}$$