ESTIMATED LOADINGS FROM SEVEN MICHIGAN TRIBUTARIES AND RECOMMENDATIONS FOR TRIBUTARY SAMPLING STRATEGIES

by

Robert M. Day
Surface Water Quality Division
Michigan Department of Natural Resources
Lansing, Michigan 48909

Project Officer

David Rockwell

Project Nos. S-005741-01-2,
S-005741-02-1, S-005741-03

GREAT LAKES NATIONAL PROGRAM OFFICE
REGION V
U.S. ENVIRONMENTAL PROTECTION AGENCY
CHICAGO, ILLINOIS 60605

ABSTRACT

Annual load estimates of twelve parameters from seven Michigan tributaries were calculated from 1984 to 1986. Estimates were calculated by dividing sample concentrations into high and low strata and applying Beale's Ratio Estimator. The greatest annual loads of the twelve parameters usually came from the St. Joseph followed by the Black or Rouge rivers and the lowest annual loads came from either the Pere Marquette or Ontonagon rivers.

Monte Carlo studies indicate that flow stratified sampling strategies yield unbiased and relatively precise total phosphorus load estimates when the samples were selected randomly. Strategies that confine sampling to the first half of the year or neglect either the rising area or falling area of the hydrograph will yield biased load estimates. A systematic sampling strategy will insure that each sample within each strata has an equal probability of being selected and usually yields unbiased total phosphorus load estimates.

Sample sizes necessary to estimated total phosphorus loads were calculated for four of the seven Michigan tributaries studied using load average and variance predicted by flow variability versus load variability regression equations. This method can be used to provide sample size estimates for many tributaries with little or no prior information about total phosphorus concentrations but is not reliable for the most event responsive rivers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Funding for this project was provided by the Environmental Protection Agency, Great Lakes National Program Office. Event sampling programs are labor intensive and many Michigan Department of Natural Resources personnel helped with data collection. Sampling was coordinated and conducted by Rick Lundgren, Frank Horvath and Bob Wood. Additional assistance was provided by Jim Rossio, Greg Goudy, Dave Kenaga, Chris Hull, Jim Young, Amy Peterson, Bruce Rabe and Rob MacLean.

Colleagues who provided comments on earlier drafts include Jim Rossio, Dave Kenaga, Greg Goudy, Rick Lundgren and Bob Wood. Also, R. Peter Richards (Heidelberg College) and David M. Dolan (International Joint Commission) provided comments on an earlier draft of this report.

CONCLUSIONS

Annual load estimates of total phosphorus, suspended solids, ammonia, total Kjeldahl nitrogen, nitrate, calcium, sodium, silica, sulfate, magnesium and potassium were calculated by dividing sample concentrations into two groups, or strata, and applying Beale's Ratio Estimator. The sample concentrations were divided into high and low strata with the cut-off being the historical upper 20th percentile of flow.

Annual load estimates calculated from 1984 to 1986 on the Black, Clinton, Rouge and Huron rivers were variable from year to year. Annual loads seemed to be related to the magnitude of the average annual flows or to the actual number of high flow days in a year. In 1984 annual loads were also estimated from the St. Joseph, Pere Marquette, and Ontonagon rivers. The greatest annual loads of the twelve parameters usually came from the St. Joseph followed by the Black or Rouge rivers. The lowest annual loads came from either the Pere Marquette or Ontonagon rivers.

Event sampling strategies yield excellent load estimates regardless of the relationship between load and flow. However, event sampling is resource intensive and not required unless loads of the constituent increase with increasing flow. Plots of daily average load versus daily average flow indicate a positive relationship between loads and flow for all twelve parameters in the Black, Clinton, Rouge, Huron, Ontonagon, and St. Joseph rivers. Suspended solids and ammonia in the Pere Marquette

River did not increase with flow and therefore loads could be estimated with a fixed interval sampling program instead of an event sampling program.

The results of Monte Carlo studies indicate that random sampling is the only way to insure that load estimates will be unbiased. Strategies that confine sampling to the first half of the year or neglect either the rising arm or falling arm of the hydrograph will yield biased total phosphorus load estimates.

Although it is difficult to develop a completely random sampling strategy, systematic sampling insures that each sample within each strata has an equal probability of being selected. The results of Monte Carlo studies indicate that in most cases systematic sampling yields unbiased total phosphorus load estimates.

The number of samples required to estimate loads will not be the same for each river. Sample size estimates were calculated using load average and variance estimates obtained directly from the complete data sets. Load estimates from the Monte Carlo studies were usually within the precision specified by the sample size estimation formula.

The variance of total phosphorus loads can be predicted from flow variability. The load variability can then be used to predict the number of high and low flow samples required from each river. Estimated sample sizes were calculated using load average and variance predicted by flow variability versus load variability regression equations. This method can be used to provide sample size estimates for many tributaries with little or no prior information about the constituent of concern but is not reliable for the most event responsive rivers.

Sample size estimates were calculated for four of the seven Michigan tributaries studied using the load variability versus flow variability relationship. Sample size predictions were good for the Ontonagon, Huron and Clinton rivers but poor for the most event responsive Black river. Low intensity sampling on the more stable Pere Marquette and St. Joseph rivers yielded relatively precise loads supporting the contention that rivers with stable flows generally require less intensive sampling programs.

INTRODUCTION

The Great Lakes are the largest body of freshwater in the world and support a variety of human activities. They receive wastes from point sources such as municipal and industrial facilities as well as from non-point sources including combined sewer overflows, urban and rural runoff, and atmospheric deposition. Although complete mass balances have not been conducted for all the Great Lakes, tributaries are known contribute large amounts of certain chemical constituents. Many of these constituents are present and required in trace amounts for the existence of aquatic life but if present in excess can cause nuisance conditions or toxicity problems.

The Michigan Department of Natural Resources (MDNR) has monitored several Great Lakes tributaries for numerous chemical constituents for more than 30 years. This monitoring has been used to describe trends, identify emerging problems, document existing conditions for waste discharge permits and estimate tributary loadings. Tributary Loadings have historically been calculated by multiplying average monthly flows by a single monthly sample concentration, but indications are that although existing monitoring was sufficient for most purposes, it was poorly suited for calculating loads of most constituents.

Many tributary systems are characterized by loads that are dominated by non-point sources. Concentrations of some parameters tend to increase or remain relatively constant with increased flow. Yaksich and Verhoff (1983) reported that in several Ohio rivers, the greatest loadings occurred during periods of high flow or high flow runoff events and Richards and Holloway (1987) stated that in some Lake Erie tributaries as much as 80% of the annual load of certain constituents was delivered past a monitoring point during the 20% of the time that the highest flows occurred. In these cases where most of the annual load occurs during the 20% of the time with the highest flows the distribution of loads is usually highly skewed. Load estimates from monthly monitoring often underestimate the true load from these "event responsive" rivers by 15% to 30% (Yaksich and Verhoff 1983).

One sampling design that can substantially reduce load estimate errors is flow stratified sampling. Stratified sampling is performed by dividing the flow into subgroups or strata and sampling from each strata. This procedure breaks the flow into groups that are less variable than the complete flow record. Strata with highly variable loading rates can be sampled more intensively than the less variable strata so that estimate errors within each strata are minimized and precision of the overall estimate is increased (Bierman et al 1988). Also, precision can be gained by forming strata so that a heterogenous flow record is divided into fairly homogenous parts (Snedecor and Cochran 1980).

Richards and Holloway (1987) conducted Monte Carlo studies to test various sampling strategies and load estimation techniques using large data sets from three Lake Erie tributaries. Based on these studies, they recommended flow stratified sampling with proportionately more samples collected during periods of high flow. They found that for event responsive streams in Ohio, less than 50 samples per year provided strongly biased and imprecise load estimates. Yaksich and Verhoff (1983) and Bierman et al (1988) also concluded that sampling strategies should be stratified by flow in these event responsive rivers. Yaksich and Verhoff (1983) recommended an event sampling strategy for Lake Erie tributaries that included 15 to 20 grab samples over two or three of the largest events with 5 to 10 additional steady flow samples. They stated that their strategy would yield a load estimate with a 10% to 20% standard error.

The MDNR presently monitors the water quality of several rivers throughout the state with a fixed station monthly monitoring program. As previously mentioned, one goal of that program is to provide data to calculate annual pollutant loads to the Great Lakes from the tributaries. This project was undertaken to sample several rivers more extensively during high flow periods in order to obtain better load estimates and to develop a load estimation sampling strategy that would be applicable to Michigan rivers.

PROJECT DESIGN

Site Descriptions and Sampling Methods

Seven tributaries were selected for study including the Black, Clinton, Huron, Rouge, Ontonagon, Pere Marquette and St. Joseph rivers (Figure 1). River watersheds ranged in size from 1201 Km^2 to 12,124 Km^2 with the smallest being the Rouge and the largest being the St. Joseph (Table 1). Land use and soil types varied among watersheds. The Ontonagon and Pere Marquette drainage basins are mostly forested and wetlands; the Black, Huron, Clinton and St. Joseph watersheds are primarily agricultural; and the Rouge watershed is primarily urban and suburban (Table 2). All the watersheds are predominately loam soils except for the Pere Marquette, which is mostly sandy soils (Table 3). Maps of the tributaries are included in Appendix 1.

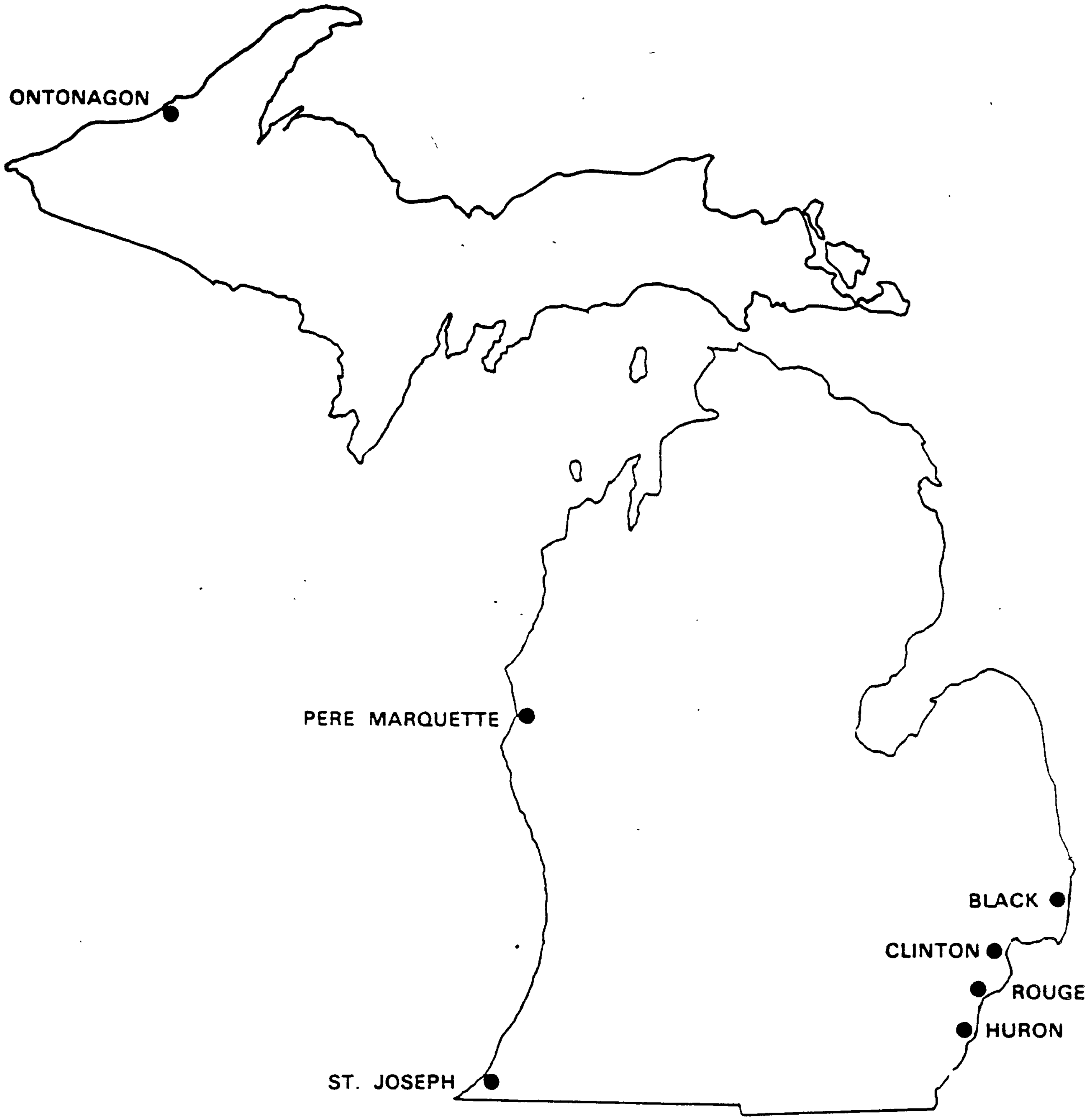


Figure 1. River mouth stations sampled by the Michigan Department of Natural Resources.

Table 1. Drainage area of the project watersheds.

Tributary	sq. mi	sq. km
Rouge	467	1210
Black	711	1842
Pere Marquette	740	1917
Clinton	760	1968
Huron	908	2352
Ontonagon	1390	3600
St. Joseph	4681	12123

Table 2. Land use (%) by watershed.

Watershed	Urban & Suburban	Agricultural & Range	Forest & Wetlands	Inland Waters
Ontonagon	0.1	13.0	83.8	3.1
Pere Marquette	0.6	33.2	64.8	1.4
Black	2.4	82.8	14.8	<0.1
Huron	8.2	67.4	22.4	2.1
Clinton	25.6	62.8	9.9	1.7
Rouge	73.4	23.6	2.8	0.2
St. Joseph	3.1	72.7	22.9	1.3

Table 3. Soil types (%) by watershed.

Watershed	Clay	Loam	Sand
Ontonagon	36.4	46.0	17.6
Pere Marquette	15.8	7.9	77.0
Black	18.2	75.0	6.9
Huron	10.1	85.3	4.6
Clinton	17.4	71.8	10.8
Rouge	28.6	48.4	23.0
St. Joseph	8.6	81.5	10.0

The rivers were sampled over a 3-year period during 1984 through 1986. The study was conducted on all seven rivers in 1984, but only the Black, Clinton, Huron and Rouge were sampled in 1985 and 1986. Three sampling strategies were used including (1) monthly throughout each year, (2) weekly during the spring when flows are typically highest (scheduled samples), and (3) twice daily during periods of high flow caused by precipitation and/or snow melt (event samples). Water samples collected using monthly and scheduled strategies were analyzed for suspended solids, total phosphorus, ammonia, total Kjeldahl nitrogen, nitrates, chlorides, calcium, sodium, silica, sulfate, magnesium and potassium while event samples were only analyzed for total phosphorus, total Kjeldahl nitrogen, nitrates, ammonia, chlorides and suspended solids. The number of high and low flow samples collected varied among rivers, years and parameters.

Event sampling was initiated based on weather forecasts and daily telephone monitoring of river stage heights, measured by the United States Geological Survey (U.S.G.S.), at gaging stations on each river. When it was determined that an event was starting, sampling was initiated focusing primarily on the rising arm, the peak, and initial falling slope of the event hydrograph. Samples were usually collected twice a day for seven consecutive days during the high flow event.

Surface water grabs were taken as close to the mouth of each tributary as possible but upstream of areas influenced by seiches. Samples were collected with a can sampler at about 30 cm below the surface in the center of the stream in an area of high flow. Sample collection, handling and preservation procedures are described in " Quality Assurance Manual for Water and Sediment Samples" (MDNR 1982 edition).

Flow Measurement and Estimation

Since river sampling stations were downstream of gaging stations, it was necessary to adjust the flow value obtained at the gaging stations to reflect the additional drainage areas between the gages and the sampling stations. To estimate the discharge at the sampling site near the tributary mouth, a single gage reading or sum of gage readings was multiplied by a correction factor. The correction factor used was the drainage area ratio (DAR), calculated by dividing the drainage area above the sampling station by the drainage area above the gaging station. The estimated discharge at sampling stations in the Pere Marquette, Ontonagon, Huron, Clinton and Black rivers were obtained directly by multiplying the DAR by the appropriate gage reading (Table 4). Since there was no gage in the St. Joseph River downstream of the confluence of either the Dowagiac or the Paw Paw rivers, the flow at the mouth was estimated by multiplying the DAR by the sum of the flows at the three gages. In the Rouge River there were no gages below the confluence of either the Middle Rouge or Lower Rouge Rivers. Also, the Ford Rouge Plant continuously discharges 784 cfs of water, drawn from the Detroit River, to the Rouge River downstream of the gaging station but approximately 2.5 miles (4 km) upstream of the water sampling station. The Rouge River flow estimate at the mouth was obtained by multiplying the DAR by the sum of the three gage flows (Rouge, Middle Rouge and Lower Rouge) and adding the 784 cfs discharged from the Ford Rouge plant.

ANNUAL LOAD ESTIMATES

Load Estimation Methods

After samples have been collected with a flow stratified sampling

Table 4. Drainage Area Ratios (DAR) and U.S. Geological Survey gaging station locations by river.

River	Gages		DAR
Pere Marquette	04122500	at Scottville	1.05
Ontonagon	04040000	near Rockland	1.04
Huron	04174800	at Ann Arbor	1.21
Clinton	04165500	at Mt. Clemens	1.04
Black	04159500	near Fargo	1.48
St. Joseph	04101500	St. Joseph R. at Niles	1.09
	04101800	Dowagiac R. at Summerville	
	04102500	Paw Paw R. at Riverside	
Rouge	04166500	River Rouge at Detroit	1.24
	04167000	Middle Rouge at Garden City	
	04168000	Lower Rouge at Inkster	

strategy, a variety of methods are available for calculating the annual load. Dolan et al (1981) tested several load estimation methods, including means of loads over time, regression estimators and a ratio estimator (Beale's ratio estimator) using Monte Carlo studies with a large data set from the Grand River in Michigan. They found that Beale's ratio estimator (BRE) consistently yielded estimates with the least bias and best precision and concluded that the BRE was the best estimator for systems with complete daily flow records and relatively little concentration information. Richards and Holloway (1987) tested Beale's ratio estimator against other estimators and also concluded that the BRE provided the most precise and unbiased estimates.

For calculation purposes the flows were divided into two strata. Although the number of flow strata can be more than two, Dolan et al (1981) and Richards and Holloway (1987) also divided the flows into two strata. Dolan et al divided the strata at two times the median flow while Richards and Holloway divided the flow into the upper 20th percentile and bottom 80th percentile. In this study the flows were divided into high and low flow strata with the cut-off being the historical upper 20th percentile of flow. In other words, the cutoff flow was exceeded by 20% of the recorded flows and was greater than 80% of the recorded flows. Percentiles of flow are available (in five percentile intervals) from U.S.G.S. flow duration analyses.

Annual Loads from Seven Tributaries

The total annual loads of twelve constituents from seven tributaries were calculated using the BRE and dividing the samples into high and low flow strata (Table 5). In some cases, estimates of annual loads varied

Table 5. Annual loads from seven Michigan tributaries (metric tonnes per year).

River and Year	Total Phos.	Total Suspended Solids	Ammonia	Total Kjeldahl Nitrogen	Total Nitrate	Total Calcium	Total Sodium	Total Silica	Total Sulfate	Total Cloride	Total Magnesium	Total Potassium
Black River												
1984												
Load	184.0	79490	226.1	1397	1462	38310	8693	1197	36480	16590	11390	3172
+/-95% C.I.	32.6	22420	163.4	46	371	11070	3165	153	13420	6460	3490	267
nh	47	48	7	47	7	7	7	7	7	7	7	7
nl	25	25	14	25	14	14	14	14	14	14	14	14
1985												
Load	225.4	100900	170.6	1229	1317	32260	5945	1331	31780	14530	9035	3290
+/-95% C.I.	90.3	54190	45.2	301	279	11260	1993	396	13310	4770	3221	414
nh	41	41	41	41	41	11	11	10	12	12	11	11
nl	48	49	49	49	49	13	14	14	14	14	14	14
1986												
Load	199.6	81890	257.4	1371	1111	33360	7572	1521	28670	15660	10000	3794
+/-95% C.I.	21.4	26700	67.2	77	173	12180	3180	619	9860	2020	3670	289
nh	45	43	45	48	45	10	10	10	11	45	10	10
nl	48	48	48	48	48	17	17	18	18	48	17	17
Clinton River												
1984												
Load	100.1	25560	97.67	671.4	1108	31110	28990	1112	24120	45540	9642	1875
+/-95% C.I.	23.5	8242	20.84	56.6	218	1820	5170	140	5110	11700	598	103
nh	32	32	6	32	6	5	5	6	6	6	5	5
nl	39	41	14	40	14	15	15	13	14	14	15	15
1985												
Load	167.4	50120	190.1	1067	1492	51820	44450	2093	42180	78870	14960	2902
+/-95% C.I.	36.8	16060	38.3	131	167	6830	10920	301	4930	17200	2150	206
nh	48	48	48	48	48	4	14	13	15	15	14	14
nl	41	42	42	42	42	10	11	11	11	11	11	11
1986												
Load	120.0	36400	123.6	909.8	1184	44700	49030	1676	27010	66760	13080	2553
+/-95% C.I.	20.4	11890	18.3	56.5	230	5790	15640	2100	6200	3770	1860	109
nh	76	73	76	76	76	16	16	17	19	74	16	16
nl	27	27	27	27	27	12	12	12	12	27	12	12
Rouge River												
1984												
Load	114.2	24210	389.9	1110	620.2	40830	29730	1253	30220	58000	10580	2242
+/-95% C.I.	16.2	6979	113.5	82	211.7	2770	4700	544	3010	18150	570	234
nh	33	44	4	33	4	3	3	4	4	4	3	3
nl	36	26	15	36	15	16	16	15	15	15	16	16
1985												
Load	186.1	41920	640.1	1658	942.8	54530	56170	1932	44430	100400	13580	2637
+/-95% C.I.	36.2	19930	82.5	173	109.1	3600	15880	209	4180	23860	900	180
nh	50	50	50	50	50	12	12	11	13	13	12	12
nl	45	46	46	45	46	12	13	13	13	13	13	13
1986												
Load	126.6	25300	488.6	1328	562.7	46630	42240	1314	32160	79560	12280	3119
+/-95% C.I.	13.4	6632	47.5	103	44.2	4140	11490	167	3850	9970	1260	651
nh	56	54	56	55	56	15	15	16	18	55	15	15
nl	37	37	37	37	37	11	11	11	10	37	11	11

Table 5. continued.

River and Year	Total Phos.	Total Suspended Solids	Ammonia	Total Kjeldahl Nitrogen	Total Nitrate	Total Calcium	Total Sodium	Total Silica	Total Sulfate	Total Cloride	Total Magnesium	Total Potassium
Huron River												
1984												
Load	35.49	10840	38.34	521.3	450.3	29260	14720	874.8	25430	27240	8309	1258
+/-95% C.I.	2.48	1944	39.89	20.7	68.0	1500	1200	294.4	1130	1970	510	77
nh	36	36	6	36	6	5	5	6	6	6	5	5
nl	35	36	15	35	15	16	16	15	15	15	16	16
1985												
Load	64.89	23680	120.8	770.8	760.7	46260	22990	1714	43510	43230	12990	1810
+/-95% C.I.	7.67	5386	25.5	50.2	53.6	2910	4060	355	4020	6500	640	118
nh	42	42	42	42	42	12	12	11	13	13	12	12
nl	53	54	54	54	54	12	13	13	13	13	13	13
1986												
Load	47.90	15000	78.89	727.0	780.6	45460	24520	1375	34080	41840	12920	1907
+/-95% C.I.	2.85	1943	11.95	22.6	43.3	2050	3100	375	1080	1710	300	111
nh	38	38	38	38	38	9	9	9	10	38	9	9
nl	53	53	53	53	53	15	15	16	16	53	15	15
Ontonagon River												
1984												
Load	110.2	104200	40.16	671.0	154.7	18550	4079	4424	8421	3186	5156	1712
+/-95% C.I.	29.6	50520	10.68	47.9	42.0	580	365	288	933	378	378	428
nh	31	31	8	31	7	10	10	8	8	8	8	8
nl	80	80	18	80	18	18	18	18	18	18	18	18
Pere Marquette River												
1984												
Load	34.00	5900	137.6	475.2	143.9	30610	6915	2750	13580	10690	10600	353.2
+/-95% C.I.	3.35	1554	40.3	30.3	19.5	1370	645	312	705	1050	620	51.0
nh	17	16	15	17	15	16	16	16	16	16	15	15
nl	8	9	9	8	9	9	8	8	8	8	9	9
St. Joseph River												
1984												
Load	317.5	80850	620.1	3972	7803	273900	50970	11450	204800	93500	81720	8534
+/-95% C.I.	44.9	22410	201.2	297.6	913	12130	3960	2750	9800	5520	6170	286
nh	10	10	9	10	10	9	9	9	9	9	9	9
nl	14	14	14	14	14	14	14	14	14	14	14	14

nh= number of high flow samples
nl= number of low flow samples

substantially among different years. For example, the annual total phosphorus load in the Huron River was approximately 83% greater in 1985 than 1984. Most of the estimated loads from the Rouge, Clinton, and Huron rivers were highest in 1985, intermediate in 1986 and lowest in 1984. This is probably related to annual average daily flows that were also highest in 1985, intermediate in 1986 and lowest in 1984 (Table 6).

Estimated loads from the Black River did not follow this pattern even though the annual average daily flows did. In the Black River, from 1984 to 1986, the lowest annual average daily flow occurred in 1984 followed by 1986 and 1985. However, more high flow days, or days in which the daily average flow exceeded the historical upper 20th percentile cut-off flow of 347.8 cfs, occurred in 1984 followed by 1986 and 1985. Estimated annual loads of total phosphorus and suspended solids were highest in 1985 and lowest in 1986 following the pattern of the relative magnitude of annual daily average flows. At the same time, estimated annual loads of total Kjeldahl nitrogen, nitrate, calcium, sodium, sulfate and chloride were highest in 1984, the year with the most high flow days. It may be that the number of high flow days was more important than the magnitude of flow on high flow days. In such a case, loads of some parameters may be less in years with a few large events than in years with many smaller events.

Estimates of annual loads from the Ontonagon, Pere Marquette and St. Joseph rivers are available for 1984. Fewer samples were collected in the Pere Marquette and St. Joseph rivers compared to the other tributaries but sampling effort on the Ontonagon River was relatively intense. Scheduled samples from the Ontonagon were collected by an MDNR Conservation Officer stationed at White Pine and event samples were

Table 6. Average daily flow (cfs), 20th percentile cut-off flow (cfs) and the number of days in each high flow and low flow strata for the Black, Clinton, Rouge and Huron rivers, 1984-1986, and the Ontonagon, Pere Marquette and St. Joseph rivers, 1984.

River	Year	Flow Cut-off	High Flow Days	Low Flow Days	Ave. High Flow	Ave. Low Flow	Annual Ave. Daily Flow
Black							
	1984	347.8	143	223	1633	140.0	723.3
	1985	347.8	109	256	2927	97.84	942.7
	1986	347.8	129	236	2195	131.0	860.5
Clinton							
	1984	713.1	65	301	1472	342.5	543.1
	1985	713.1	140	225	1971	356.0	975.5
	1986	713.1	140	225	1323	439.8	778.6
Rouge							
	1984	1143	67	299	1731	932.6	1079
	1985	1143	129	236	1877	953.9	1280
	1986	1143	117	248	1654	979.0	1195
Huron							
	1984	904.9	62	304	1187	350.7	492.4
	1985	904.9	99	266	1671	444.0	776.8
	1986	904.9	71	294	1408	552.7	719.1
Ontonagon							
	1984	1518	62	304	3602	924.1	1378
Pere Marquette							
	1984	879.9	161	205	1097	705.6	877.8
St. Joseph							
	1984	5927	91	275	7842	3841	4836

collected by park rangers from Porcupine Mt. State Park. The precision estimates for these three rivers were comparable to the other four tributaries, but if annual load estimates are as variable as those from the four eastern tributaries, then caution should be used in extrapolating estimates to other years.

In 1984 the greatest annual loads of twelve parameters usually came from the St. Joseph River followed by the Black or Rouge rivers. Large loadings from the St. Joseph river are not surprising since the average daily flow in the St. Joseph river was more than 3.5 times the daily average flow in any of the other rivers and nearly 73% of the watershed is developed for agriculture. Also, both the Black and Rouge river watersheds have large urban or agricultural areas that may be non-point sources of some constituents. The smallest annual loadings of each constituent came from either the Pere Marquette or Ontonagon rivers. Both of these watersheds are relatively undeveloped and dominated by forests and wetlands.

SAMPLE STRATEGY DEVELOPMENT

Determining the Necessity of Event Sampling Strategies

Yaksich and Verhoff (1983) found that event sampling strategies yielded excellent load estimates in all cases regardless of the relationship between concentration and flow. However event sampling is more resource intensive than other sampling strategies and is not required unless loads of the constituent increase with increasing flow. When concentration and flow are not related annual loads can be estimated with fixed interval sampling programs.

To determine which constituents in each tributary actually required a flow stratified sampling strategy, daily average loads were plotted against the corresponding daily average flow. Daily average loads were calculated on each day samples were collected by multiplying daily average flow (cfs) by parameter concentration (mg/l) and by a conversion factor of 2.45 (cfs x mg/l x 2.45 = Kg/day). Least squares linear regression estimates were calculated and a t-test was used to demonstrate that the loads of some parameters were related to flow.

Plots of loads versus flow of twelve parameters in Seven tributaries are included in Appendix 2 and the regression of loads on flow in the Black, Rouge, Clinton, Huron, Ontonagon and St. Joseph rivers indicate a statistically significant (alpha 0.05) positive relationship between loads and flows for all parameters. The variability tended to increase with increased flow which is one reason for taking a proportionately higher number of samples during high flow periods.

In the Clinton and Rouge rivers, sodium and chloride concentrations tended to increase with flows but loads were highly variable at all flows. This may have been due to chloride uses not related to flow, such as seasonal use of road deicers. Urban areas, where large amounts of deicers are used, are much more extensive in the Clinton and Rouge watersheds than in the other five tributaries monitored.

In the Pere Marquette River, loads of suspended solids and ammonia were not related to flow. Therefore, load estimates of suspended solids and ammonia from the Pere Marquette River do not require event sampling and could be obtained with a less labor intensive fixed interval sampling program. All other constituent loads require event sampling to obtain reliable estimates.

Testing for Bias Introduced by Event Sampling Strategies

Another objective of the project was to develop a sampling strategy that would yield relatively precise and accurate load estimates (in this case total phosphorus loads) from Michigan tributaries. To test several different high flow sampling strategies, Monte Carlo runs were conducted on three large data sets of total phosphorus concentrations. The data sets selected were the Sandusky River (1834 total phosphorus samples collected during calendar years 1982-1985) the Raisin River (1237 total phosphorus samples collected during water years 1983 to 1986) and the Grand River (361 samples collected between March 1, 1976 and March 1, 1977). These data sets were obtained through STORET, the Environmental Protection Agency's data storage and retrieval computer system. All three had duplicate samples on some days, missing values on some days, or both. Therefore, the data sets were adjusted so that there was a single total phosphorus concentration recorded for each day. Average concentrations were calculated on days with multiple samples and concentrations were estimated by linear interpolation on days when no samples were collected. A "known" annual load and average daily load were calculated using the adjusted daily total phosphorus concentrations and daily average flows recorded at U.S.G.S. gaging stations. Although the true load cannot be "known", these data sets were the most complete available.

The next step was to assess different methods of stratified random sampling by drawing subsamples from the complete data sets and comparing estimates to the "known" load. The data sets were broken down into individual years within each tributary so that there were a total of nine complete data sets (four each from the Sandusky and Raisin and one from the Grand). Subsamples were drawn and average daily loads were calculated two hundred and fifty times for each of the nine different adjusted data sets and each of the five different sampling strategies. The number of samples selected for each subsample was calculated using a sample size estimation formula that requires an estimate of average and variance of the load as well as a specified confidence interval.

A precision of +/- 50% was selected for the estimates of average load calculated from the Monte Carlo runs. This precision was selected for the Monte Carlo runs because the data sets were adjusted to have one sample per day and the estimated sample size could not exceed the number of days in each strata. Also, a relatively small estimated sample size provides a larger number of random combinations of subsamples. Investigators estimating tributary loads generally require more precise estimates than +/- 50% and to achieve a greater precision more samples are required. However, conclusions about the best sampling strategy, based on Monte Carlo studies, will be independent of the precision of load estimates.

Daily average loading rates and 95% confidence intervals were calculated for each estimate along with bias, which was the percent difference between the "known" load and the estimated load. Each group of runs was tested for deviations from a normal distribution using a test for skewness and a test for kurtosis. The average estimated load from each group of runs that was normally distributed, or could be transformed to a normal distribution, was tested for deviation from the known load using a t-test. Median estimates were calculated for all subsets with distributions that could not be transformed to normal.

The first flow stratified sampling strategy tested on each data set was random sampling from each strata. Individual daily total phosphorus samples were selected using a Lotus 123 random number generator. One data set was non-normal and had a median bias of -4.05%; but the average bias of the other seven estimates of average daily loads (Kg/day) ranged from -0.605% to 0.266% and none of the averages of daily loads were significantly different than the known load (Table 7). This indicates that "random" sampling of high and low flow days is a strategy that would usually provide estimates that, on average, are unbiased. Unfortunately it is impossible to use random numbers to select sampling days without having prior knowledge of the number and date of occurrence of high and low flow days in an upcoming year. Therefore, several flow stratified sampling programs were tested to document any bias introduced by non-random sampling and to propose an alternative program.

Previous studies have indicated that daily load estimates may be influenced by season. In spring 1977, MDNR personnel collected total phosphorus samples from several southeastern Michigan tributaries during high flow conditions. They found the highest total phosphorus concentrations during the first event of the season despite relatively low flows during the event (Schroeter 1978). Peak total phosphorus concentrations tended to decline with each of the first three successive events, regardless of flow, in each of the tributaries sampled. These data suggest that if a disproportionate number of high and low flow samples were to be collected in the spring, the resulting annual load estimate may be biased.

To test this hypothesis, Monte Carlo runs were conducted using subsamples drawn randomly from the first half of the available high and low flow days to simulate a sampling strategy that concentrates sampling

Table 7. Total phosphorus average daily load estimates (kg/day) and average percent estimated bias from Monte Carlo analyses for the Sandusky, Grand and Raisin rivers.

Sampling Strategy	Average Estimated Percent Bias							
	Sandusky River							
	1982		1983		1984		1985	
"known Load"	1670		998.5		1581		1183	
Random	1668	-0.119%	998.9	0.0400%	1517 M	-4.05% M	1186	0.262%
Seasonal	1522 **	-7.07%	1123 **	12.5%	1388 **	-12.2%	1229 **	3.89%
No Rising Hydro	1738 **	4.07%	1001	0.250%	1550 M	-1.96% M	1151**	-2.70%
No Falling Hydro	1739 **	4.10%	1107**	10.9%	1851 **	17.1%	1358 **	14.8%
Random Groups	1655 M	0.898%	999.3	0.0801%	1642 M	3.86% M	1196 M	1.10%
	Grand River							
	3/1/76-2/28/77							
"known Load"	1734							
Random	1734	-						
Seasonal	1607 **	-7.32%						
No Rising Hydro	1683 **	-2.94%						
No Falling Hydro	1745	0.634%						
Random Groups	1727	-0.403%						
	Raisin River							
	1983		1984		1985		1986	
"known Load"	589.8		452.2		563.3		396.2	
Random	591.1	0.220%	453.1	0.199%	564.8	0.266%	393.8	-0.605%
Seasonal	472.5 **	-19.9%	465.0 **	2.83%	601.2 **	6.73%	339.9 **	-14.2%
No Rising Hydro	573.1 **	-2.83%	423.3 **	-6.39	521.7 **	-7.39	397.7	0.379%
No Falling Hydro	673.7 **	14.2%	541.9 **	19.8%	690.1 **	22.5%	431.9 **	9.01%
Random Groups	591.8 M	0.339%	441.0 M	-2.48%	566.3 *	0.534%	397.8	0.404%

* significantly different than the known load (alpha=0.05)
** significantly different than the known load (alpha=0.01)
M: Median value was calculated due to non-normal distribution of the averages.

effort during the first part of a year. The sample sizes remained the same even though samples from days toward the end of the year were excluded from all subsets. All of the average estimates calculated were significantly biased, but the direction of the bias was not predictable. The range of bias estimates was from -19.9% to 12.5% with four of the average bias estimates positive and five negative (Table 7). Therefore, sampling should not be unproportionately concentrated in one season or bias may be introduced. Data collected from the Rouge and Clinton rivers indicate that this type of seasonal variability may be especially pronounced with chloride concentrations.

Schroeter (1978) also compared total phosphorus concentrations from the rising and falling arms of event hydrographs and concluded that total phosphorus concentrations were generally higher during the rising hydrograph. This indicates that if a sampling strategy were to systematically neglect either the rising arm or the falling arm, then bias may be introduced by the sampling strategy.

To test this hypothesis, high flow samples were divided into three categories. The first category included samples on the rising arm of the hydrograph, the second category included samples at the peak of an event hydrograph while the third category included samples from the falling arm of the event hydrograph. To test a strategy that consistently missed the beginning of an event hydrograph, high flow subsamples were selected exclusively from high flow days in categories two and three and low flow samples were selected randomly from the entire number of low flow days. This type of sampling strategy may be implemented accidentally if field crews are unable to respond fast enough to an event and subsequently miss the beginning of each event.

Six of the nine average daily load estimates were significantly biased, two were not significantly biased, and one set of estimates was non-normal and not tested but had a median bias of -1.96%. Average bias ranged from -7.39% to 4.07% and of the average biases that were significantly different than zero, five were negative and one was positive (Table 7). Although this strategy did not introduce bias in all cases, two-thirds of the average estimates were biased and one was untested indicating the potential for this strategy to yield inaccurate estimates.

To assess the effects of missing samples at the end of an event, Monte Carlo runs were made with subsets that included high flow samples randomly selected from high flow days in categories one and two and low flow samples selected randomly from the entire low flow data set. Again, this type of strategy may be implemented accidentally if field crews are consistently unable to continue sampling a site for the duration of an event, and the falling arm of an event hydrograph is sampled less often than earlier portions of the hydrograph. All the average daily load estimates from the nine sets of runs were significantly different than the known load except for the Grand River average estimate. The average bias estimates were positive and ranged from 0.634% to 22.5% (Table 7). Therefore, it appears that strategies that consistently miss samples on the falling arm of the hydrograph may be introducing bias.

Flow Stratified Systematic Sampling

It appears that the key to developing an unbiased stratified sampling strategy is to insure that within each strata, each sample has the same probability of being selected. However, it is difficult to develop a plan to sample randomly without prior knowledge of future flows. One method would be to use a systematic sampling strategy where samples are drawn at regular intervals based on the percentage of subsamples desired (See Snedecor and Cochran 1980 for further information on systematic sampling). For example, if the historical upper 20th percentile of flow is used as a cut-off between high and low flow strata, then an average year will have 72 high flow days (365 x 20% = 72). If the estimated high flow strata sample size is 24 then it is necessary to collect samples on one third of the high flow days. If the high flow days are arranged chronologically and "counted off" into groups of three, then in an average year there would be three groups of 24 samples each. A number between one and three could be randomly selected and would designate a particular group of samples.

For example, assume that in an average year the number one was selected randomly, high flow sampling would be initiated on the first high flow day of the year and samples would be collected on high flow days 1,4,7,10,......64,67,70 for a total of 24 samples. However, most years would not have exactly 72 high flow days and 72 is not divisible by all estimated sample sizes. If 72 is not divisible by the estimated sample size then the investigator will have to use a rounded "real number" spacing interval. For example, if the estimated sample size is 30 then a sample should be collected every 2.4 days. If the sampling started on day one then the sampling interval should be 1, 3.4, 5.8, 8.2, 10.6,....65.8, 68.2, 70.6 but samples would actually be collected on days 1,3,6,8,11....66,68,71.

To test a systematic sampling strategy, high flow days in each of the data sets from the Sandusky, Raisin and Grand rivers were arranged in chronological order, counted off based on the estimated sample size, and divided into groups. Each subsample used to estimate a load consisted of a randomly selected group of high flow samples combined with low flow samples selected randomly from the entire low flow data set. Distributions of estimates from five of the Monte Carlo runs were non-normal and not transformable, usually due to bimodal distributions based on the high flow group randomly selected to calculate an individual estimate. Four of the average estimates were tested against the "known" and one was significantly biased (alpha 0.05). Median bias ranged from 3.86% to -2.48% and average bias ranged from -0.403% to 0.534% with 0.534% being statistically different than zero (Table 7).

If a monitoring program were conducted over many years the average number of samples per year could be predicted but for any one year the number of samples collected could be highly variable. During a wet year with more than the average number of high-flow days additional samples would need to be collected since indications are that discontinuing sampling before the end of the year would introduce bias to the sampling strategy. However, a potential benefit of a systematic sampling strategy is that additional samples are collected during years with more than average high flow days and this should improve estimates by sampling more often during more variable years. Also, fewer samples would be collected during dry years without a loss in precision.

The assumption was made that low flow samples will be collected "randomly". Less attention is paid to low flow sampling because generally the low flow strata contributes less to the annual load and is less variable. Although no strategies for random sampling in the low flow strata were tested, collecting the samples over the entire year (i.e regular fixed interval sampling) should be sufficient.

SAMPLE SIZE ESTIMATION

Sample Size Estimation Method

The number of samples required to estimate loads is an important aspect of any sampling strategy. Generally sample sizes can be predicted by using the following formula:

$$n_{est} = (t^2 \times S^2)/(D^2 \times X^2)$$

where:

n_{est} = estimated sample size

t^2 = student's t value squared

S^2 = variance of the daily load

D^2 = precision, as a percentage of the average, squared (ie. D=0.5 would indicate a precision of +/- 50%)

X^2 = average daily load squared

The approach taken was to estimate the sample size within each flow strata, so an estimate of the daily average load and variance of the daily average load within both the high and low flow strata was required.

Again, sample size estimates for Monte Carlo studies were predicted using average and variance estimates calculated from the complete data sets. If predictions of variance and average are accurate then the estimated 95% confidence interval should have been within +/- 50% of the estimate. Confidence intervals for loads to the Sandusky River, calculated from random sampling, ranged from +/- 8.29% to +/- 51.3% of the estimate (Table 8). Confidence intervals for loads to the Grand and Raisin rivers, ranged from 7.62% to 40.9%, and 7.30% to 47.0%,

Table 8. Low, high and median 95% confidence intervals calculated on load estimates (Kg/day), from Monte Carlo subsampling, for the Sandusky, Grand and Raisin rivers.

River and Year	Strategy	Sample Size	+/- 95% confidence interval low	high	median	+/- 95% confidence interval % low	% high	% median
Sandusky River								
	Random							
1982		66	106.3	906.4	584.0	9.48%	51.3%	34.5%
1983		66	67.42	203.9	138.9	8.29%	20.4%	14.6%
1984		66	131.2	778.0	302.3	9.28%	47.0%	19.5%
1985		66	98.39	228.1	176.0	9.27%	18.8%	14.7%
	Seasonal							
1982		66	151.3	764.0	595.3	14.6%	49.6%	38.7%
1983		66	86.53	171.8	159.9	8.64%	16.0%	14.1%
1984		66	170.6	248.4	215.5	12.6%	18.5%	15.5%
1985		66	134.5	230.3	209.5	11.8%	18.6%	16.8%
	No Rising Hydro.							
1982		66	36.07	357.9	562.2	7.81%	48.2%	32.3%
1983		66	76.01	206.1	149.0	8.91%	20.1%	15.2%
1984		66	106.5	792.3	320.1	10.2%	48.3%	21.7%
1985		66	98.99	207.4	167.0	9.02%	18.0%	14.4%
	No Falling Hydro.							
1982		66	159.5	933.9	746.1	14.1%	53.3%	44.1%
1983		66	122.0	203.9	190.0	12.0%	18.8%	16.5%
1984		66	159.5	730.9	718.9	10.0%	41.5%	38.3%
1985		66	134.7	207.6	189.4	10.3%	15.3%	14.0%
	Systematic Sampling							
1982		95-96	399.6	472.0	407.5	24.4%	27.2%	25.1%
1983		75	118.5	156.1	153.9	11.9%	15.6%	15.2%
1984		71	225.4	539.8	534.3	14.9%	32.7%	31.7%
1985		77	130.0	164.6	157.3	11.2%	13.0%	13.0%
Grand River								
3/1/77 to	Random							
3/1/78		13	127.3	824.1	316.7	7.62%	40.9%	18.4%
	Seasonal							
		13	116.8	822.5	352.7	8.08%	48.8%	21.9%
	No Rising Hydro.							
		13	151.0	702.3	336.9	8.50%	36.6%	19.3%
	No Falling Hydro.							
		13	120.1	748.8	290.8	7.54%	42.0%	18.1%
	Systematic sampling							
		16-17	169.6	331.5	309.1	9.51%	43.0%	17.1%

Table 8. Continued.

River and Year	Strategy	Sample Size	+/- 95% confidence interval low	high	median	+/- 95% confidence interval % low	% high	% median
Raisin River								
	Random							
WY 1983		39	43.89	301.6	177.7	9.80%	47.0%	29.6%
WY 1984		39	47.50	115.5	81.11	11.3%	23.4%	17.9%
WY 1985		39	76.64	151.1	121.2	14.0%	26.7%	21.4%
WY 1986		39	24.56	104.2	62.94	7.30%	25.8%	16.2%
	Seasonal							
WY 1983		39	30.54	92.35	56.44	7.24%	18.8%	11.9%
WY 1984		39	51.29	91.58	78.24	11.0%	20.2%	15.4%
WY 1985		39	100.4	153.3	144.5	20.6%	26.1%	23.9%
WY 1986		39	21.84	63.13	33.31	6.74%	17.8%	9.83%
	No Rising Hydro.							
WY 1983		39	40.09	305.8	187.3	10.3%	47.7%	32.3%
WY 1984		39	45.32	106.4	73.16	11.3%	26.0%	17.4%
WY 1985		39	43.49	135.6	112.7	10.7%	21.3%	21.5%
WY 1986		39	29.23	110.6	68.74	8.20%	27.1%	17.5%
	No Falling Hydro.							
WY 1983		39	55.18	278.9	234.7	11.1%	41.1%	31.8%
WY 1984		39	50.81	106.4	84.84	10.2%	19.5%	15.7%
WY 1985		39	130.4	147.5	132.7	18.1%	21.2%	19.3%
WY 1986		39	28.44	104.0	87.30	7.83%	23.7%	19.3%
	Systematic Sampling							
WY 1983		67-68	124.5	171.1	141.4	20.2%	27.4%	23.3%
WY 1984		60-61	55.8	73.1	67.46	11.4%	17.7%	15.5%
WY 1985		42-43	108.6	132.3	115.1	18.6%	23.8%	20.3%
WY 1986		56	40.0	80.0	68.23	10.1%	20.0%	17.0%

respectively. Calculated 95% confidence intervals from the systematic sampling strategy ranged from 11.2% to 37.2% of Sandusky River loads, 9.51% to 43.0% of Grand River loads, and 10.1% to 27.4% of the Raisin River loads. Confidence intervals rarely exceeded +/- 50% and were usually much less than +/- 50%.

In some cases there was a relatively large range in confidence intervals. Data from a tributary, year and subsample that by chance yield a low confidence interval, should not be taken as an indication that fewer samples could be collected in the next year. For example, one combination of samples taken from the Sandusky River in 1982 yielded an estimate with a 95% confidence interval of +/- 9.48%, while another combination of samples from the same tributary and year yielded an estimate with a 95% confidence interval of +/- 51.3%. A decision to change the sample size based on either of these confidence intervals may lead to wasted resources on unnecessary precision or an estimate less precise than desired. A better way to adjust sample size estimates after one year of sampling would be to use improved estimates of average daily load and variability in the sample size estimation formula.

Sample size estimates of 13 for the more stable Grand River would not be considered intensive event sampling. However, the precision of the calculated estimates was always less than the desired +/- 50% indicating that the sample size was adequate. This method of sample size estimation may save investigators from making arbitrary decisions about the intensity of flow stratified sampling.

Predicting Load Variability for Sample Size Calculations

Many tributaries will not have extensive concentration data on each parameter of concern. While an approximation of the average load in each strata may be available from monthly monitoring data, variance estimates typically require more information. Richards (in press) found that one way to predict the variance of the daily load of a particular parameter was to relate it to the variance of the average daily flow. He quantified a relationship between the daily suspended solids load variance and the average daily flow variance using complete, or nearly complete, suspended solids and flow data sets from 11 tributaries to lakes Michigan, Erie and Ontario. These tributaries ranged from event responsive systems in which flow was highly variable, to stable systems with less variable flows and the watersheds ranged in size from 16,395 Km^2 to 44 Km^2.

Richards used the coefficient of variation (standard deviation divided by the average) of the logs of the set of percentiles of flow (5%,10%,15%,20%...........80%,85%,90%,95%) (CVLF5) to quantify flow variability. The CVLF5 is provided in U.S.G.S. flow duration analyses. All flows were in cfs and Richards pointed out that CVLF5 is affected by the units used to measure flow. The variability of the daily suspended solids load was quantified by calculating the coefficient of variation (CV) of the logarithms of daily suspended solids loads. A least-squares linear regression between the CVLF5 and the CV of the log of daily loads for nine of the eleven tributaries yielded a predictor equation of Y= 0.0482 + 0.7197(CVLF5) with R= 0.99. Two tributaries were excluded as outliers because Richards felt that the watersheds were small and the period of flow record was short. This equation enabled him to predict the CV of the log of suspended solids loads on any tributary which had a complete flow record.

A similar type of relationship was developed, for this project, between flow variability and total phosphorus daily load variability. Data sets from six Great Lakes tributaries with complete or nearly complete records of daily total phosphorus concentrations were used. The six tributaries were the Sandusky River, Honey Creek, (classified by Richards as event responsive) Raisin River, Maumee River, Cuyahoga River (variable responsive) and the Grand River (stable responsive). As stated earlier, the total phosphorus concentrations used from the Sandusky River were recorded during calendar years 1982-1985 and included 1834 total phosphorus measurements. From the Raisin River, 1237 total phosphorus samples were collected during water years 1983 to 1986 and 361 total phosphorus samples were collected from the Grand River between March 1, 1976 and March 1, 1977. The additional three data sets included 2359 total phosphorus samples from the Cuyahoga River, 2431 total phosphorus samples from Honey Creek and 2564 total phosphorus samples from the Maumee River collected between January 1, 1982 and December 31, 1986.

To quantify load variability the CV of the total phosphorus load was estimated for each of these rivers by calculating the antilog of the standard deviation of the logs of daily loads. For example, the standard deviation of the logs of daily average loads in the Grand River was 0.305 and the antilog of 0.305 is 2.018. A standard deviation of +/-0.305 in the logarithm of the load can be transformed back to a non-logarithmic standard deviation equal to the mean load multiplied (or divided) by 2.018. So if the standard deviation of the logarithms equaled 0.305 then the standard deviation of the geometric mean would equal +/- 1.018% of the mean. Standard deviations expressed as percentages of the mean are coefficients of variation (CV).

A Plot of the CV of total phosphorus daily loads versus CVLF5 indicates that there is a linear relationship between flow variability and load variability and that Honey Creek seems to be an outlier (Figure 2). The least squares linear regression equation, based on five points, was CV=-2.505+(CVLF5*32.2797) with R^2= 0.872. Honey Creek was the smallest and most variable of the six watersheds. The relationship may not be linear at the upper range of CVLF5's or the size of the watershed may influence the relationship between load and flow variabilities.

In order to estimate sample sizes in each strata, it is necessary to know the parameter variability within each flow strata, not just the parameter variability for the range of flow conditions within a given year. Therefore, the same type of parameter variability versus flow variability relationship was developed within each of the two flow strata.

In the high flow strata there was a linear relationship (R^2=0.967) between CVLF5 and the CV of daily high flow loads excluding Honey Creek (Figure 3). In the low flow strata there was also a linear relationship (R^2=0.847 when Honey Creek was excluded) between daily load and daily flow variability (Figure 4). The CV of daily total phosphorus load in the high flow strata could be estimated by using the high flow predictor equation CV=0.08381 +(CVLF5*7.0478) and the CV of the low flow strata can be estimated by CV=-0.8528 +(CVLF5*11.8341).

Estimated sample sizes were calculated for the high and low flow strata of each of the five rivers using variance estimates from the complete data sets and estimates calculated from the predictor equations. These two different sample size estimates were not always close and the magnitude of the absolute difference between the two estimates increased

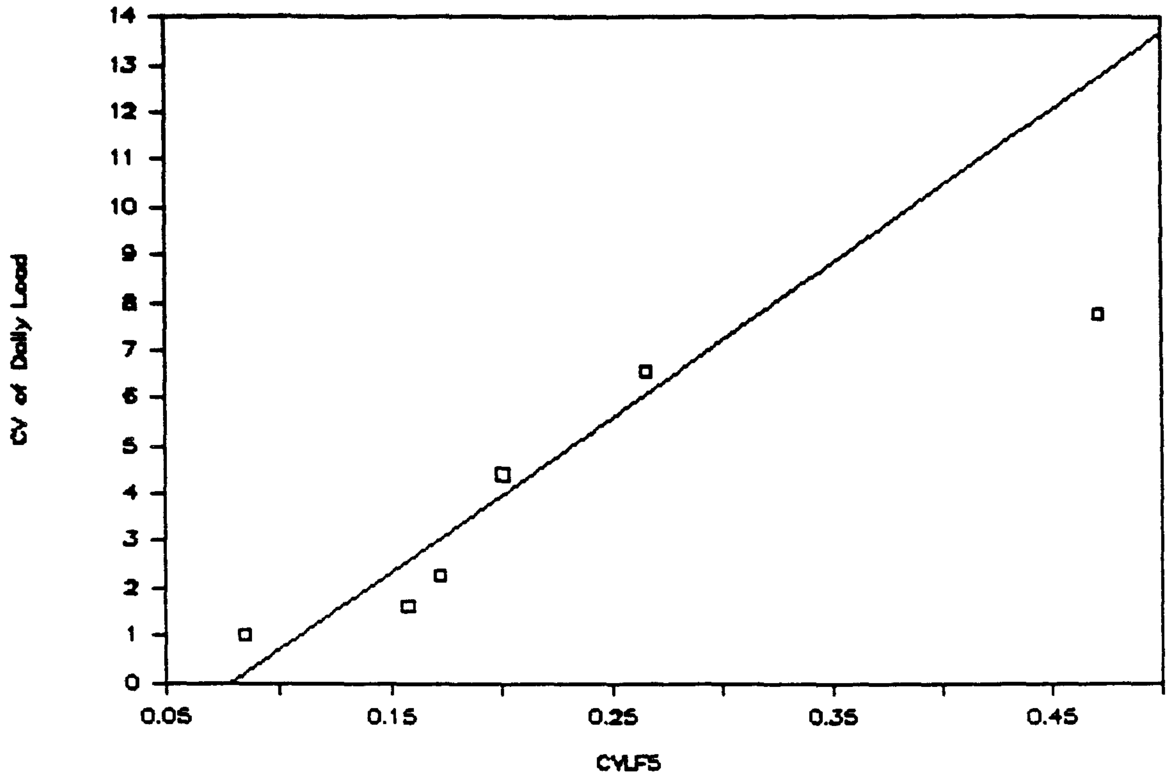


Figure 2. The Relationship between the Coefficient of Variation (CV) of Total Phosphorus Daily Loads and Average Daily Flow Variability (CVLFS).

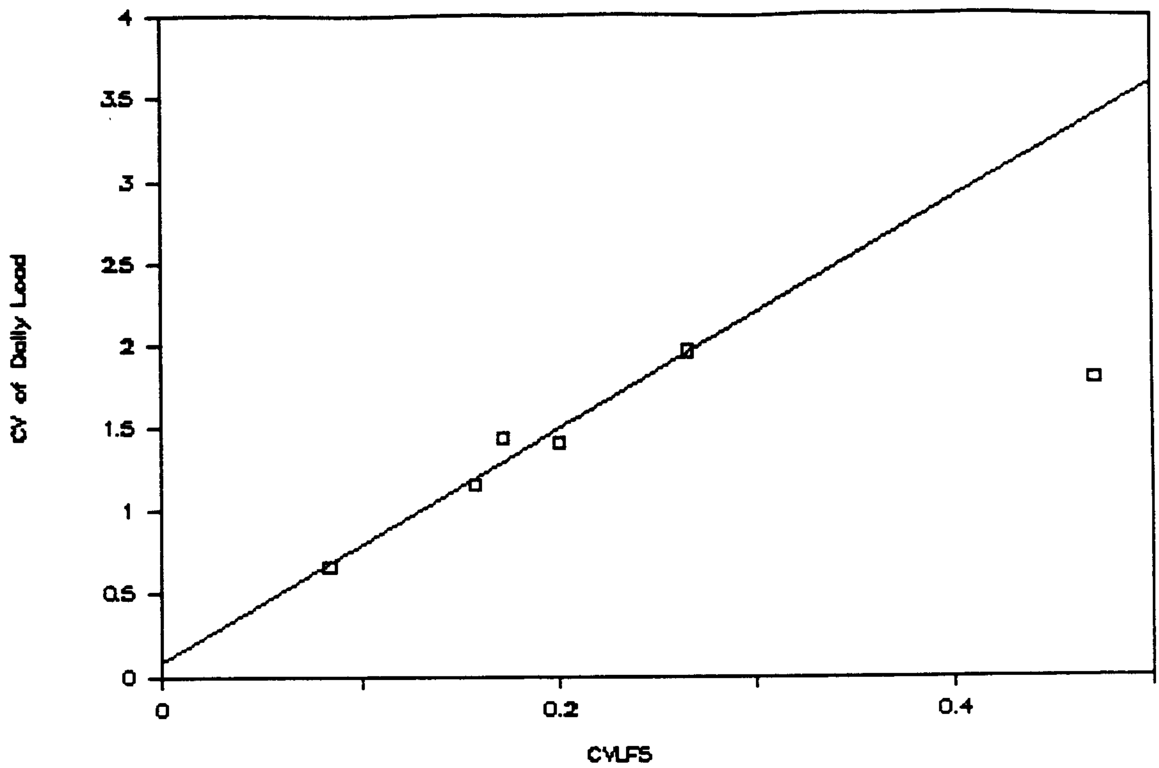


Figure 3. The Relationship between the Coefficient of Variation (CV) of Total Phosphorus Daily Loads and Average Daily Flow Variability (CVLFS) in the High Flow Strata.

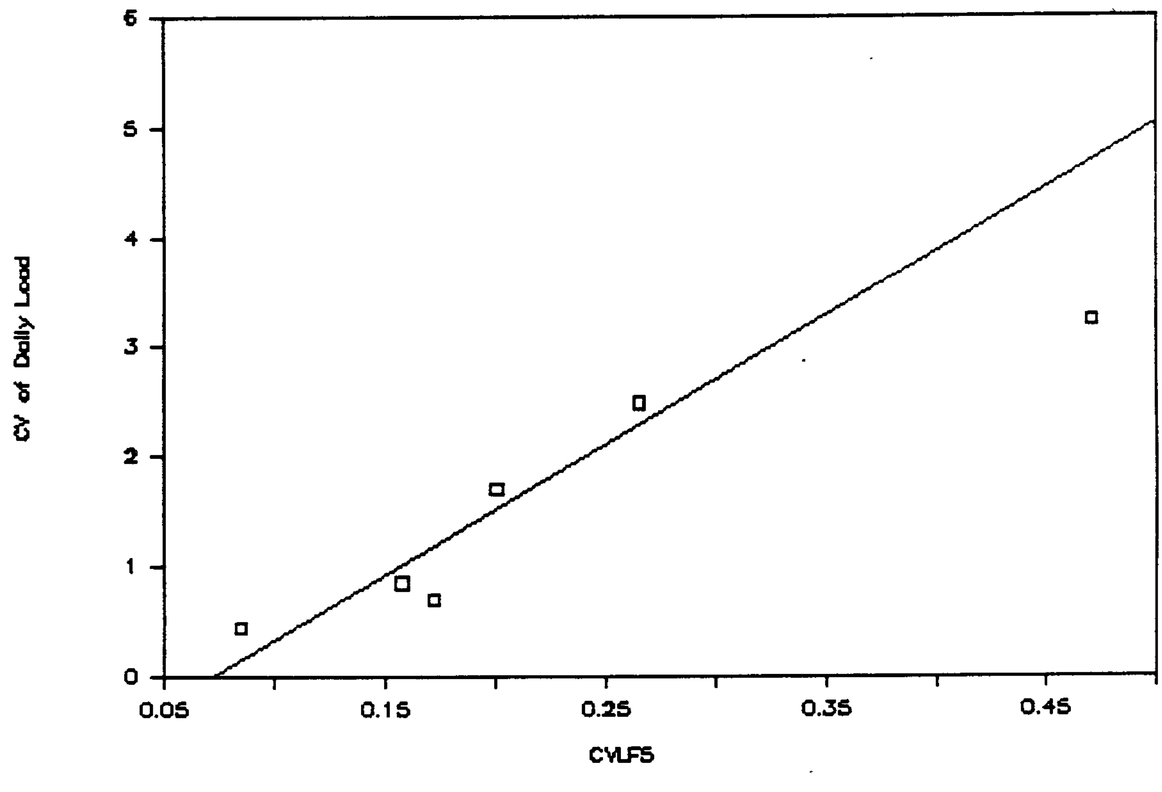


Figure 4. The Relationship between the Coefficient of Variation (CV) of Total Phosphorus Daily Loads and Average Daily Flow Variability (CVLFS) in the Low Flow Strata.

with increased flow variability. At a precision of +/-50% the absolute difference between estimated Grand River sample sizes was one and the absolute difference between Sandusky River sample sizes was seventy-eight (Table 9). This method of predicting sample size requirements is one procedure that can be used when sampling programs are desired on tributaries with little or no prior information about the constituent of concern but it seems that estimates are less reliable for the more event responsive rivers.

Flow variability versus load variability relationships may be quantified for other constituents that vary with flow. Parameters that tend to be more variable than total phosphorus will require more sampling effort to achieve the same precision while parameters that are less variable will require fewer samples.

Sample Size Estimates for Michigan Tributaries

Sampling requirements were estimated for four of the seven Michigan tributaries using the predictor equation and methods described above. The predictor equations were developed using five tributaries with CVLF5's ranging from 0.08469 to 0.26547 so the CV should only be estimated for rivers with CVLF5's in this range since the slope or relationship may change outside of this range. The CVLF5 at the mouth of each tributary was 0.03092 for the Rouge, 0.04679 for the Pere Marquette, 0.05724 for the St. Joseph, 0.08245 for the Ontonagon, 0.09867 for the Huron, 0.13991 for the Clinton, and 0.28044 for the Black rivers. The CVLF5's for the Clinton and Huron Rivers fell within this range and sample size estimates were calculated. The CVLF5 for the Ontonagon River was near the lower end of the predictor equations and the Black River was

Table 9. **Comparison between estimated sample sizes, at various levels of precision, calculated using variance and average estimates from the complete data set and using the CV predicted from the regression equation.**

precision (% of estimate)	Tributary Sandusky		Maumee		Raisin		Cuyahoga		Grand	
A. High Flow Strata										
	C*	P**	C	P	C	P	C	P	C	P
+/- 50%	32	61	21	37	30	29	37	24	8	10
+/- 40%	48	94	32	56	45	43	56	37	12	14
+/- 30%	84	166	54	98	77	74	98	63	19	22
+/- 25%	120	238	77	140	110	105	140	90	26	31
+/- 20%	185	371	119	218	170	163	218	140	39	47
+/- 10%	732	1476	467	865	670	647	865	551	147	180
B. Low Flow Strata										
	C	P	C	P	C	P	C	P	C	P
+/- 50%	34	83	21	37	9	24	11	18	5	2
+/- 40%	51	128	32	57	13	36	16	27	6	2
+/- 30%	88	226	55	98	20	64	27	46	9	4
+/- 25%	126	324	77	140	28	89	37	66	11	4
+/- 20%	195	506	120	218	42	138	58	101	16	5
+/- 10%	775	2013	468	864	161	546	221	398	57	11
C. Total Number of Samples										
	C	P	C	P	C	P	C	P	C	P
+/- 50%	66	144	42	74	39	53	48	42	13	12
+/- 40%	99	222	64	113	58	79	72	64	18	16
+/- 30%	172	392	109	196	97	138	125	109	28	26
+/- 25%	246	562	154	280	138	194	177	156	37	35
+/- 20%	380	877	239	436	212	301	276	241	55	52
+/- 10%	1507	3489	935	1729	831	1193	1086	949	204	191
D. Absolute Difference										
+/- 50%	78		32		14		6		1	

* Sample size estimates calculated using variance and average estimates from the complete data sets.

** Sample size estimates calculated using the CVLF5 and the predictor equations near the upper end of the range so sample size estimates were also calculated for these tributaries. Although sample size predictions should not be made for rivers with a CVLF5 below 0.08469, sampling requirements will decrease with a decrease in flow variability and the corresponding load variability.

The CVLF5 was lowered dramatically in the Rouge River by the Rouge Ford plant diversion. This constant addition of 784 cfs, to a median upstream flow of 129 cfs, increased the flow at the mouth without influencing the magnitude of the range between high and low flows. The Rouge River CVLF5 calculated using flows above the diversion was 0.19993 and would indicate flow variability greater than all study rivers except the Black River. At the mouth the CVLF5 was 0.03092 indicating flow variability less than all of the rivers studied. Actual Rouge River sampling yielded relatively precise 95% confidence intervals of +/-14% of the estimate in 1984 (n=69), +/-19% in 1985 (n=95) and +/-11% in 1986 (n=93). Although, these estimates are relatively precise, the results of Monte Carlo studies indicate that large ranges of confidence intervals, using the same sample size, are common. A calculated precision from any single subset, within the group, may not be a good indicator of the required sample size. On the other hand there is no evidence indicating that additional sampling would have been beneficial.

The estimated sample sizes are presented in Table 10 so that the predicted precision can be contrasted with the actual precision estimate. Comparing the estimated number of samples (171) to the actual number of samples collected in the Black River indicates that this tributary should have been sampled more intensely to insure a precision of at least +/-50%. However, 95% confidence intervals ranged from 10.8% (n=93) to 40.1%

Table 10. Predicted number of samples required per year to estimate total phosphorus loads with 95% confidence intervals less than or equal to the indicated precision of the estimate.

Precision (% of estimate)	Tributary Ontonagon	Huron	Clinton	Black
A. High Flow Strata				
+/- 50%	10	12	20	70
+/- 40%	13	17	30	107
+/- 30%	21	28	51	191
+/- 25%	30	40	73	275
+/- 20%	45	61	112	430
+/- 10%	172	236	449	1719
B. Low Flow Strata				
+/- 50%	2	4	13	101
+/- 40%	3	5	18	156
+/- 30%	4	7	30	275
+/- 25%	4	9	42	395
+/- 20%	5	12	65	615
+/- 10%	9	40	250	2457
C. Total Number of Samples				
+/- 50%	12	16	33	171
+/- 40%	16	22	48	263
+/- 30%	25	35	81	466
+/- 25%	34	49	115	670
+/- 20%	50	73	177	1045
+/- 10%	181	276	699	4176

(n=89) and it is likely that, as in the case of the Sandusky River, the predicted sampling requirements are more rigorous than necessary.

Comparing the estimated total phosphorus sample size for the Clinton River to the actual sample size indicates that precision should have been within 40% in 1984 and 30% in 1985 and 1986. The actual precision was better than the predicted precision in all three cases and was +/- 23.4% (n=71), +/- 12.0% (n=89) and +/- 17.0% (n=103) in 1984, 1985 and 1986, respectively. Sampling conducted on the Huron River should have yielded 95% confidence intervals within approximately +/- 25% of the estimate and actual confidence intervals ranged from +/- 6.0% (n=91) in 1986 to +/- 11.8% (n=95) in 1985.

Sampling effort in the Ontonagon River should have yielded a total phosphorus estimate with a 95% confidence interval of within approximately +/- 25% and the actual 95% confidence interval was just outside the predicted range at 26.9%. This could be related to problems extending the predictor line past the lowest point, variability of the estimate derived from the predictor equation, higher than normal total phosphorus load variability in the Ontonagon River in 1984 or a combination of these factors.

No sample size estimates were calculated for the Pere Marquette or St. Joseph rivers, but relatively low intensity sampling on both rivers (25 samples from the Pere Marquette and 24 samples from the St. Joseph rivers) yielded 95% confidence intervals of +/- 14.2% and +/- 9.8% for the Pere Marquette and St. Joseph rivers respectively. As mentioned earlier, calculated confidence intervals are variable and are not always good indicators of sampling requirements, but these estimates were relatively precise and support the contention that rivers with stable flows generally require less intensive sampling programs.

LITERATURE CITED

Bierman, V.J. Jr., S.J. Preston and S.E. Silliman. 1988. Development of estimation methods for tributary loading rates of toxic chemicals. Dept. Civil Eng., Notre Dame Univ. Tech. Rept. No. 183

Dolan, D.M., A.K. Yui, and R.D. Geist. 1981. Evaluation of River Load Estimation Methods for Total Phosphorus. J. Great Lakes Res. 7(3): 207-214.

Richards, R.P. (in press). Measures of Flow Variability and a New Classification of Great Lakes Tributaries. Water Quality Laboratory, Heidelberg College, 310 E. Market Street Tiffin, Ohio.

Richards, R.P. and J. Holloway. 1987. Monte Carlo Studies of Sampling Strategies for estimating Tributary Loads. Water Res. Res. 23: 1939-1948.

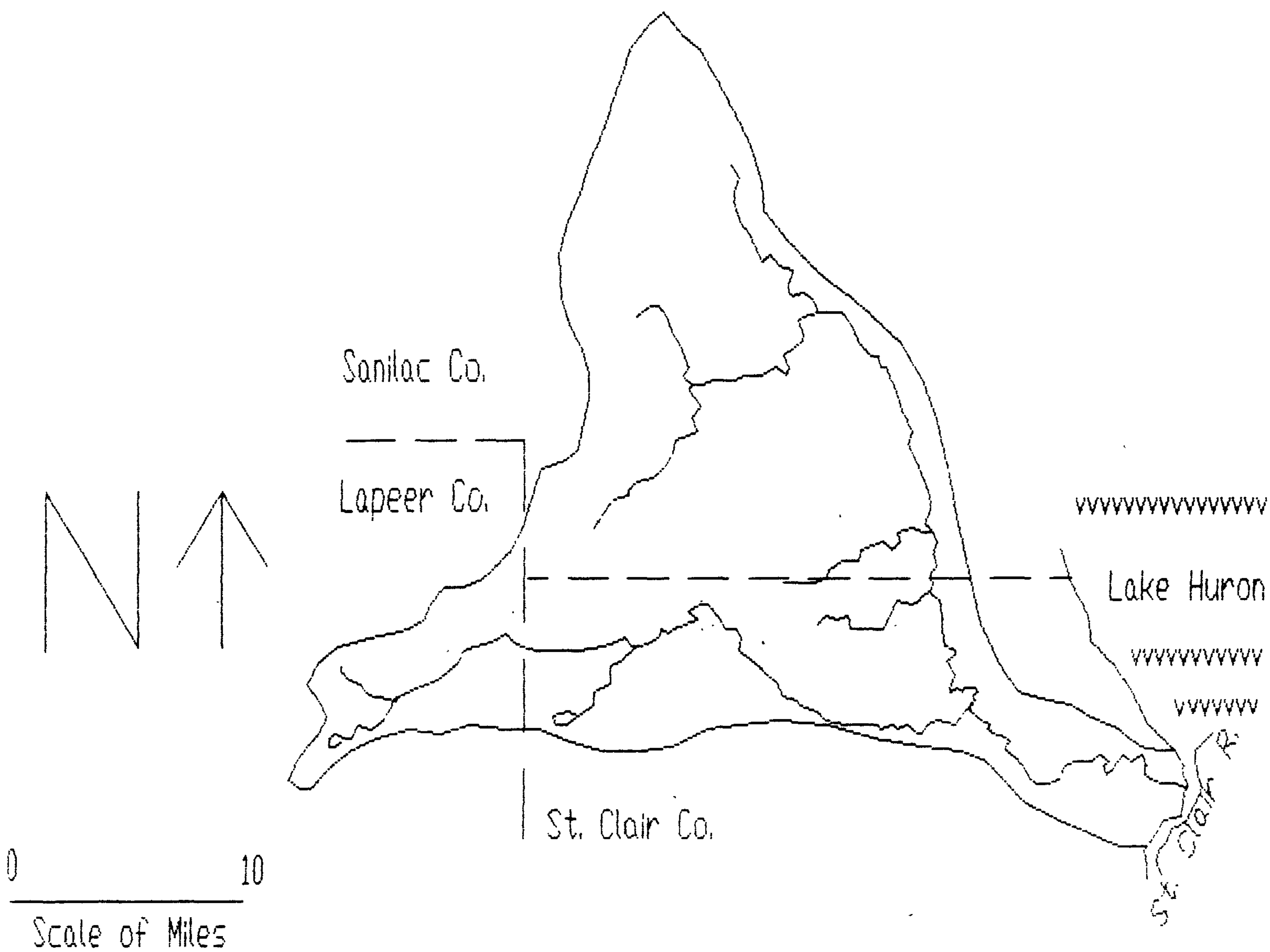
Schroeter, J. 1978. Total Phosphorus-Flow Relationship in Southeastern Michigan Tributaries. Mich. Dept. Nat. Res., Environmental Services Division, Pub No. 4833-5082.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods. Seventh ed. Iowa St. Univ. Press. Ames, Iowa.

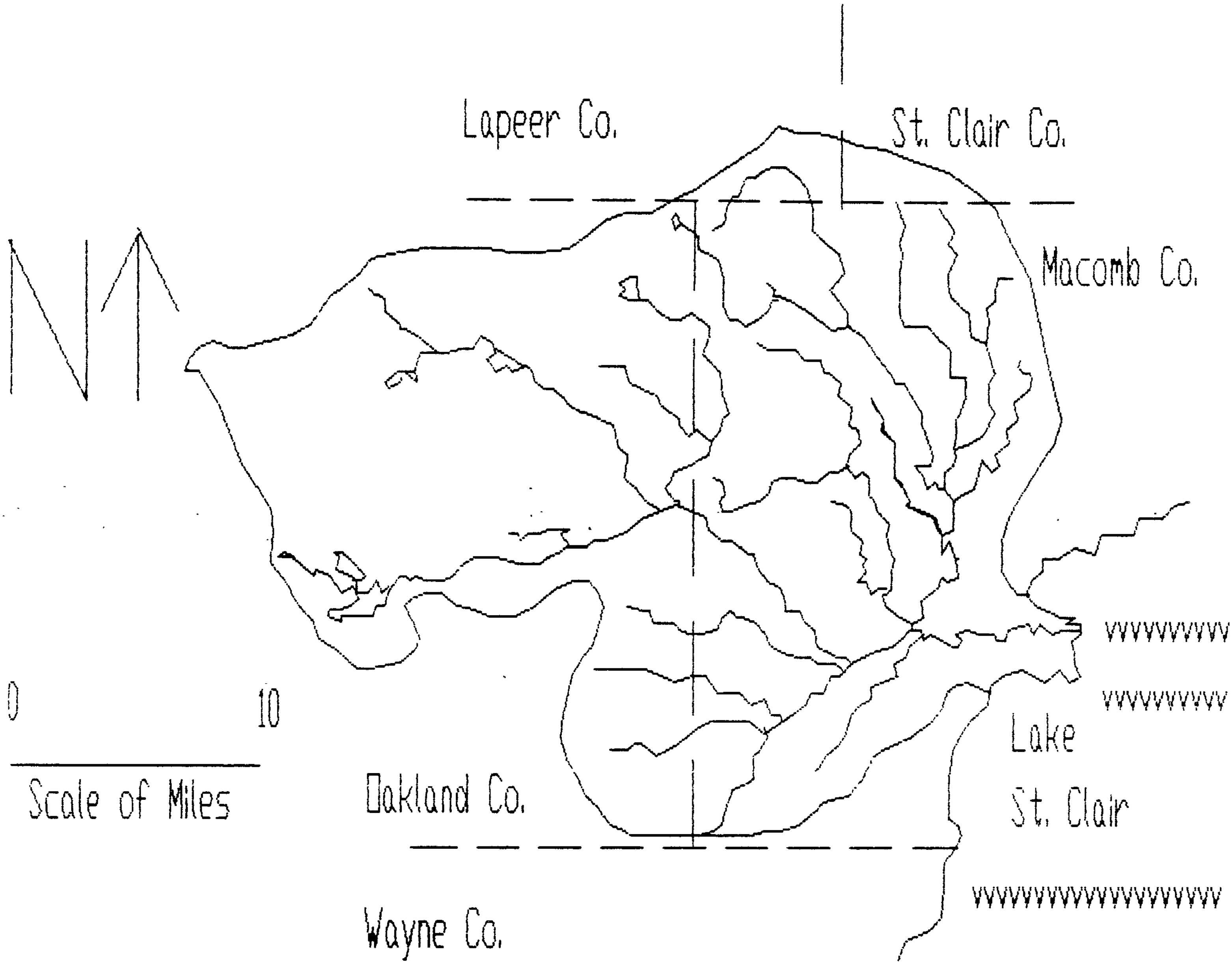
Yaksich, S.M., and F.H. Verhoff. 1983. Sampling Strategy for River Pollutant Transport. J. of the Envir. Eng. Div., ASC 109 (No. EE1): 3-8.

Appendix 1. Watershed Maps and Locations in Michigan

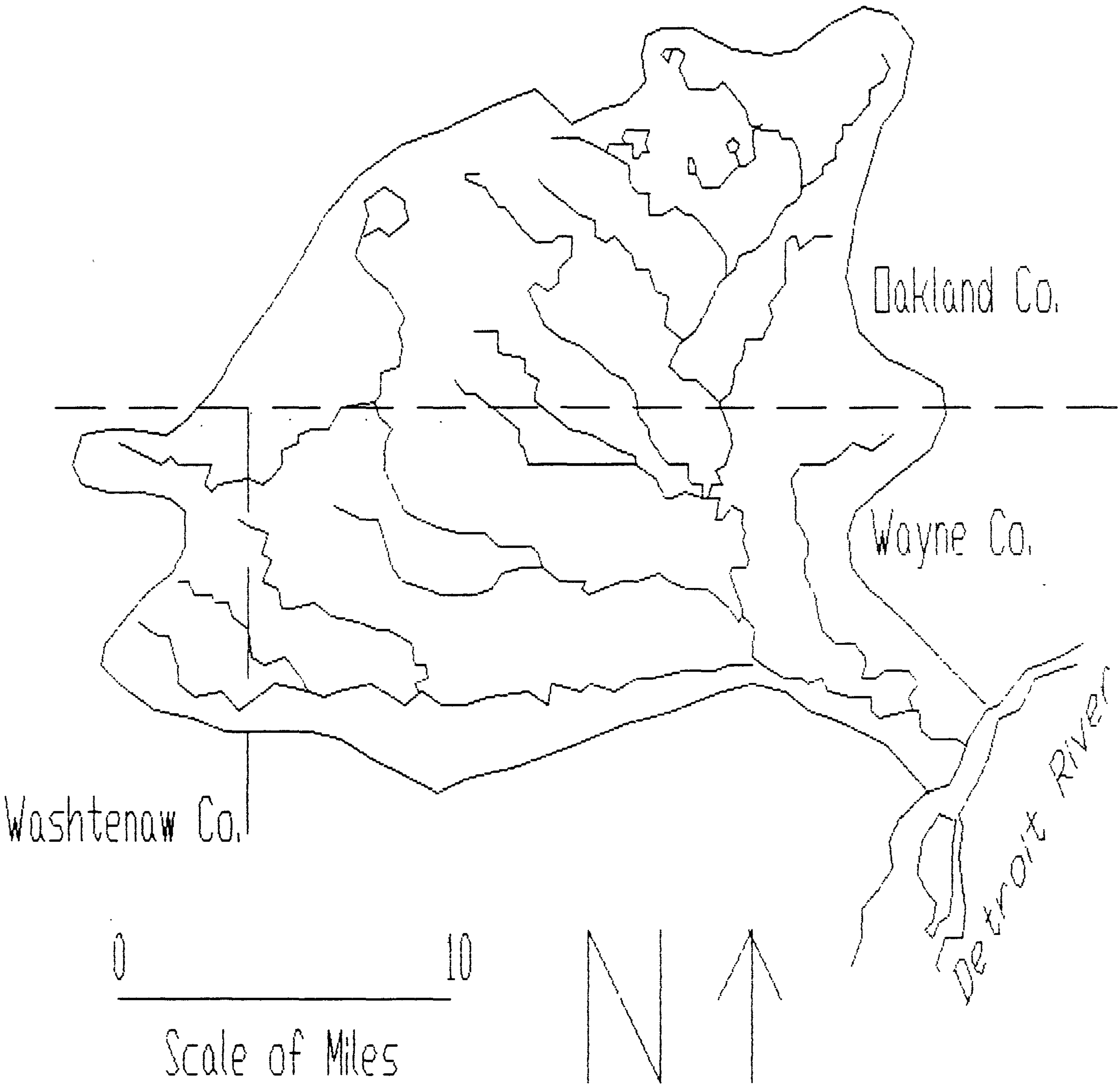
Black River Basin

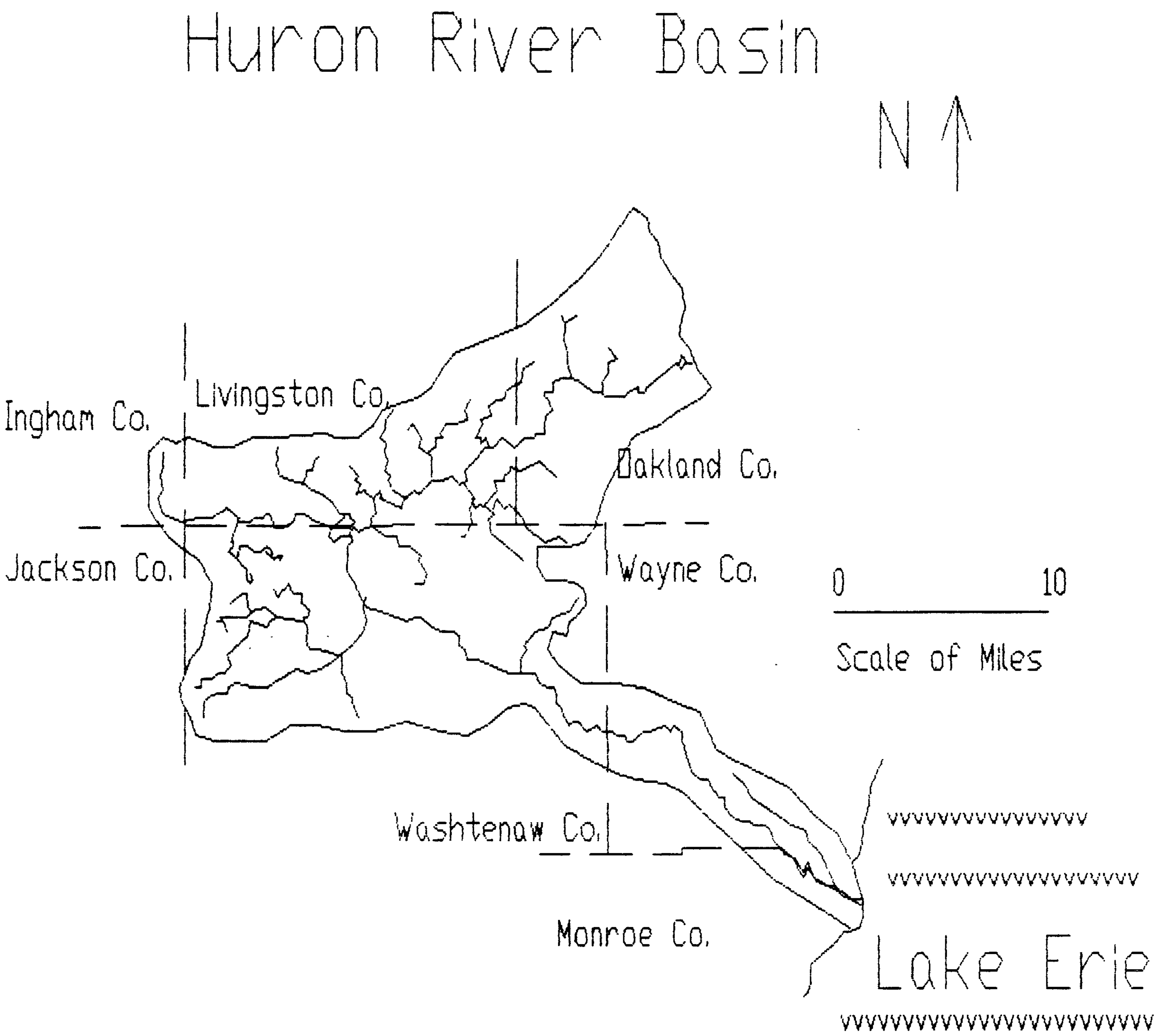


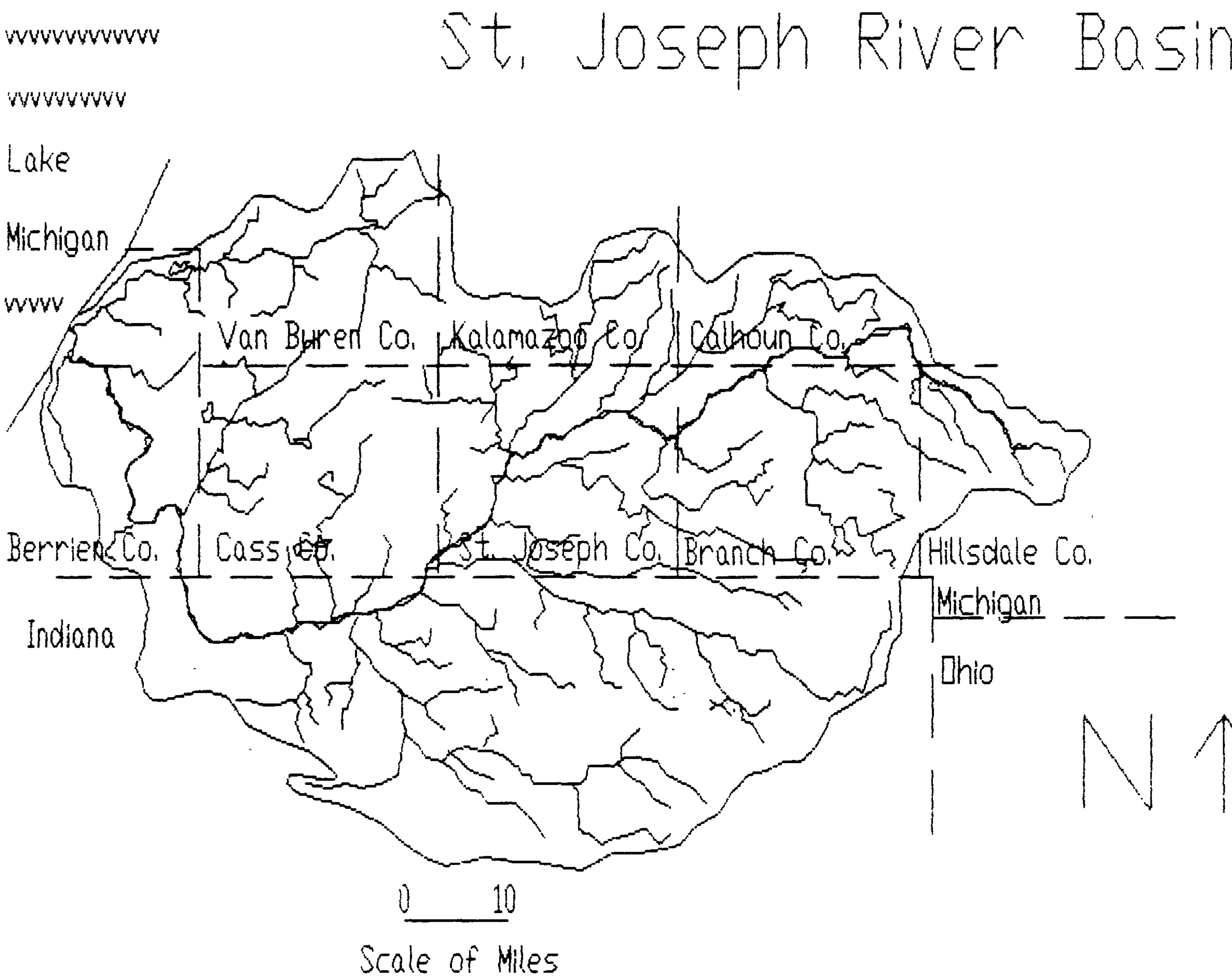
Clinton River Basin



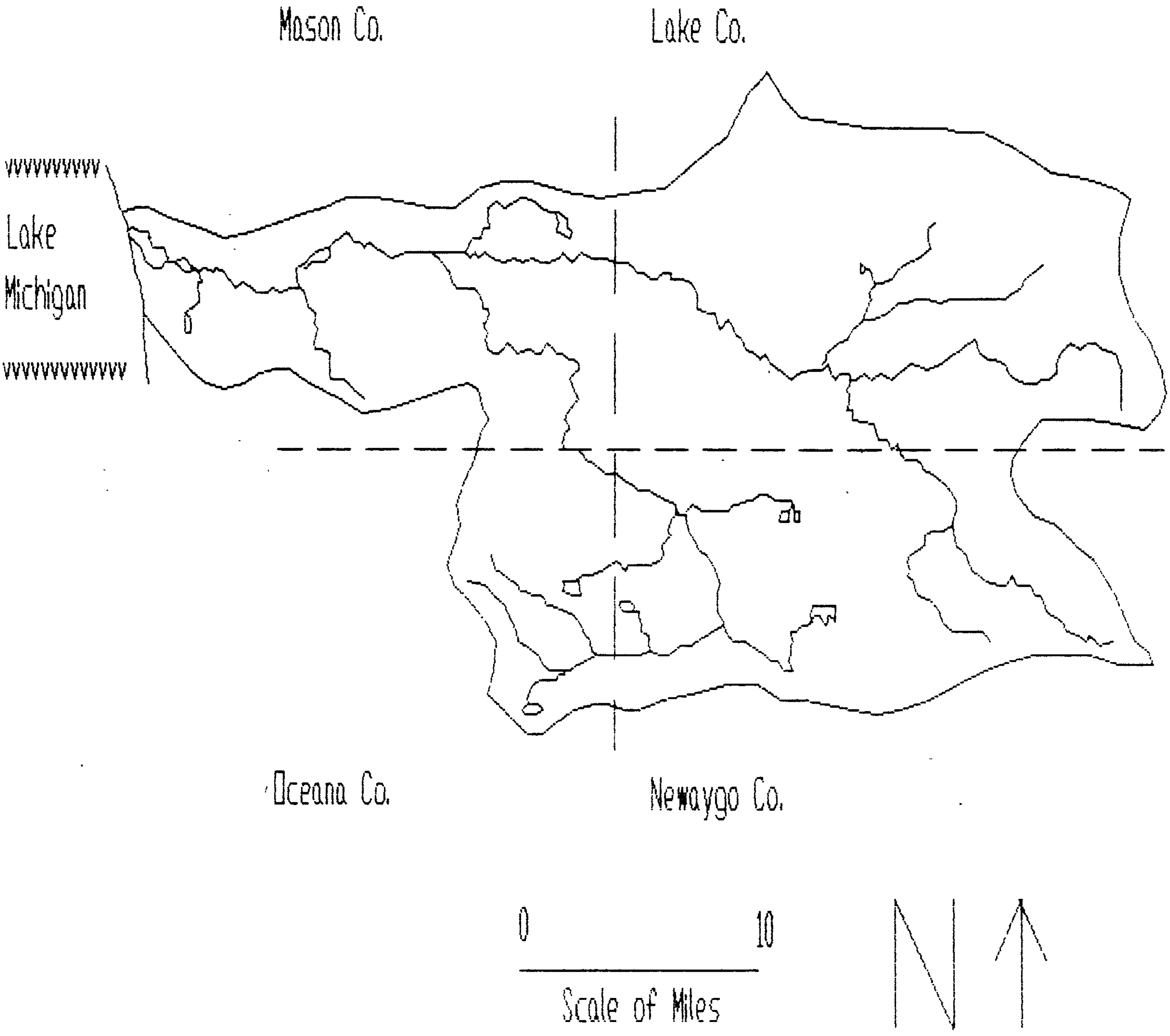
Rouge River Basin



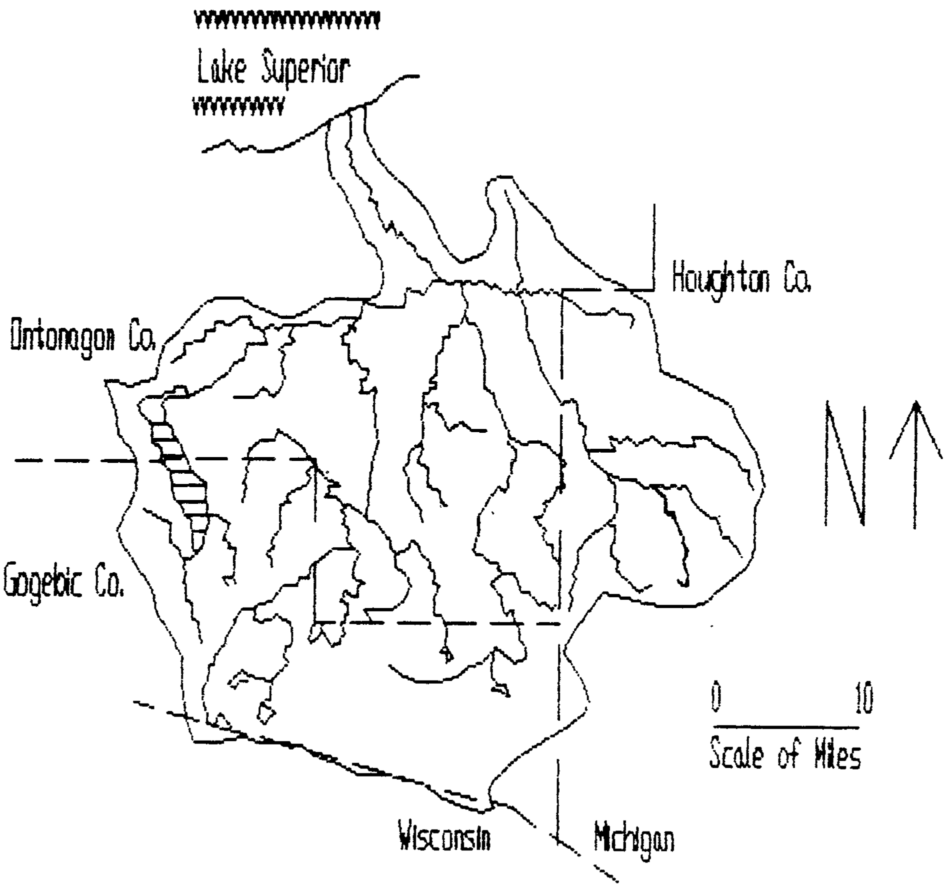

Huron River Basin
N
Livingston Co.
Ingham Co.
Oakland Co.
Jackson Co.
Wayne Co.
0
10
Scale of Miles
Washtenaw Co.
Monroe Co.
Lake Erie


St. Joseph River Basin
Lake
Michigan
Van Buren Co.
Kalamazoo Co.
Calhoun Co.
Berrien Co.
Cass Co.
St. Joseph Co.
Branch Co.
Hillsdale Co.
Michigan
Ohio
Indiana
N
0
10
Scale of Miles

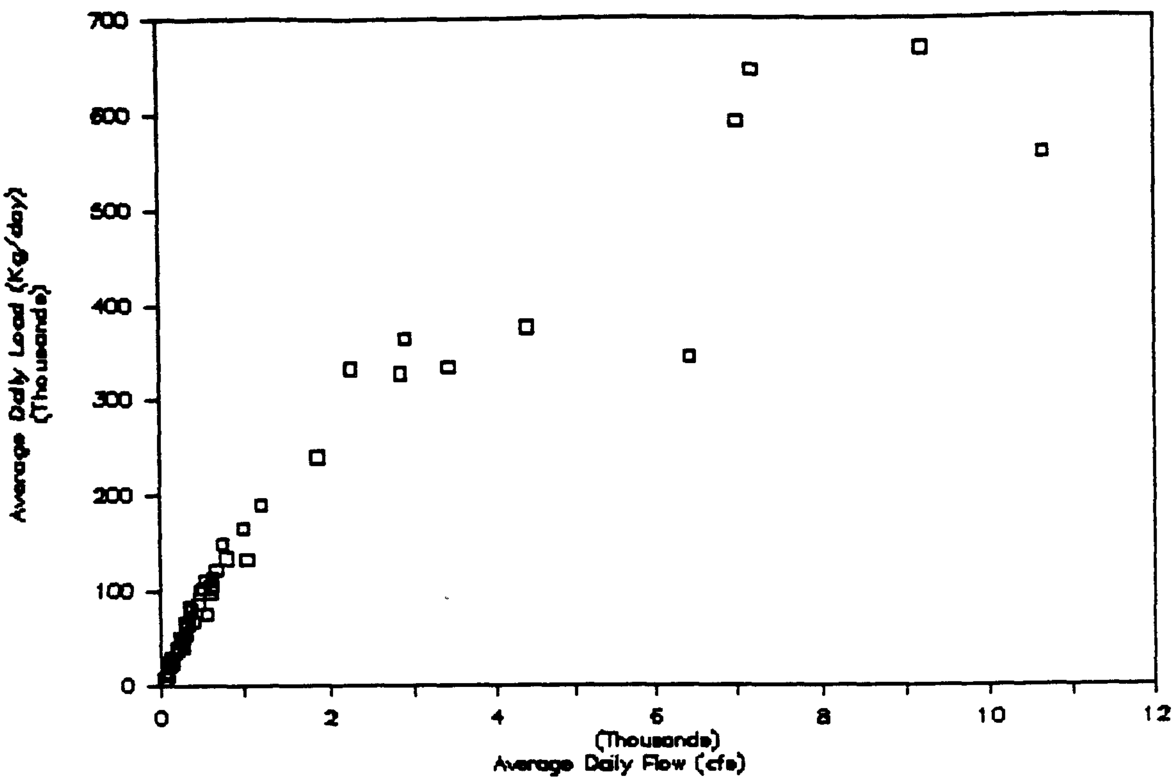
Pere Marquette River Basin



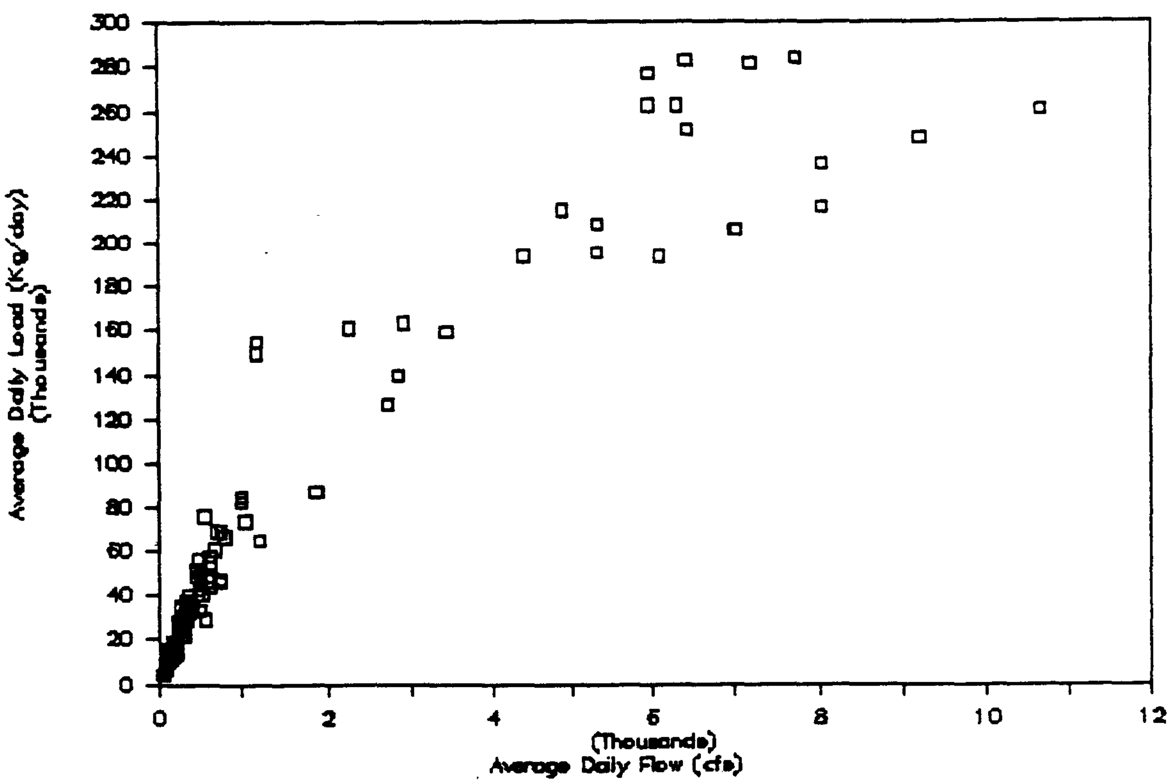
Ontonagon River Basin



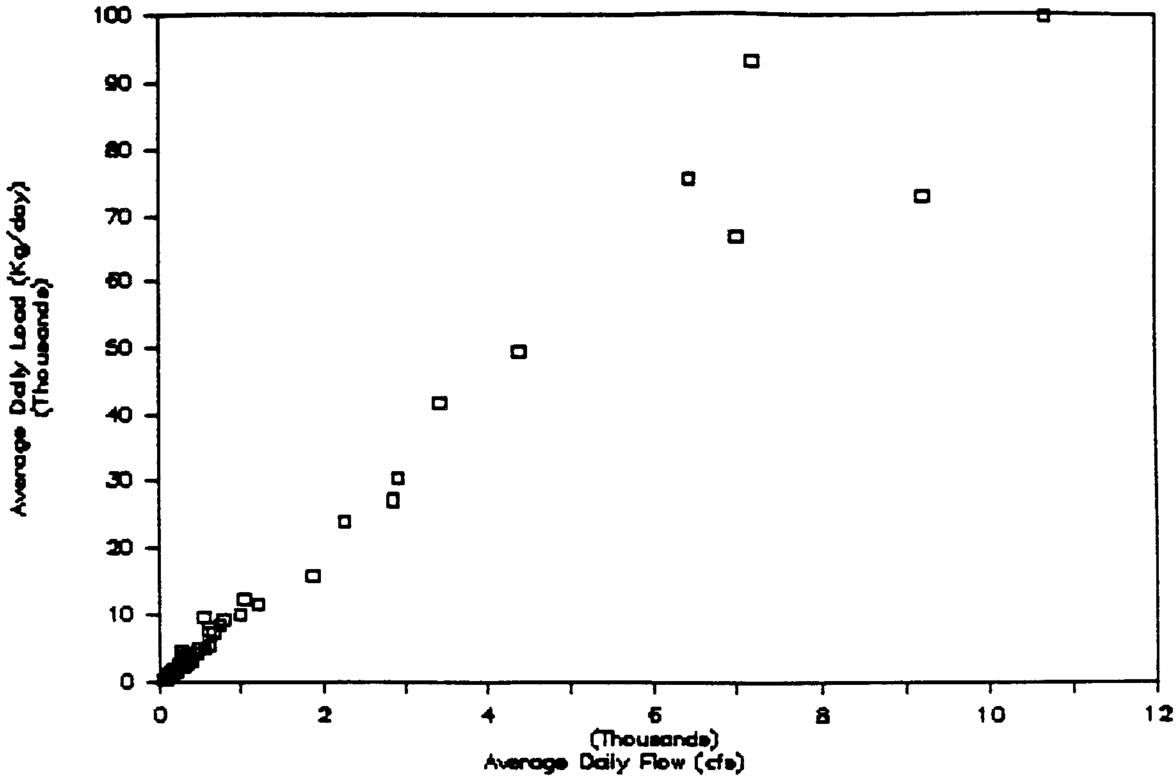
Appendix 2. Relationship between Average Daily Load and Average Daily Flow.



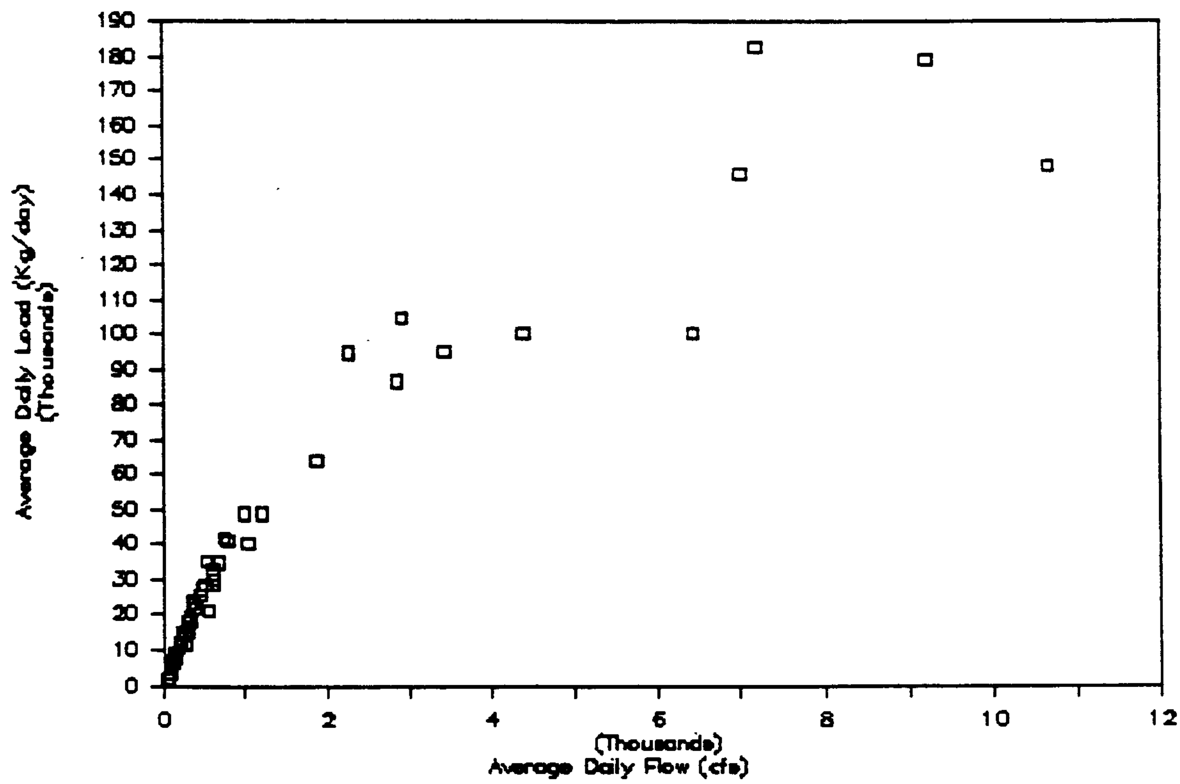
Average Daily Load of Calcium versus Average Daily Flow in the Black River (1984-1986).



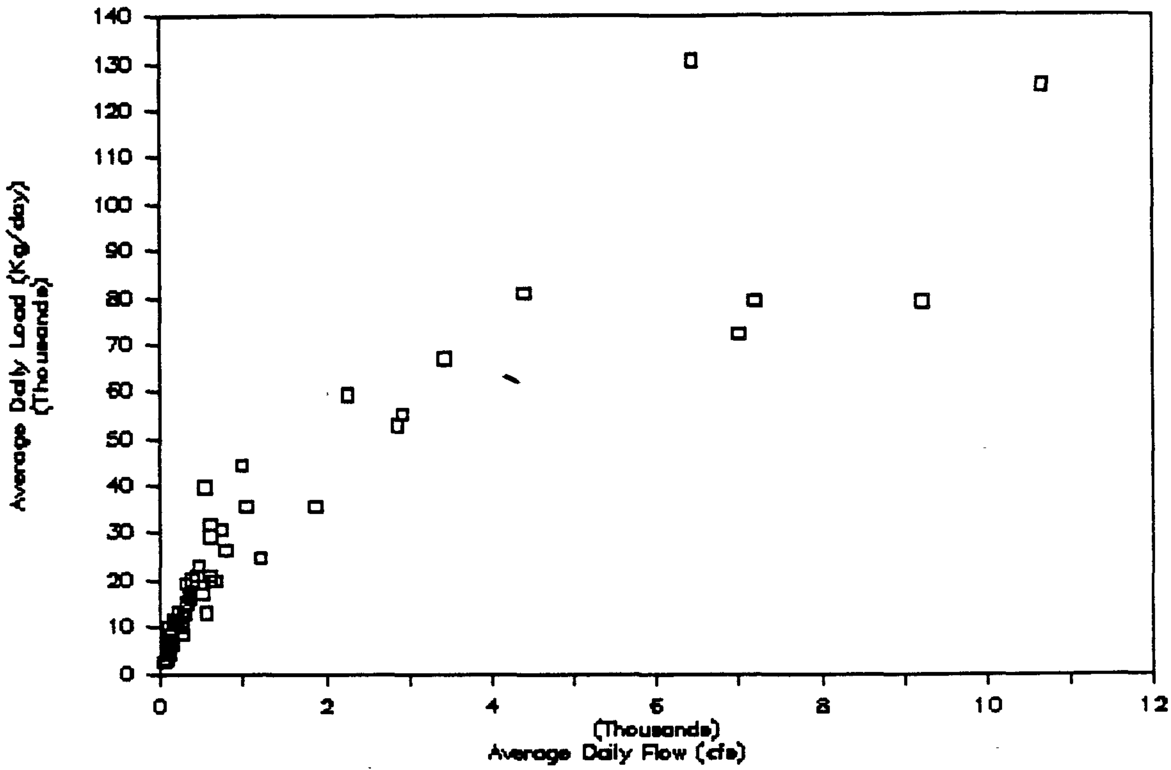
Average Daily Load of Chloride versus Average Daily Flow in the Black River (1984-1986).



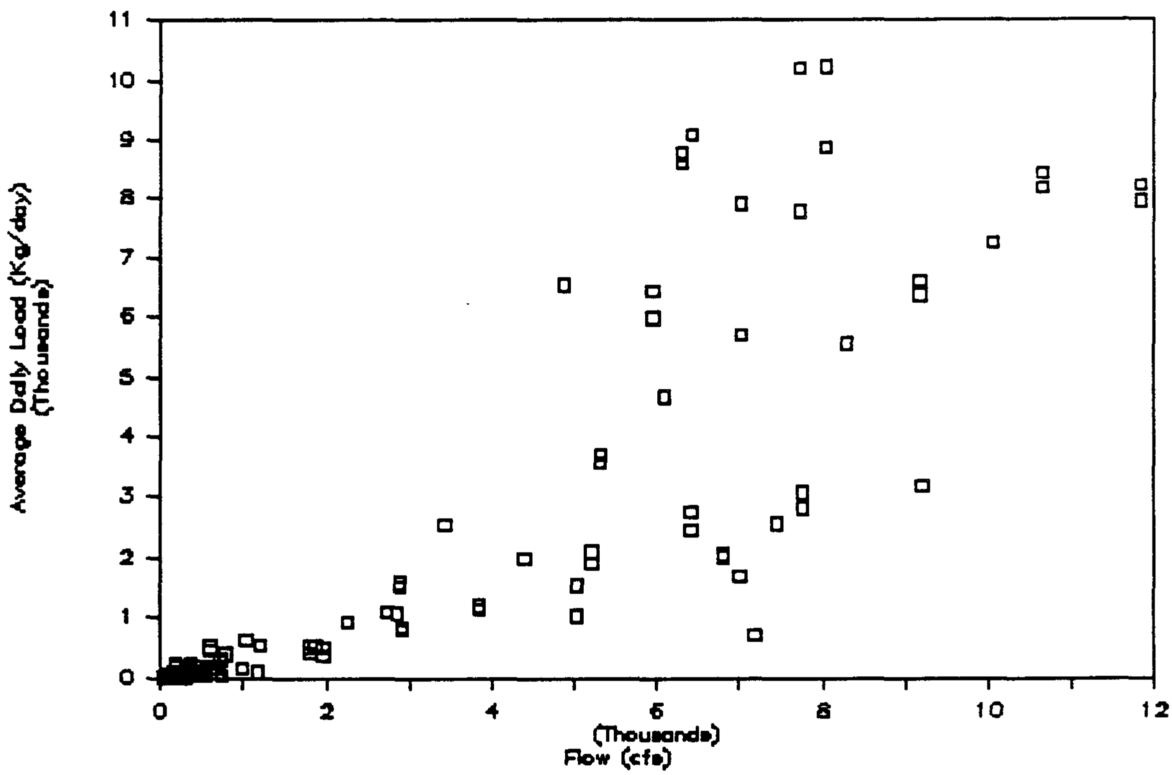
Average Daily Load of Potassium versus Average Daily Flow in the Black River (1984-1986).



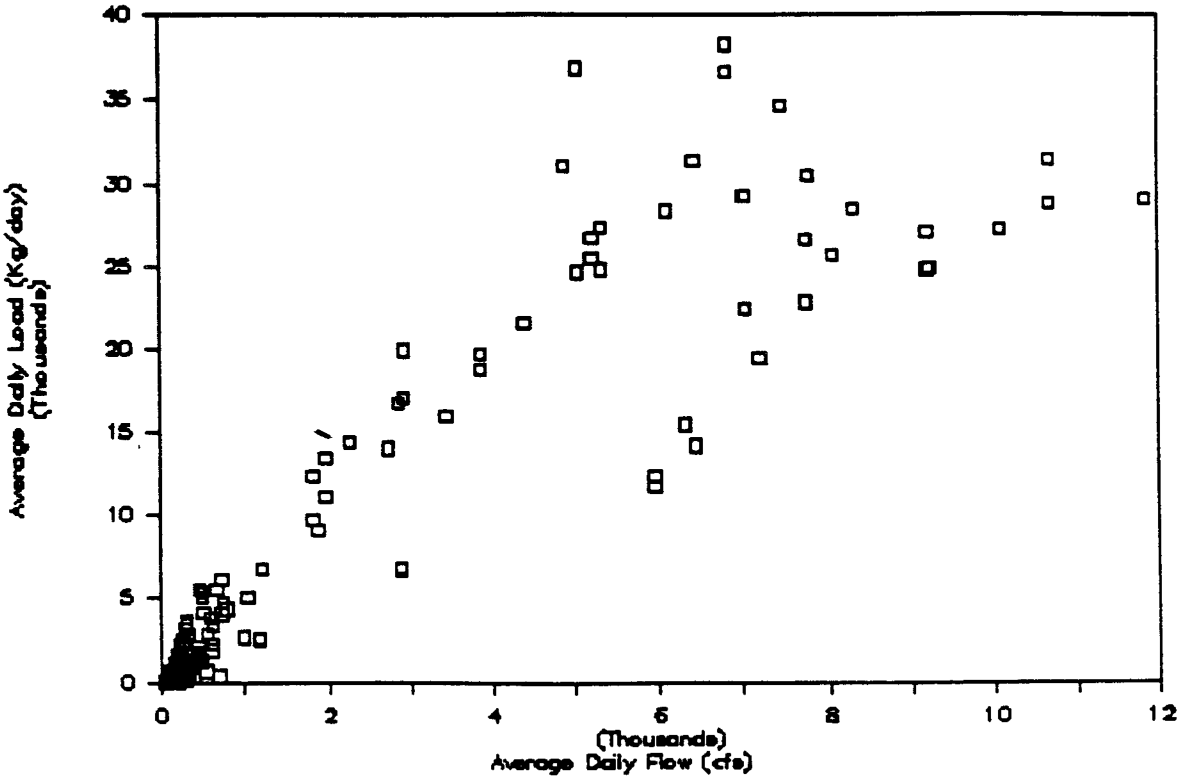
Average Daily Load of Magnesium versus Average Daily Flow in the Black River (1984-1986).



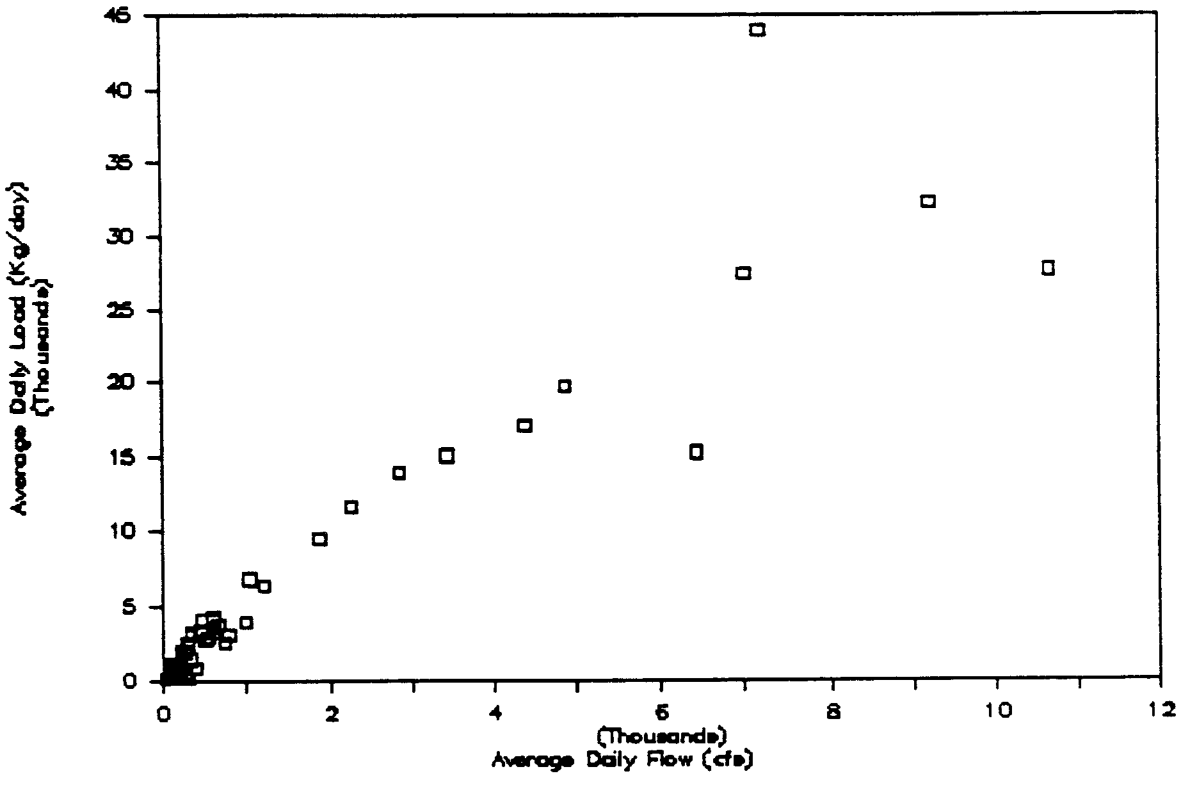
Average Daily Load of Sodium versus Average Daily Flow in the Black River (1984-1986).



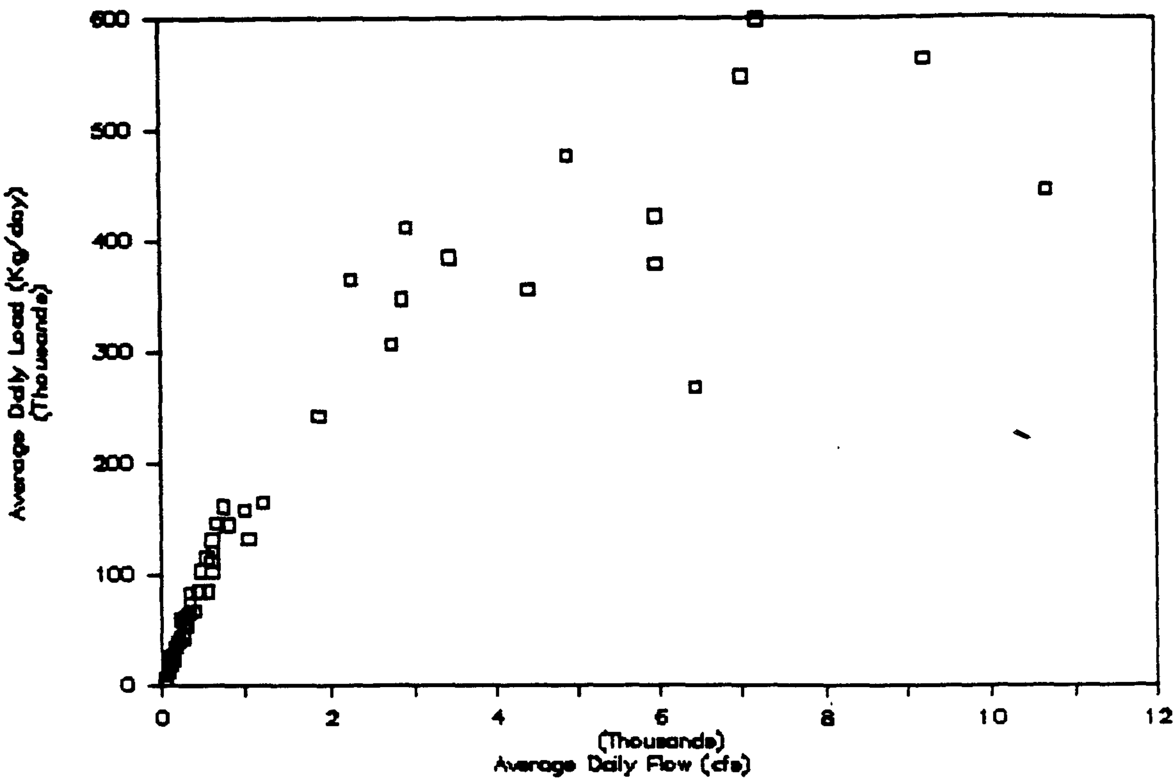
Average Daily Load of Ammonia versus Average Daily Flow in the Black River (1984-1986).



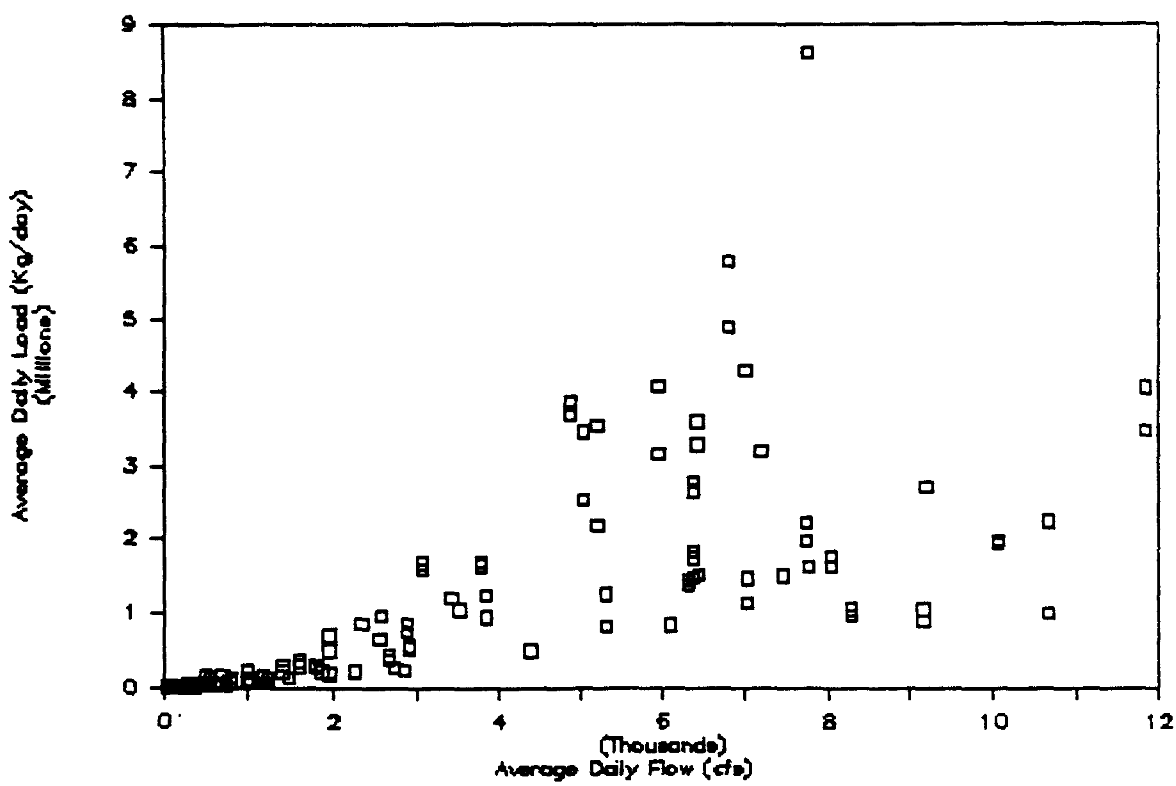
Average Daily Load of Nitrate versus Average Daily Flow in the Black River (1984-1986).



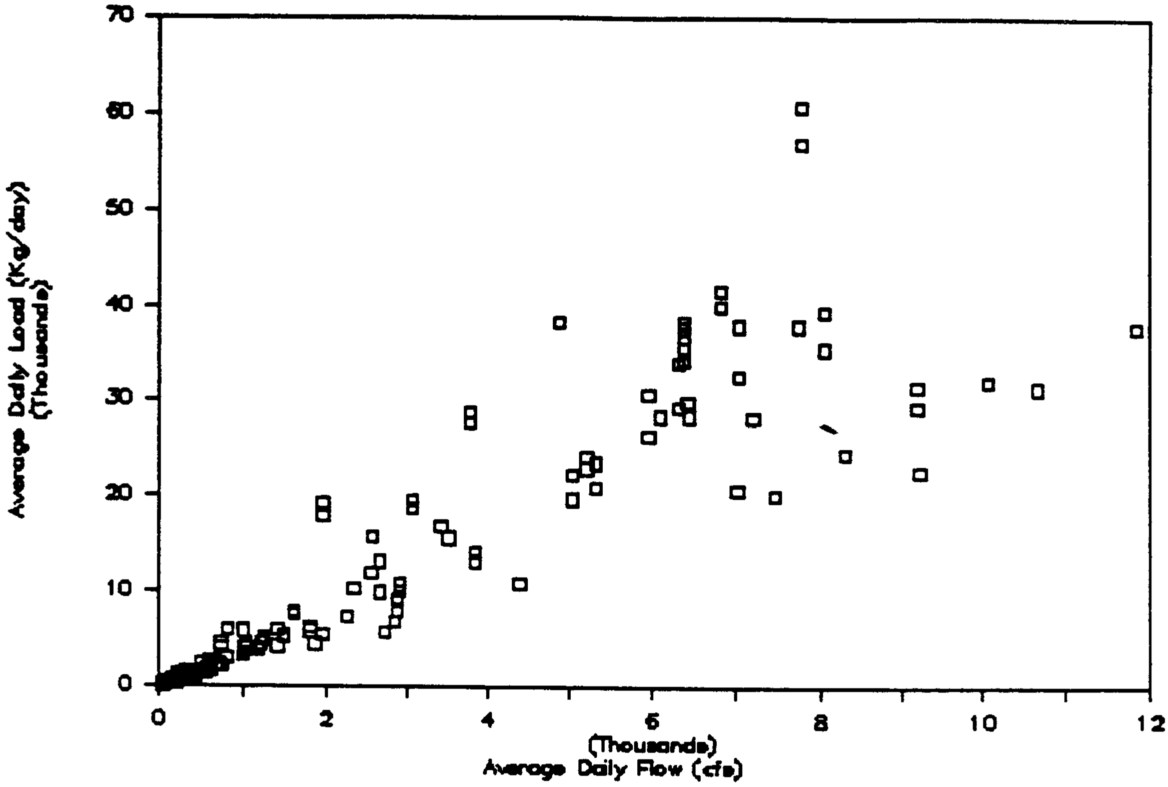
Average Daily Load of Silicate versus Average Daily Flow in the Black River (1984-1986).



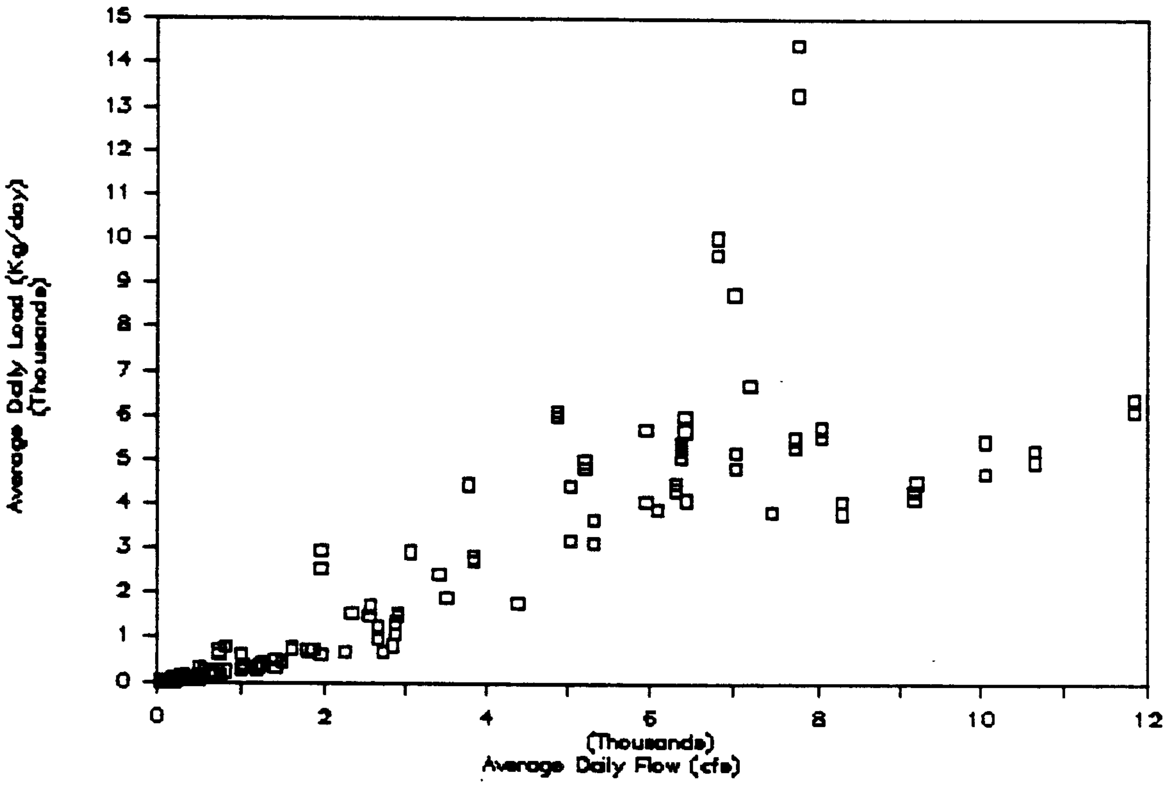
Average Daily Load of Sulfate versus Average Daily Flow in the Black River (1984-1986).



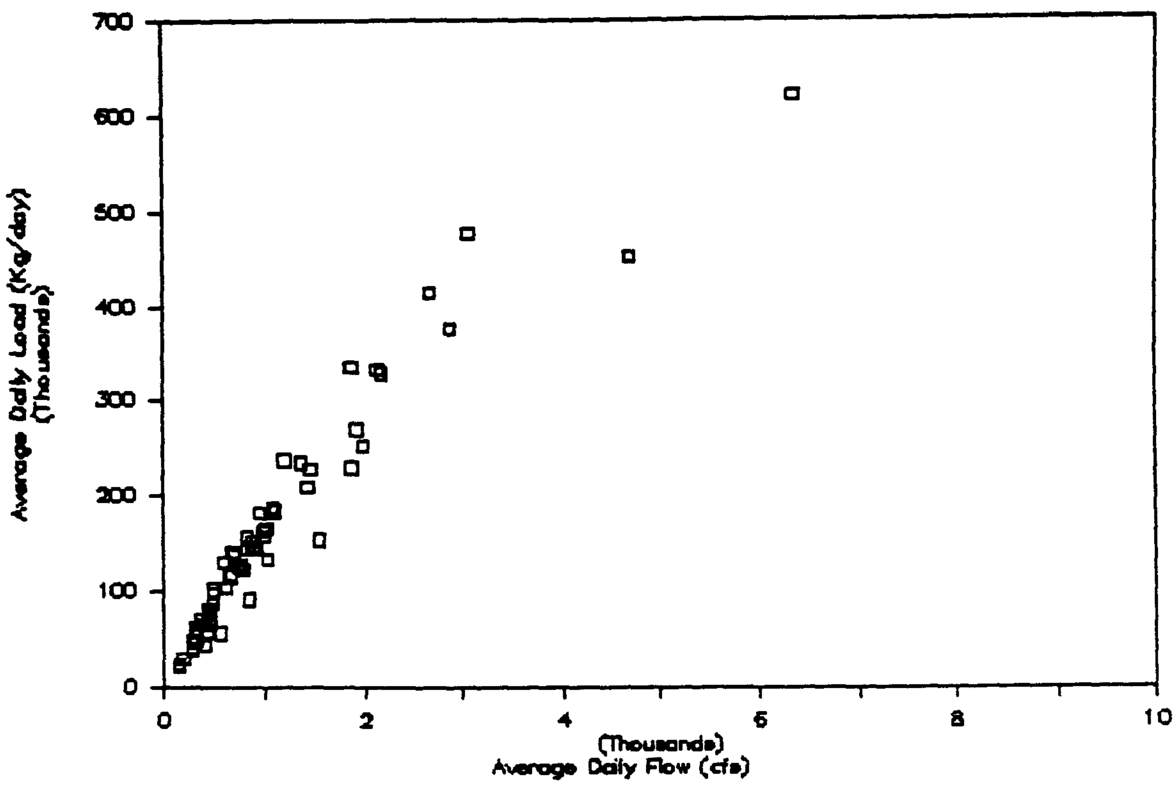
Average Daily Load of Suspended Solids versus Average Daily Flow in the Black River (1984-1986).



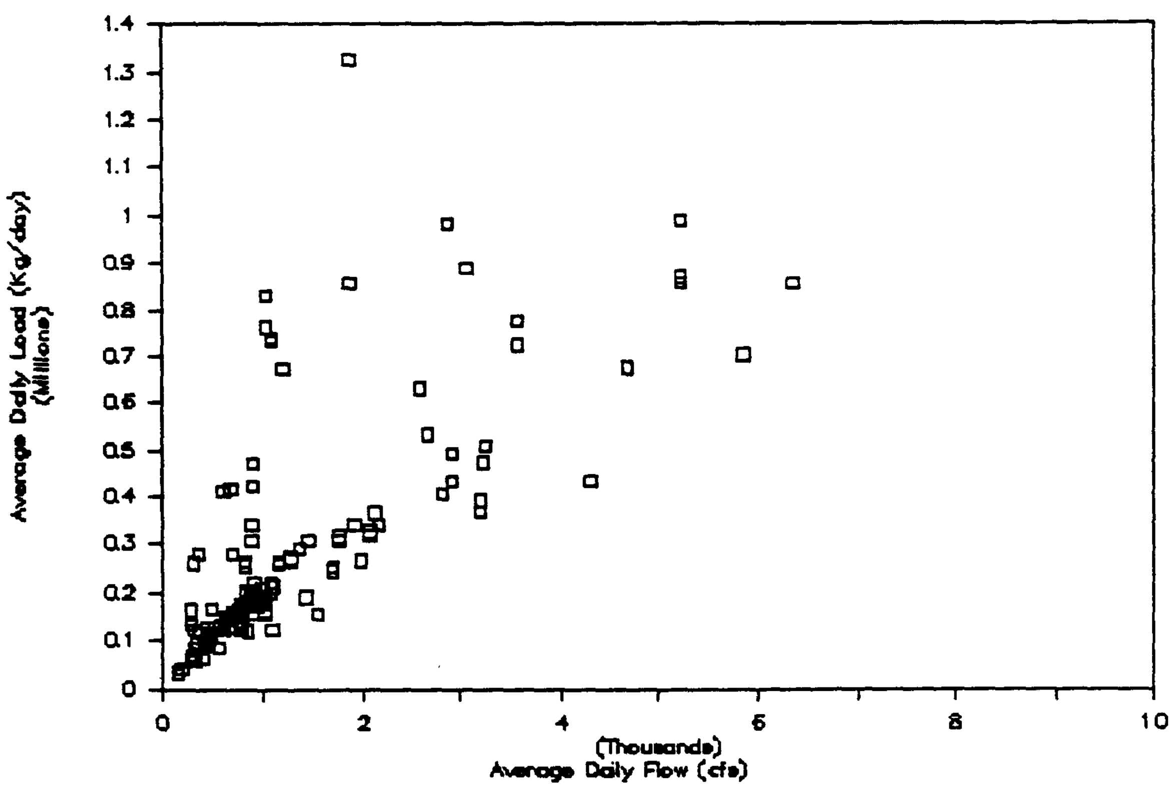
Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the Black River (1984-1986).



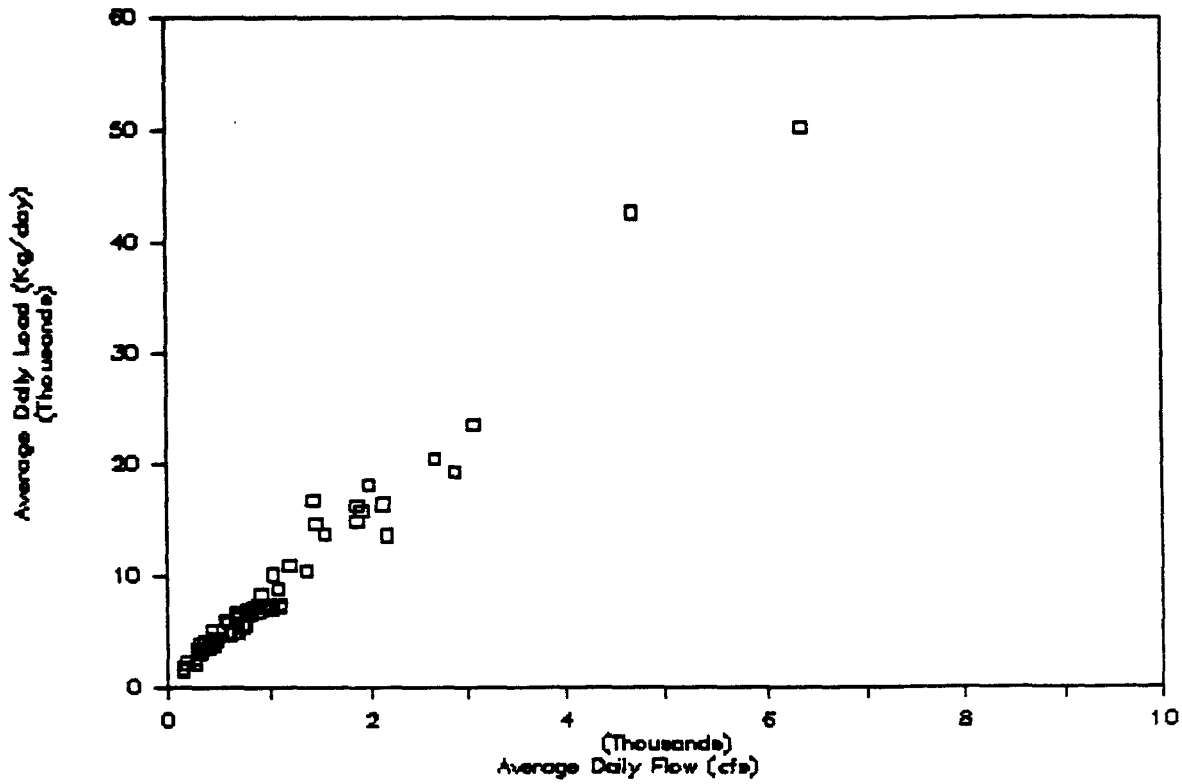
Average Daily Load of Total Phosphorus versus Average Daily Flow in the Black River (1984-1986).



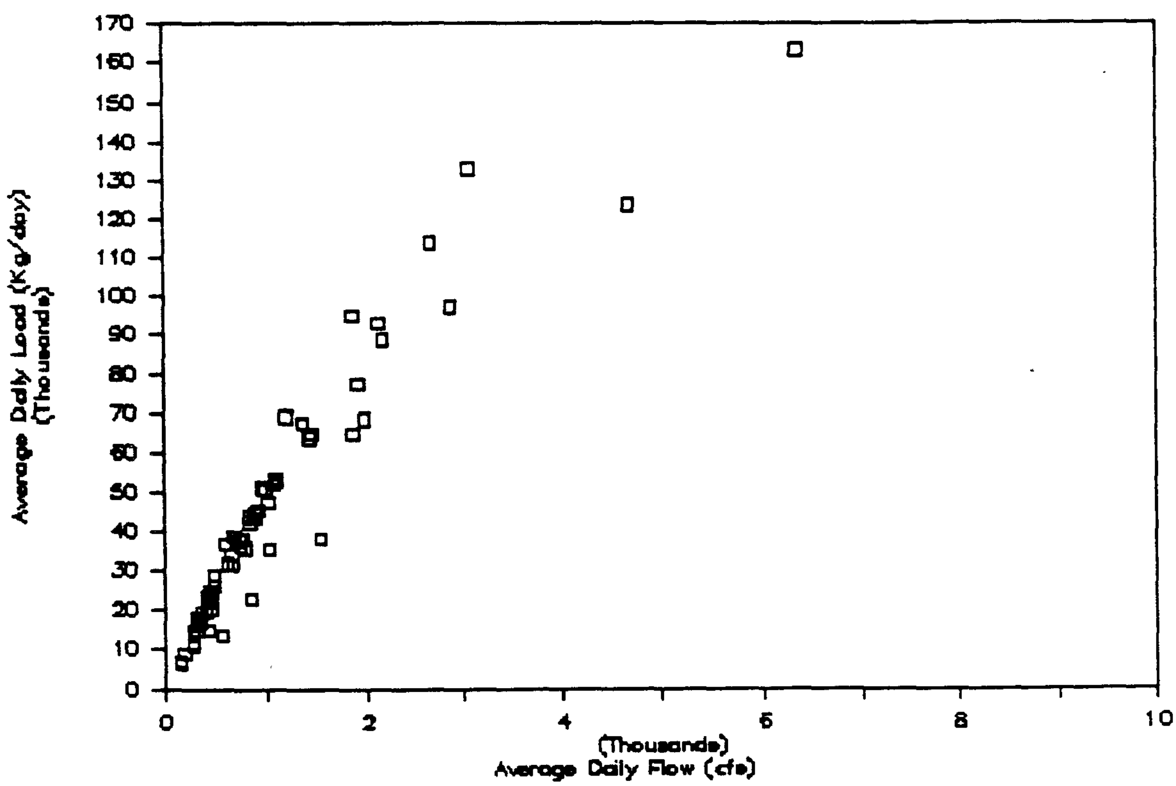
Average Daily Load of Calcium versus Average Daily Flow in the Clinton River (1984-1986).



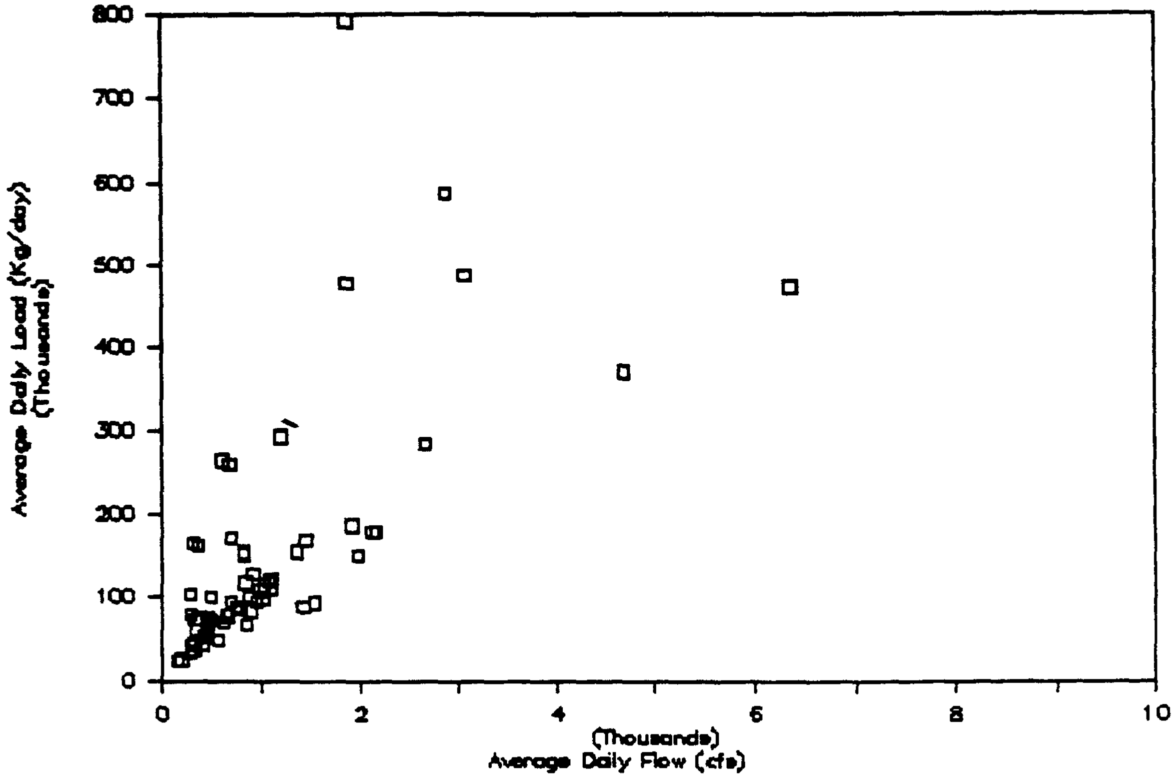
Average Daily Load of Chloride versus Average Daily Flow in the Clinton River (1984-1986).



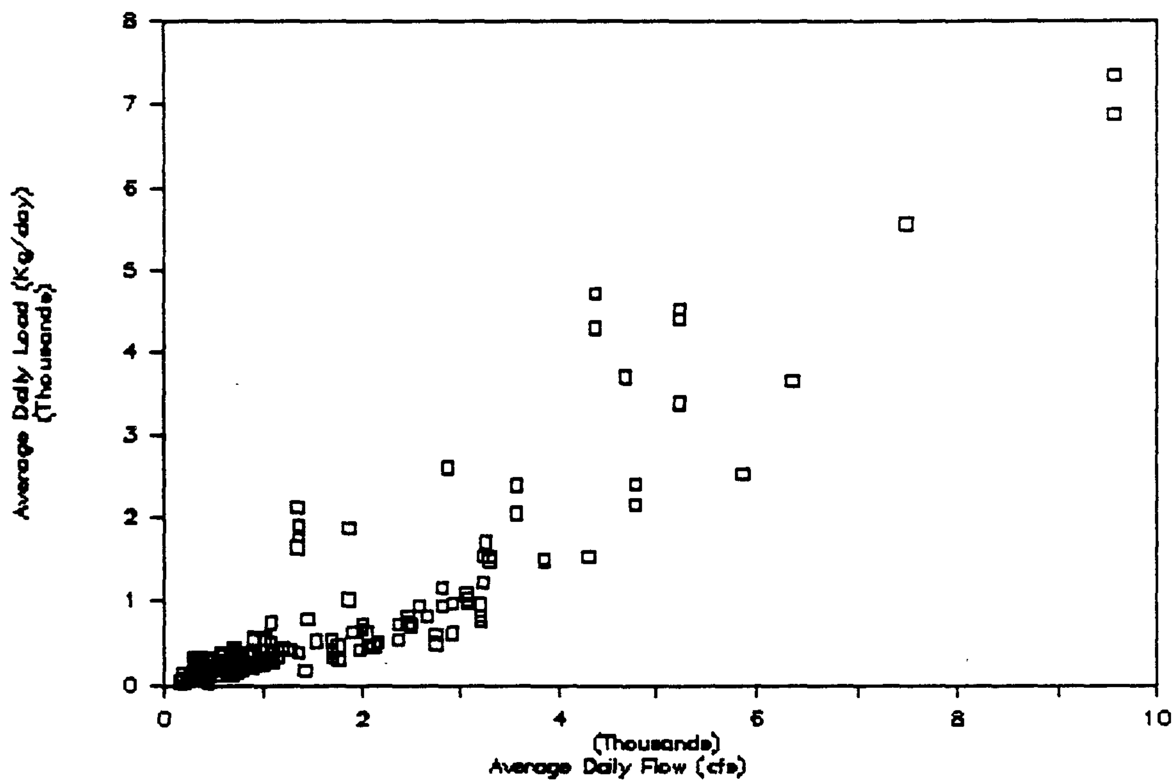
Average Daily Load of Potassium versus Average Daily Flow in the Clinton River (1984-1986).



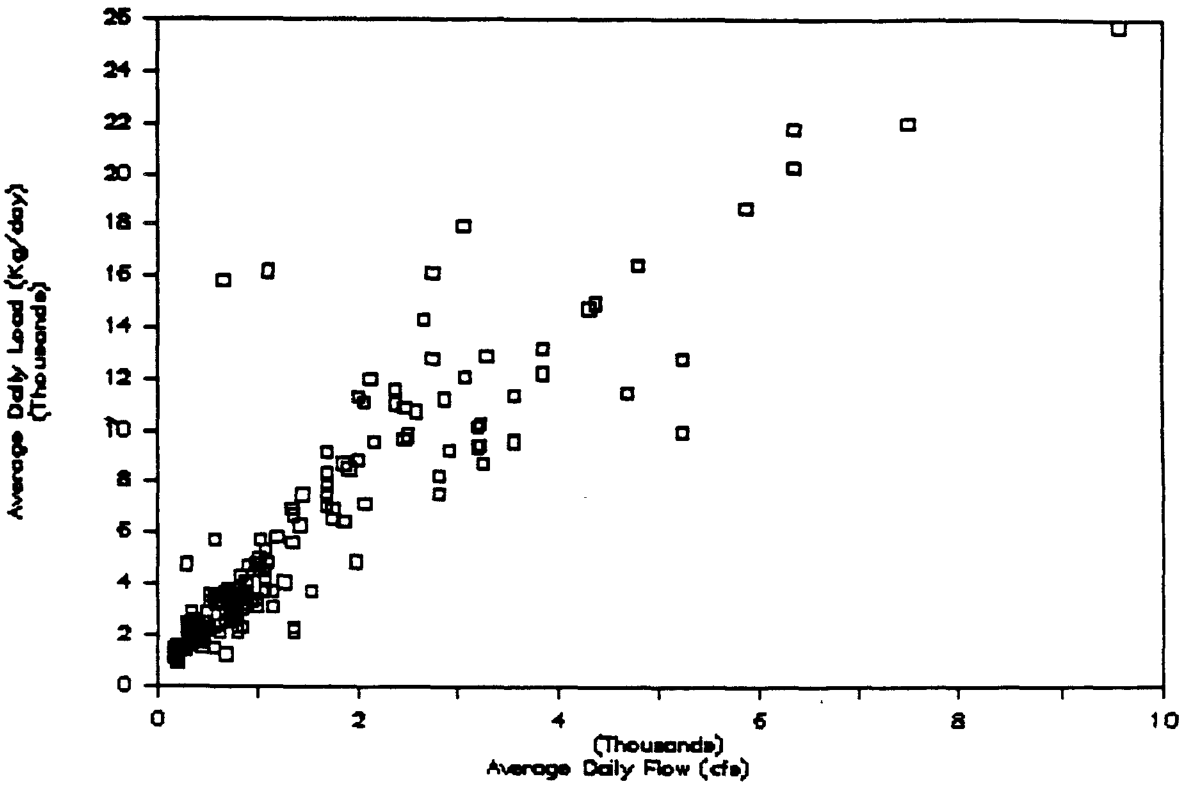
Average Daily Load of Magnesium versus Average Daily Flow in the Clinton River (1984-1986).



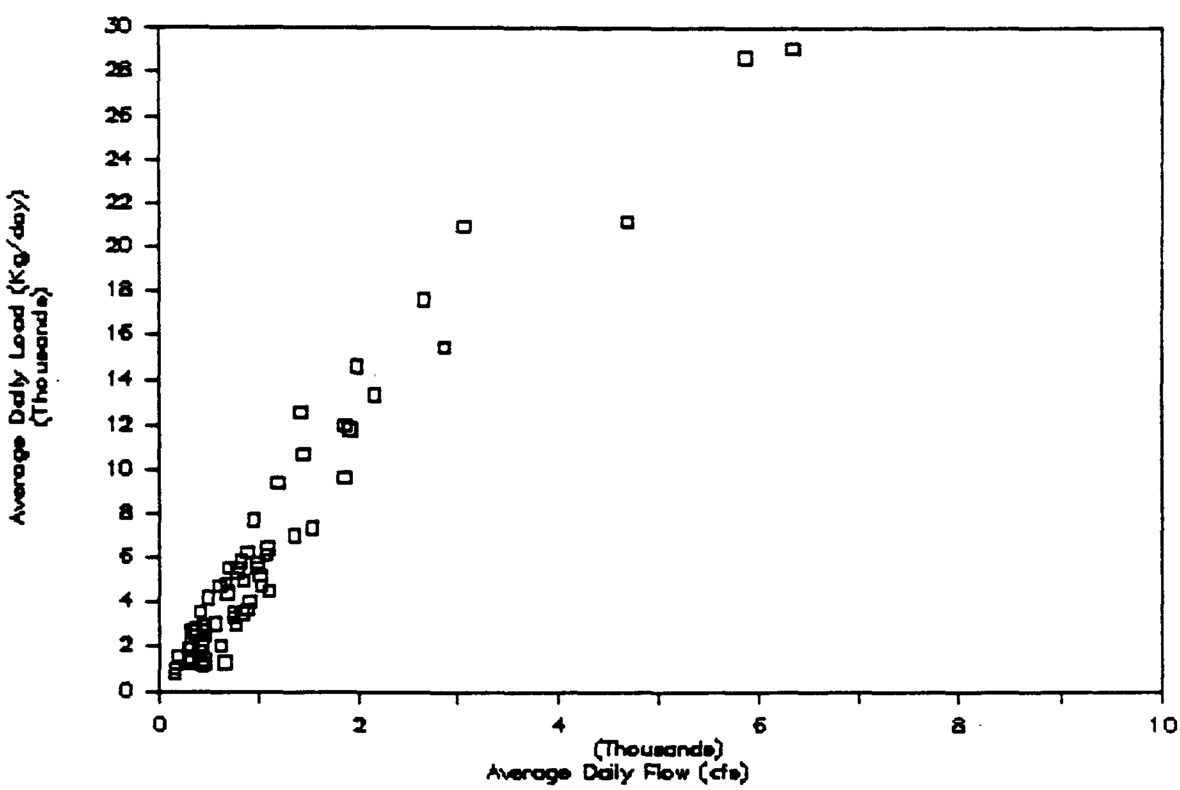
Average Daily Load of Sodium versus Average Daily Flow in the Clinton River (1984-1986).



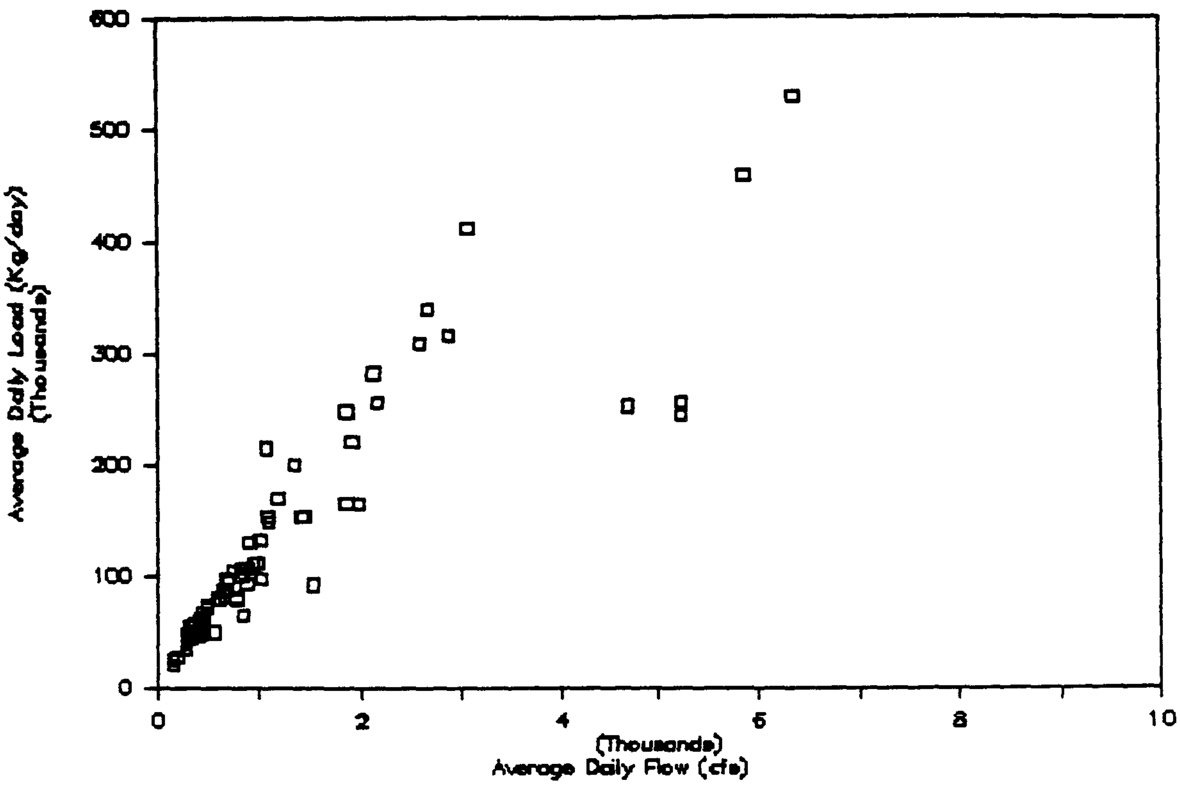
Average Daily Load of Ammonia versus Average Daily Flow in the Clinton River (1984-1986).



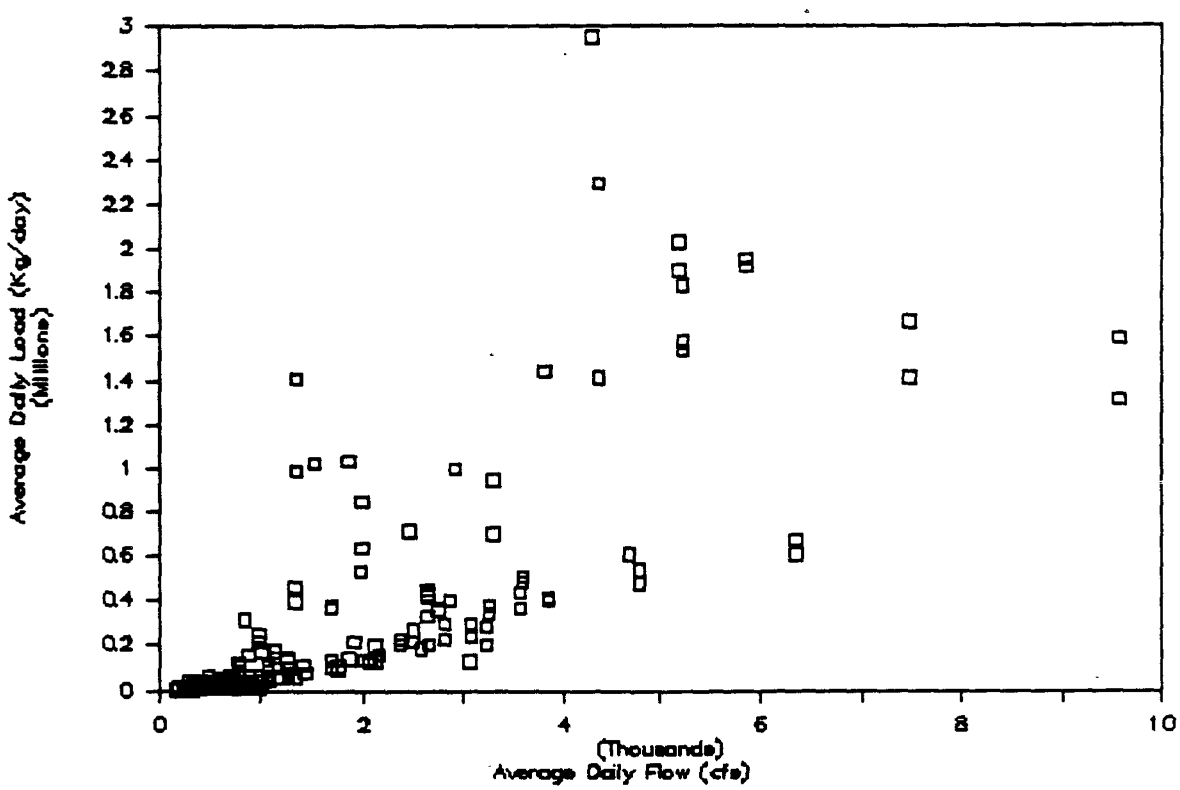
Average Daily Load of Nitrate versus Average Daily Flow in the Clinton River (1984-1986).



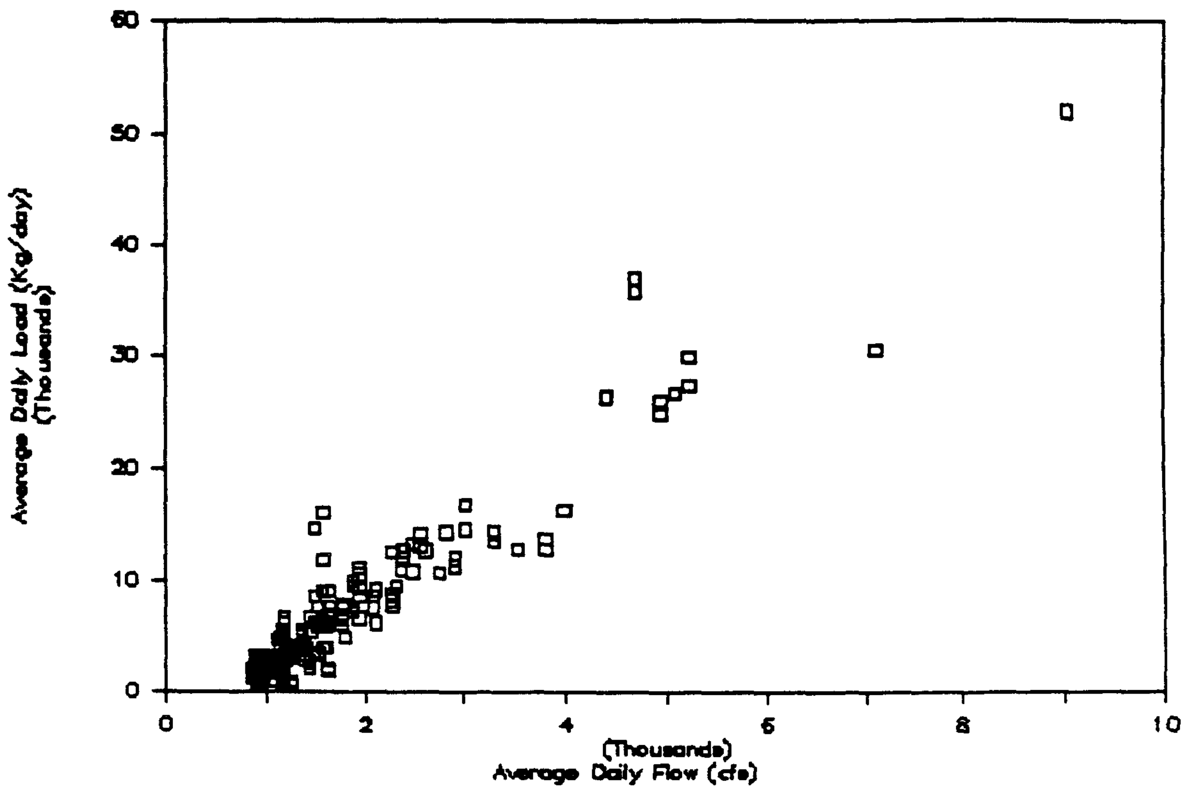
Average Daily Load of Silicate versus Average Daily Flow in the Clinton River (1984-1986).



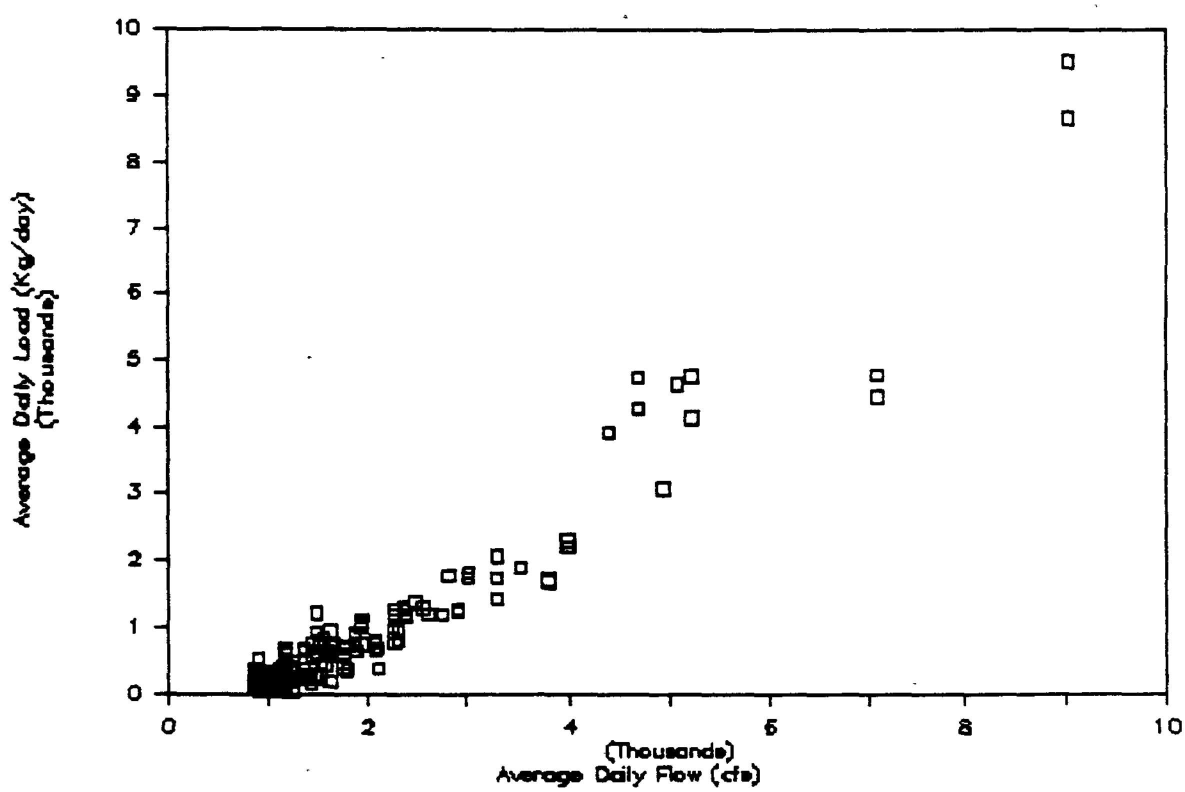
Average Daily Load of Sulfate versus Average Daily Flow in the Clinton River (1984-1986).



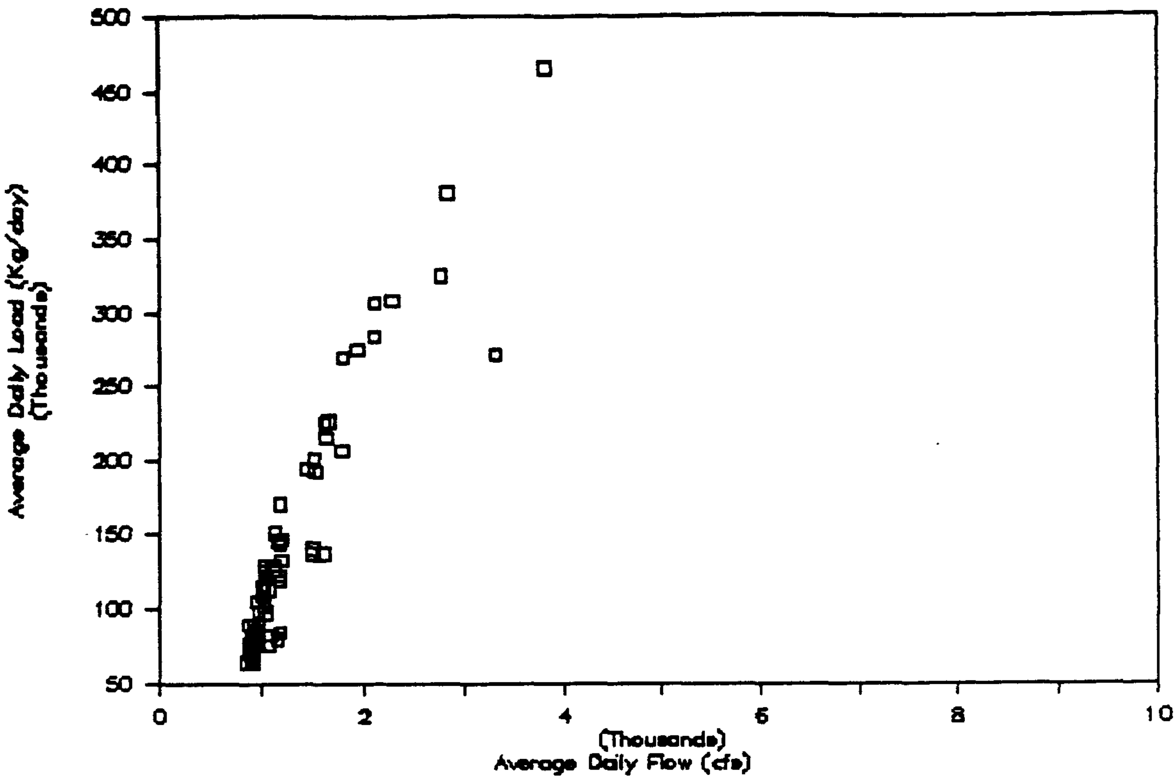
Average Daily Load of Suspended Solids versus Average Daily Flow in the Clinton River (1984-1986).



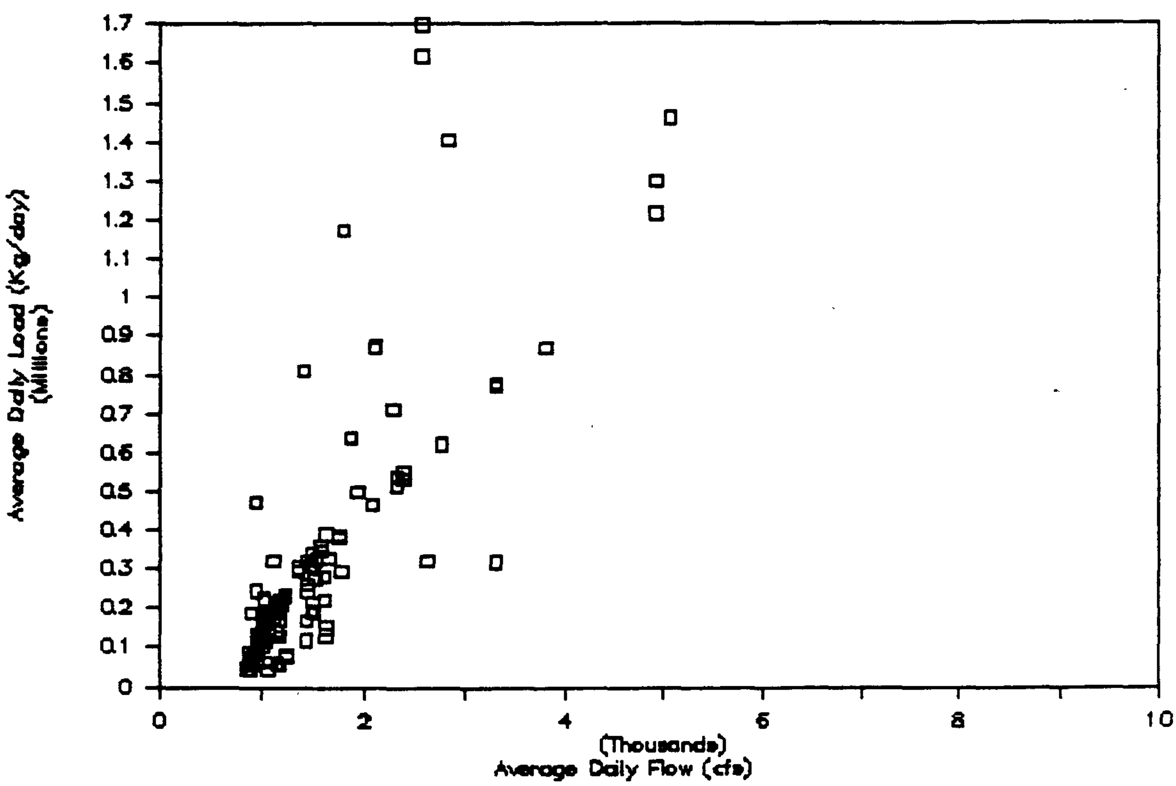
Average Daily Load of Total Kjeldahl versus Average Daily Flow in the Clinton River (1984-1986).



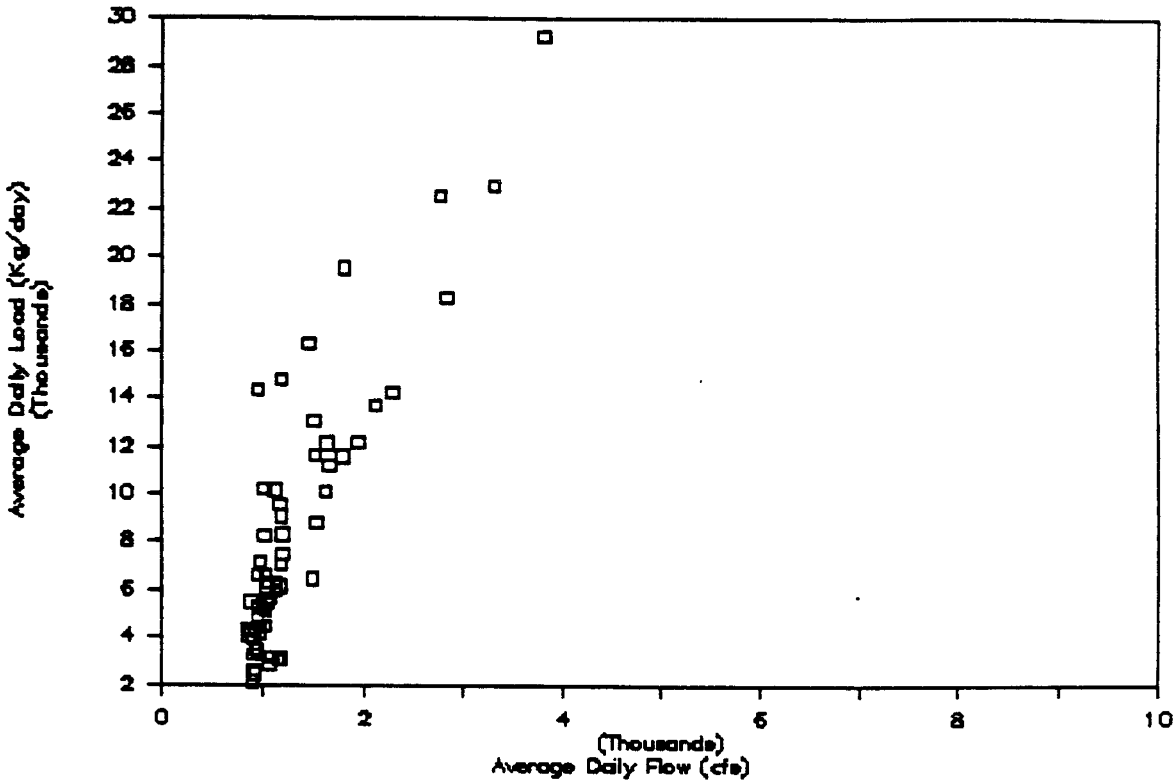
Average Daily Load of Total Phosphorus versus Average Daily Flow in the Clinton River (1984-1986).



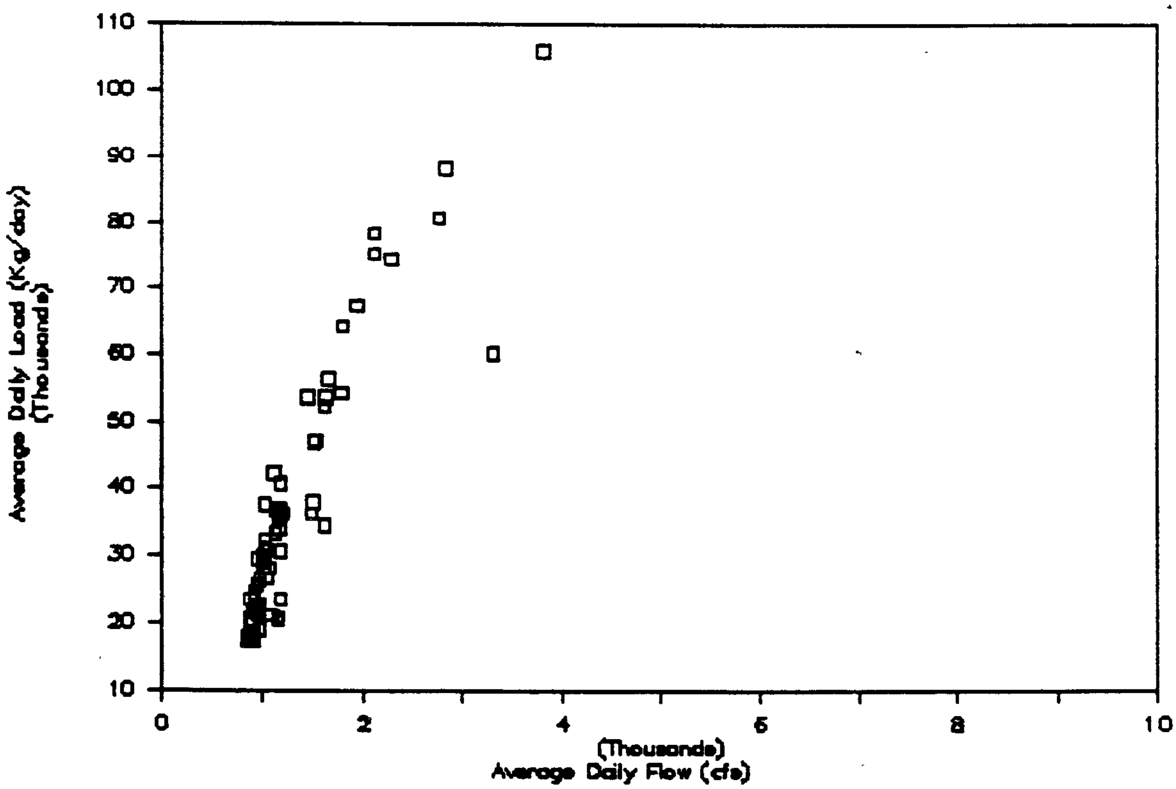
Average Daily Load of Calcium versus Average Daily Flow in the Rouge River (1984-1986).



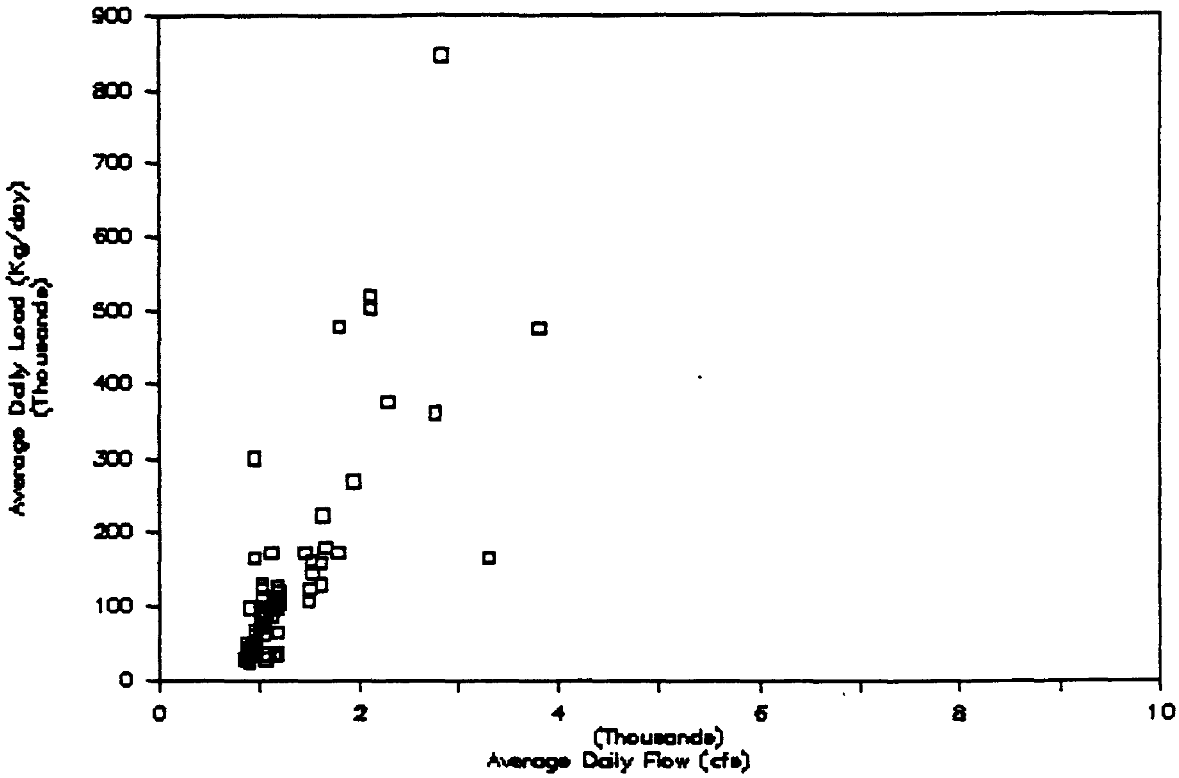
Average Daily Load of Chlorides versus Average Daily Flow in the Rouge River (1984-1986).



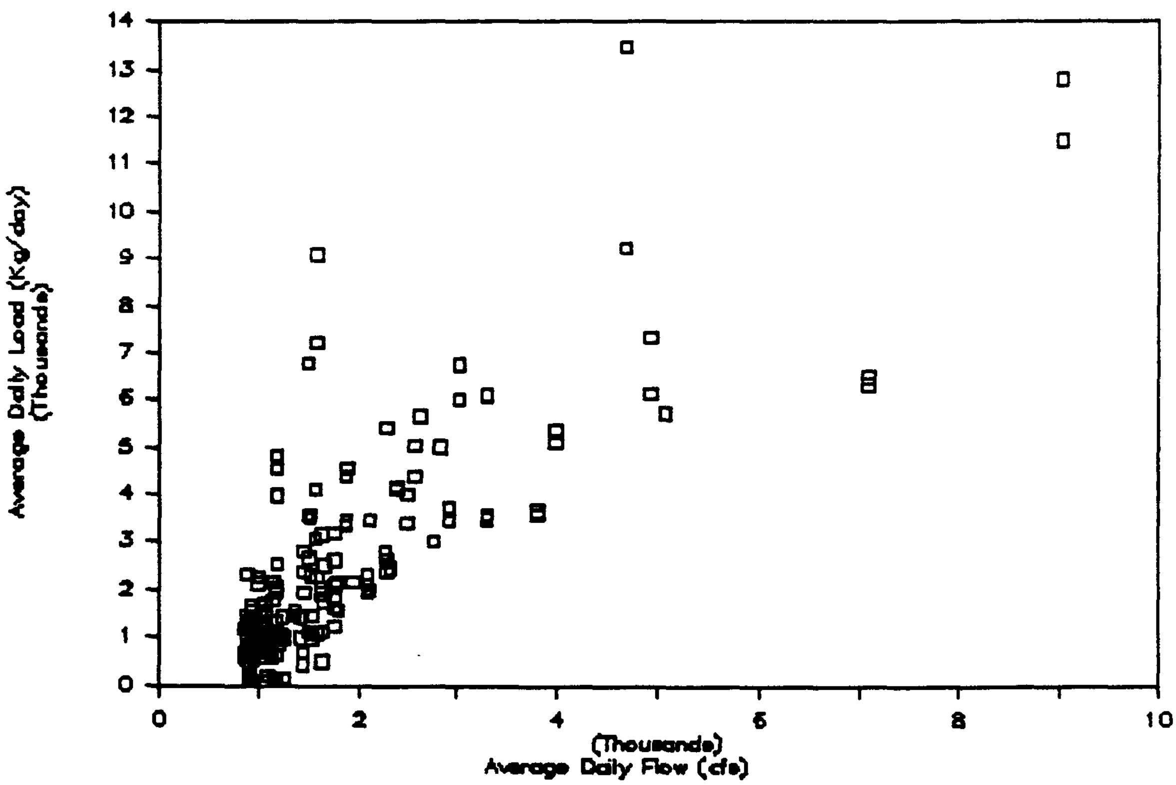
Average Daily Load of Potassium versus Average Daily Flow in the Rouge River (1984-1986).



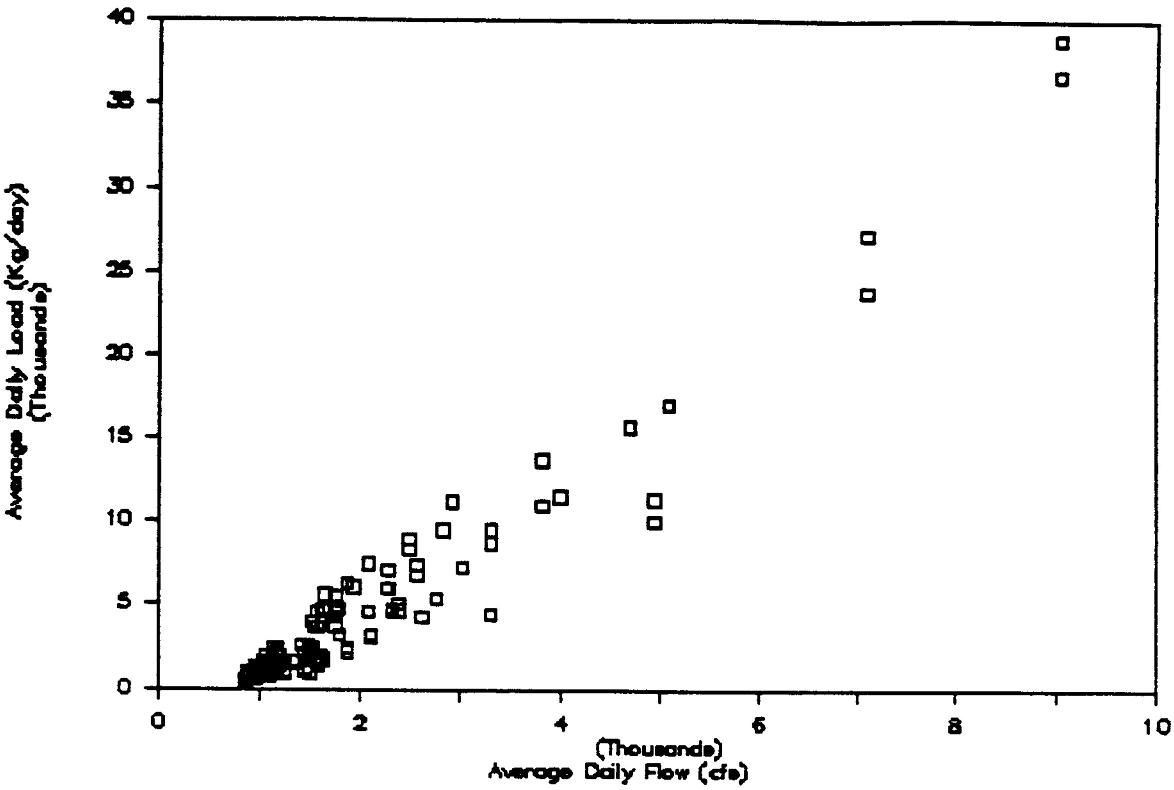
Average Daily Load of Magnesium versus Average Daily Flow in the Rouge River (1984-1986).



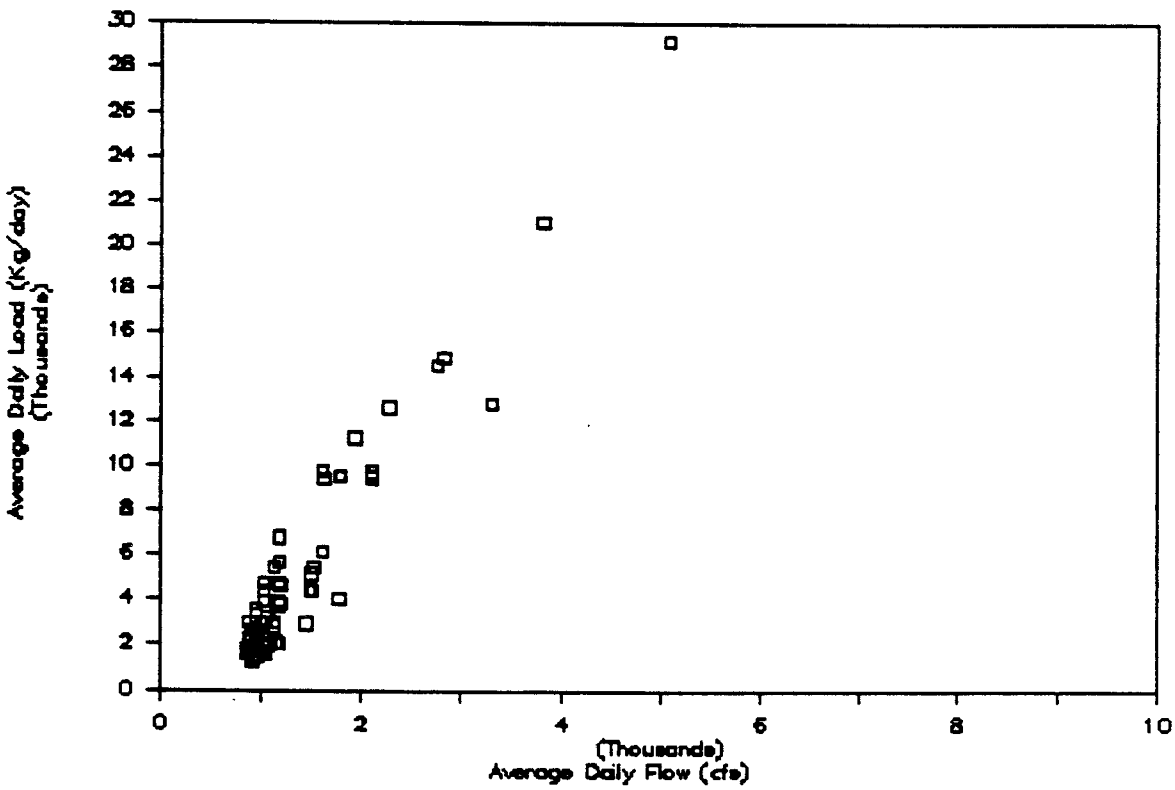
Average Daily Load of Sodium versus Average Daily Flow in the Rouge River (1984-1986).



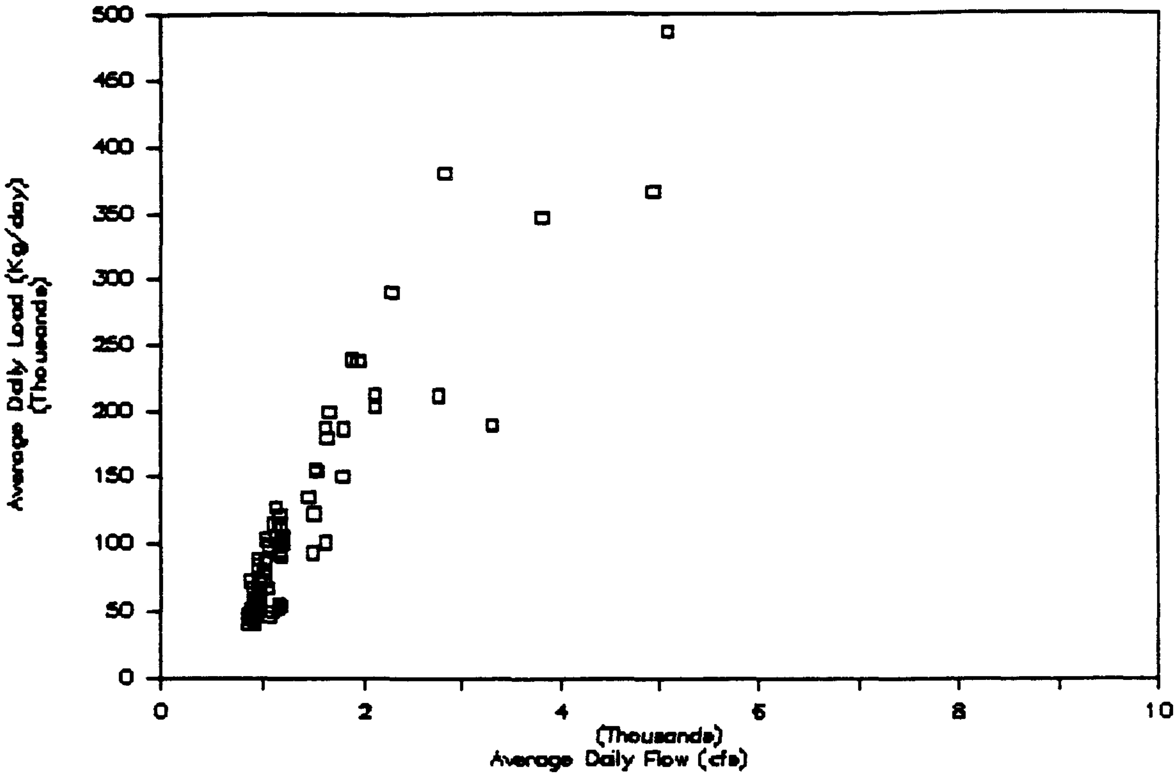
Average Daily Load of Ammonia versus Average Daily Flow in the Rouge River (1984-1986).



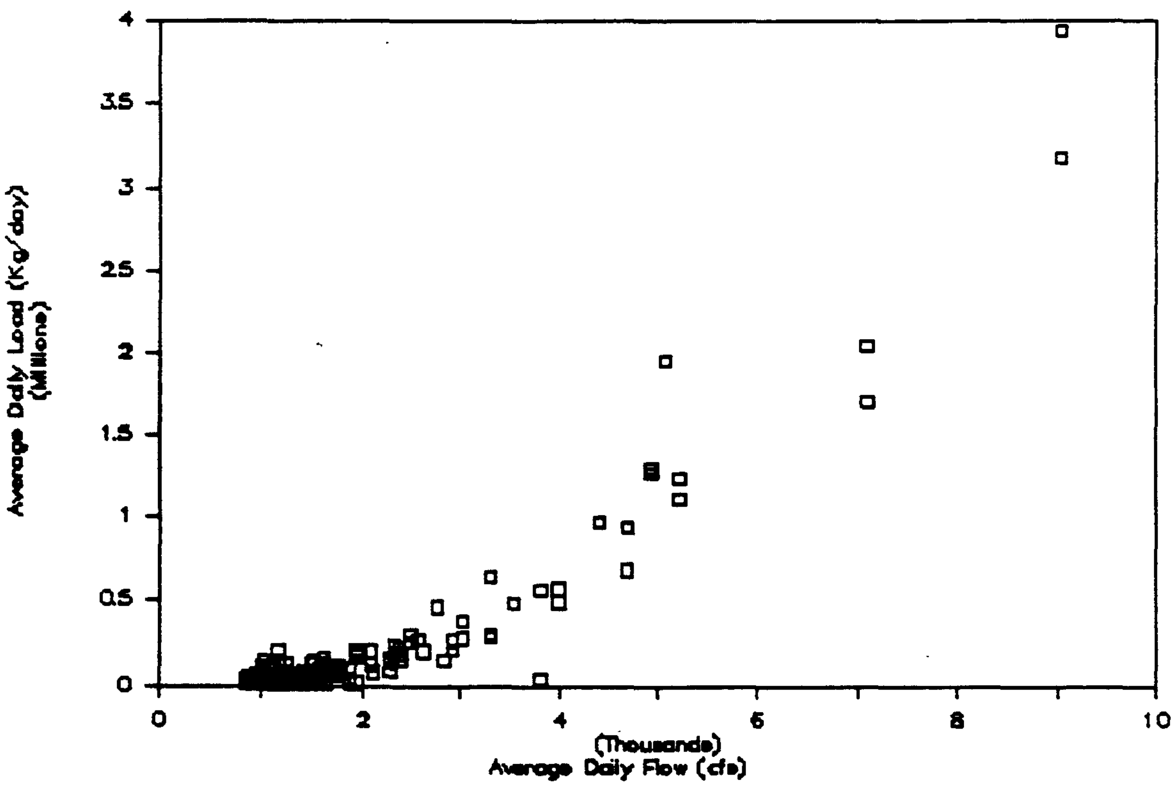
Average Daily Load of Nitrate versus Average Daily Flow in the Rouge River (1984-1986).



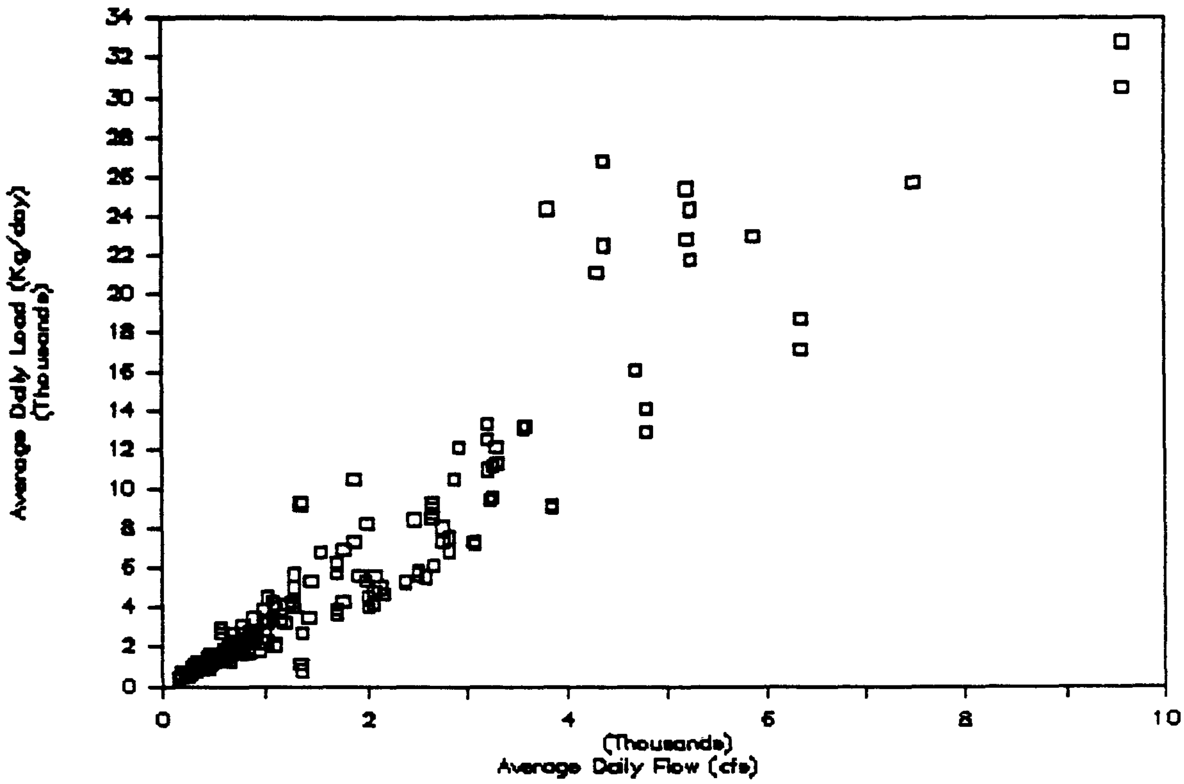
Average Daily Load of Silica versus Average Daily Flow in the Rouge River (1984-1986).



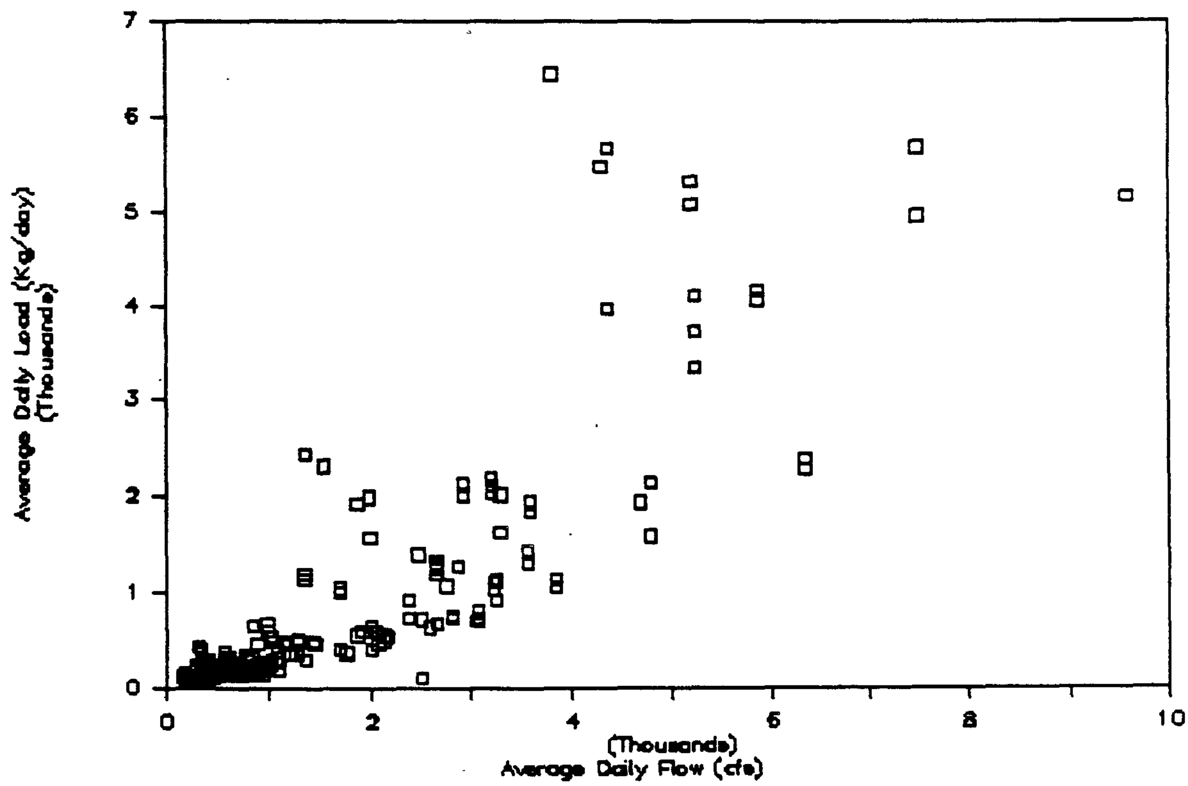
Average Daily Load of Sulfate versus Average Daily Flow in the Rouge River (1984-1986).



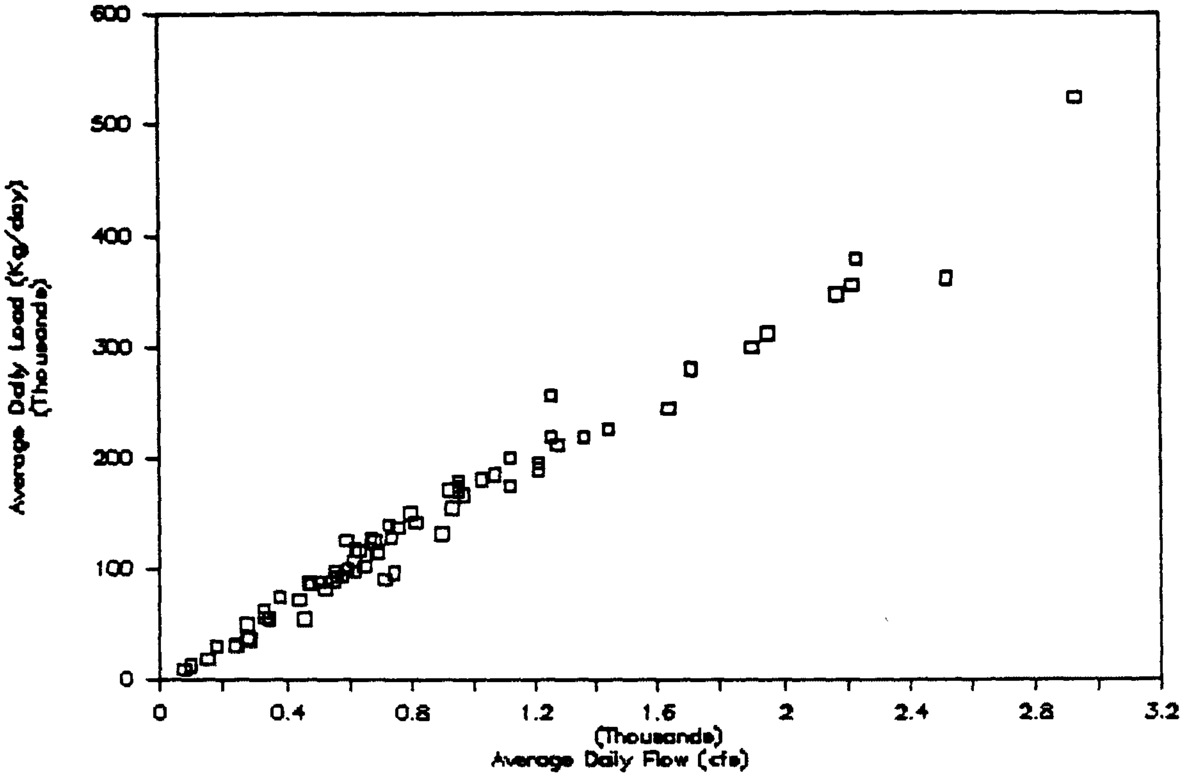
Average Daily Load of Suspended Solids versus Average Daily Flow in the Rouge River (1984-1986).



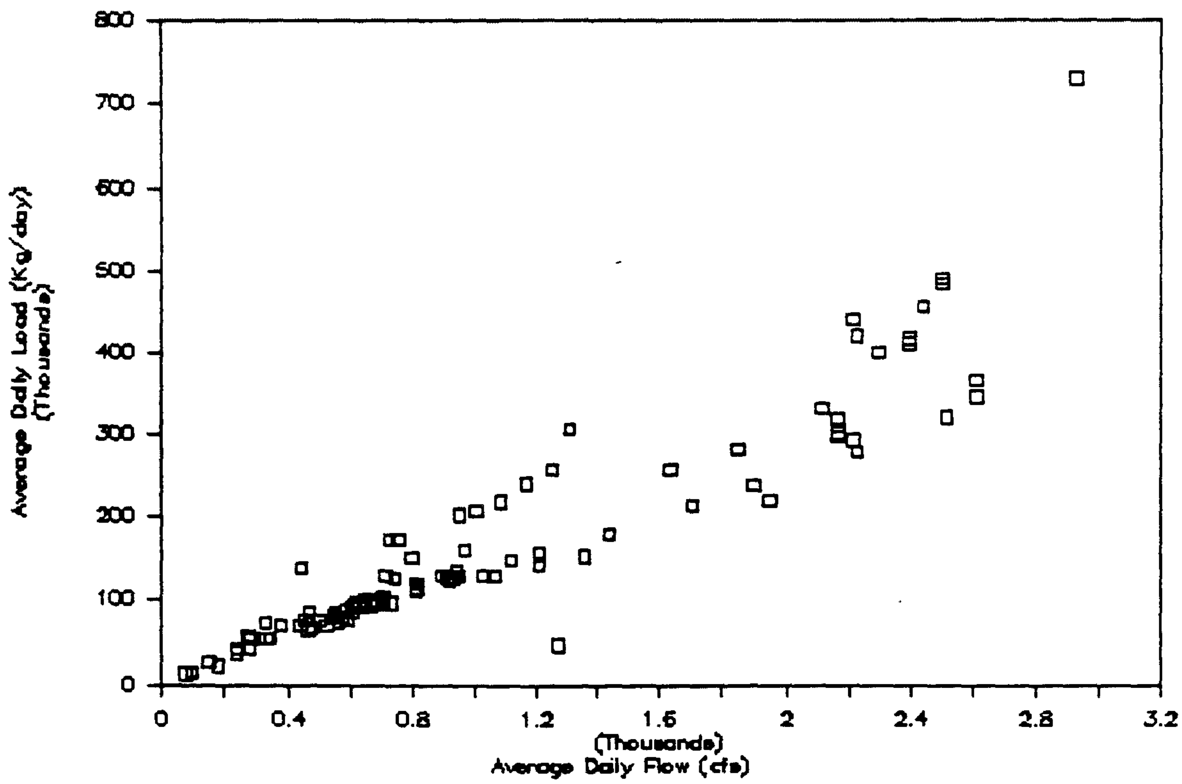
Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the Rouge River (1984-1986).



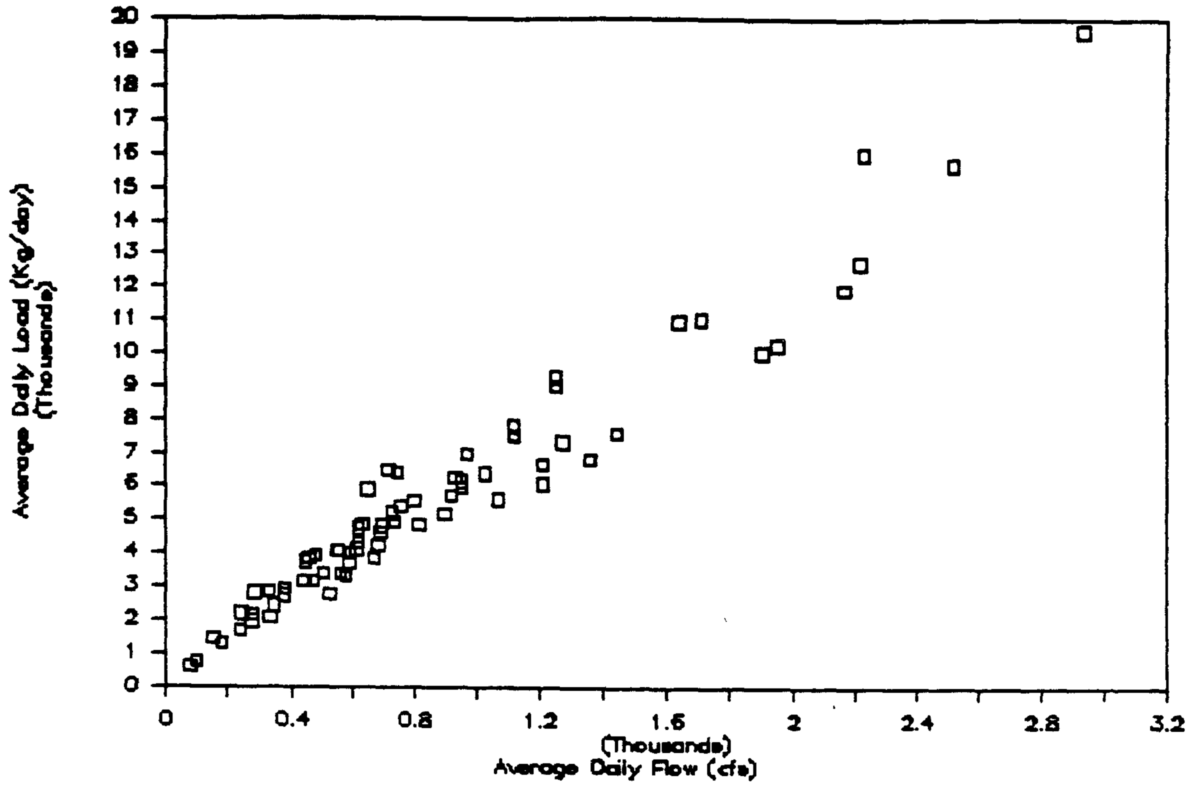
Average Daily Load of Total Phosphorus versus Average Daily Flow in the Rouge River (1984-1986).



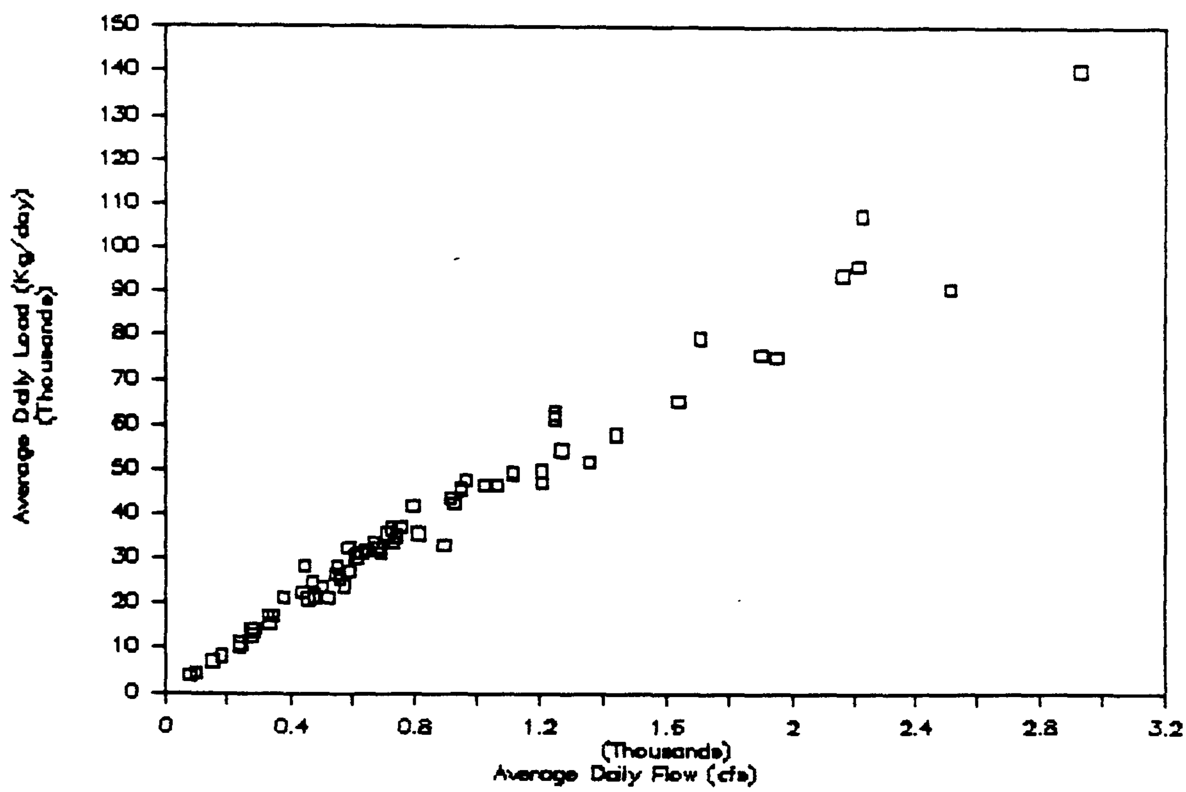
Average Daily Load of Calcium versus Average Daily Flow in the Huron River (1984-1986).



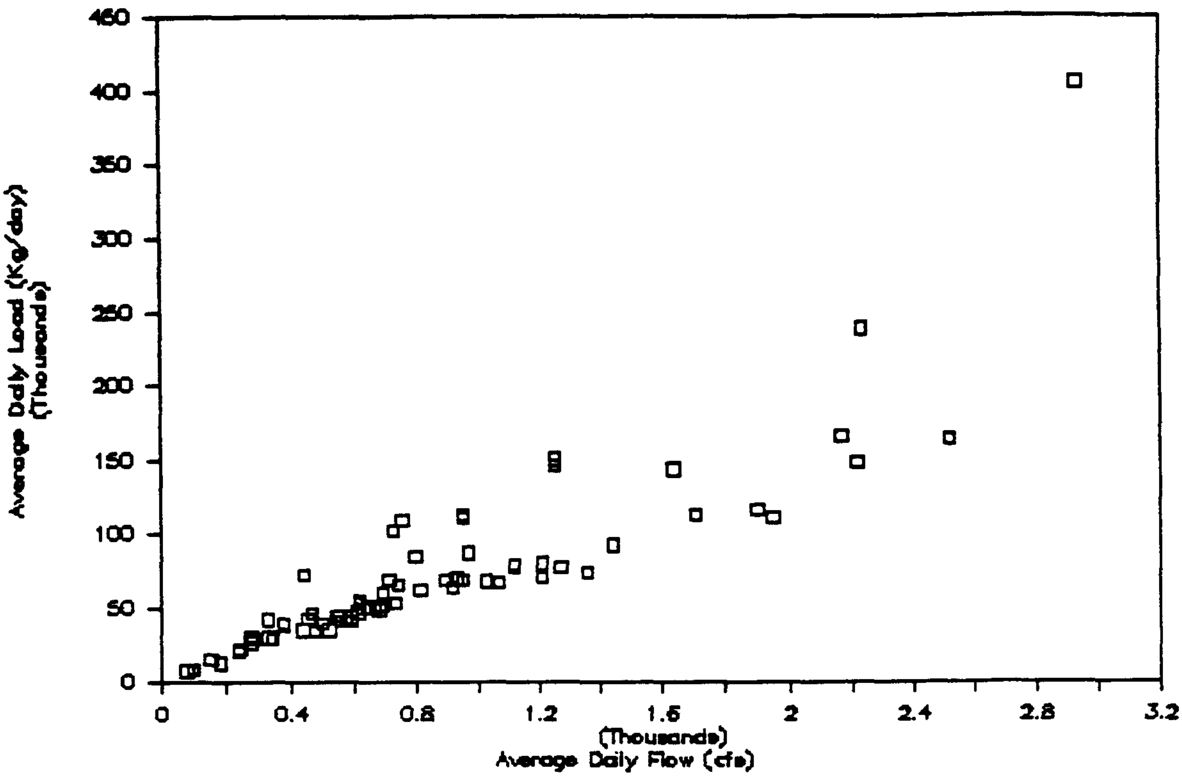
Average Daily Load of Chloride versus Average Daily Flow in the Huron River (1984-1986).



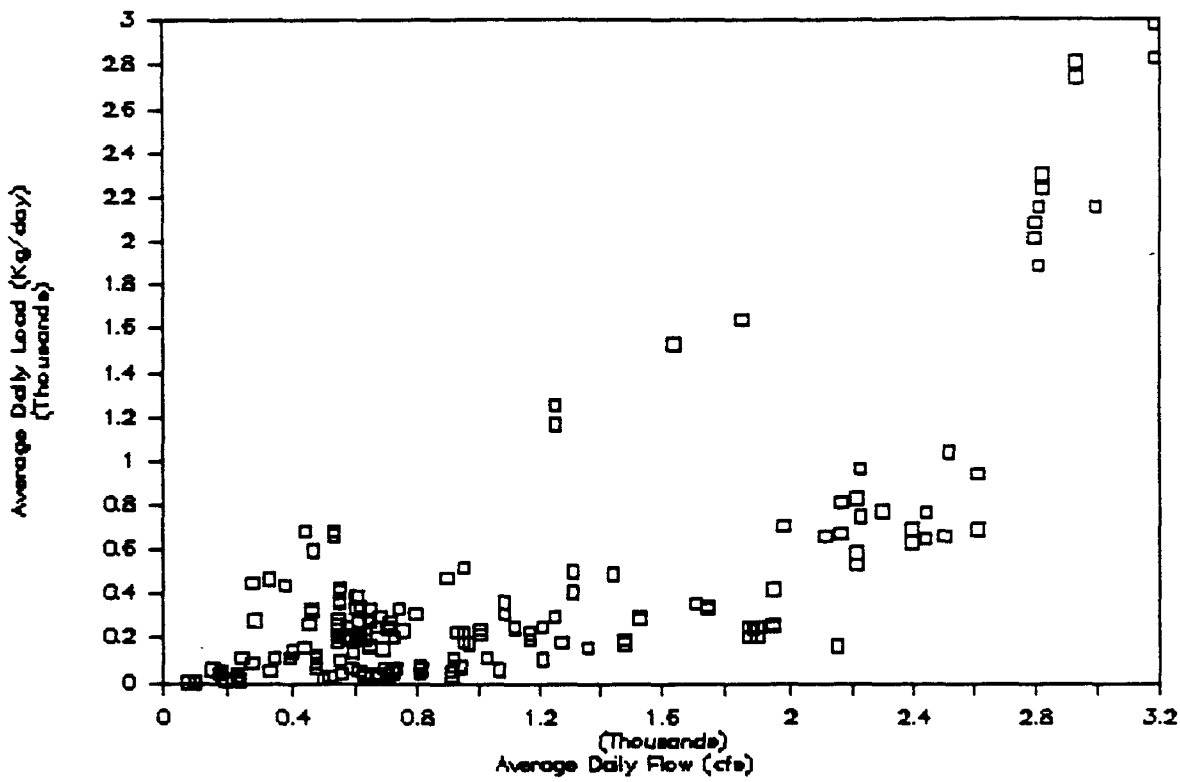
Average Daily Load of Potassium versus Average Daily Flow in the Huron River (1984-1986).



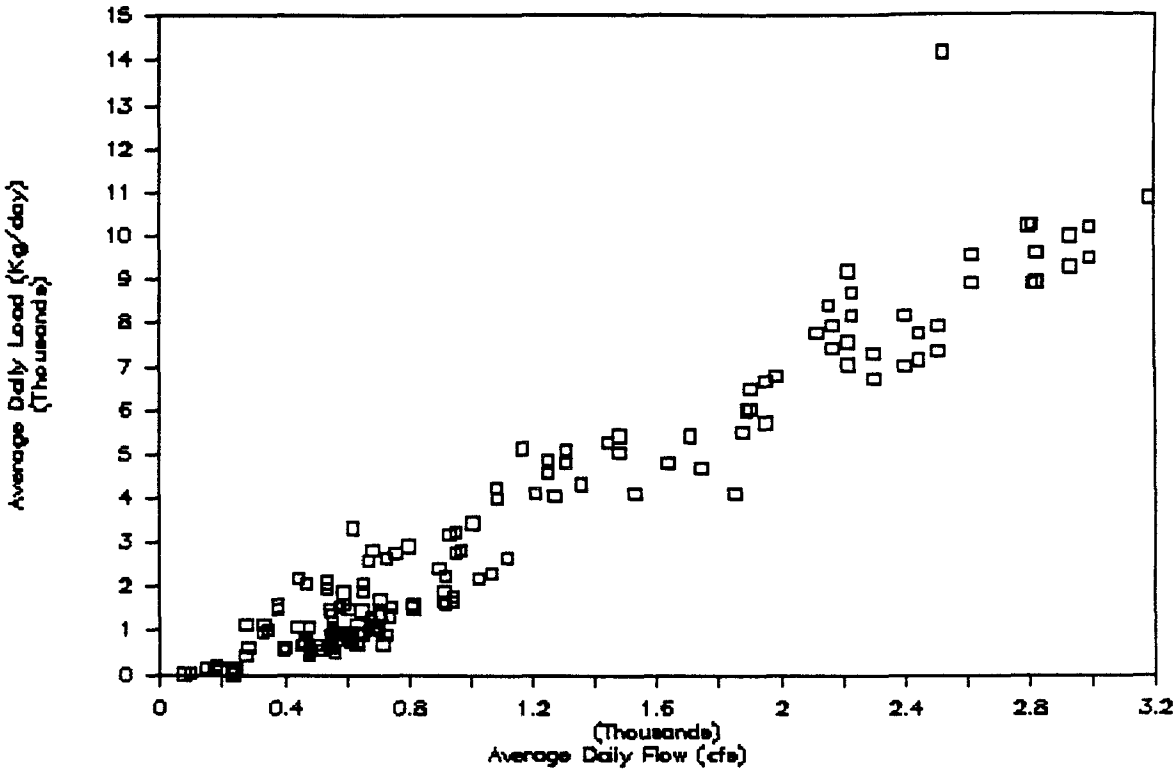
Average Daily Load of Magnesium versus Average Daily Flow in the Huron River (1984-1986).



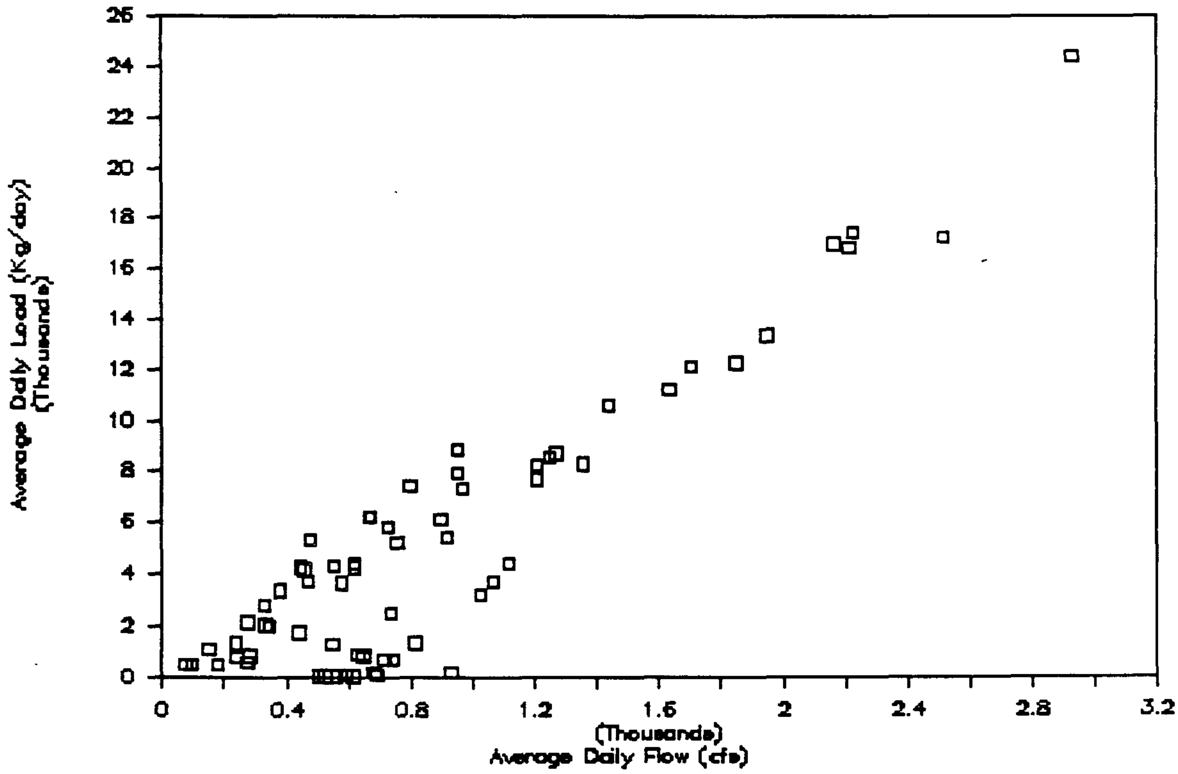
Average Daily Load of Sodium versus Average Daily Flow in the Huron River (1984-1986).



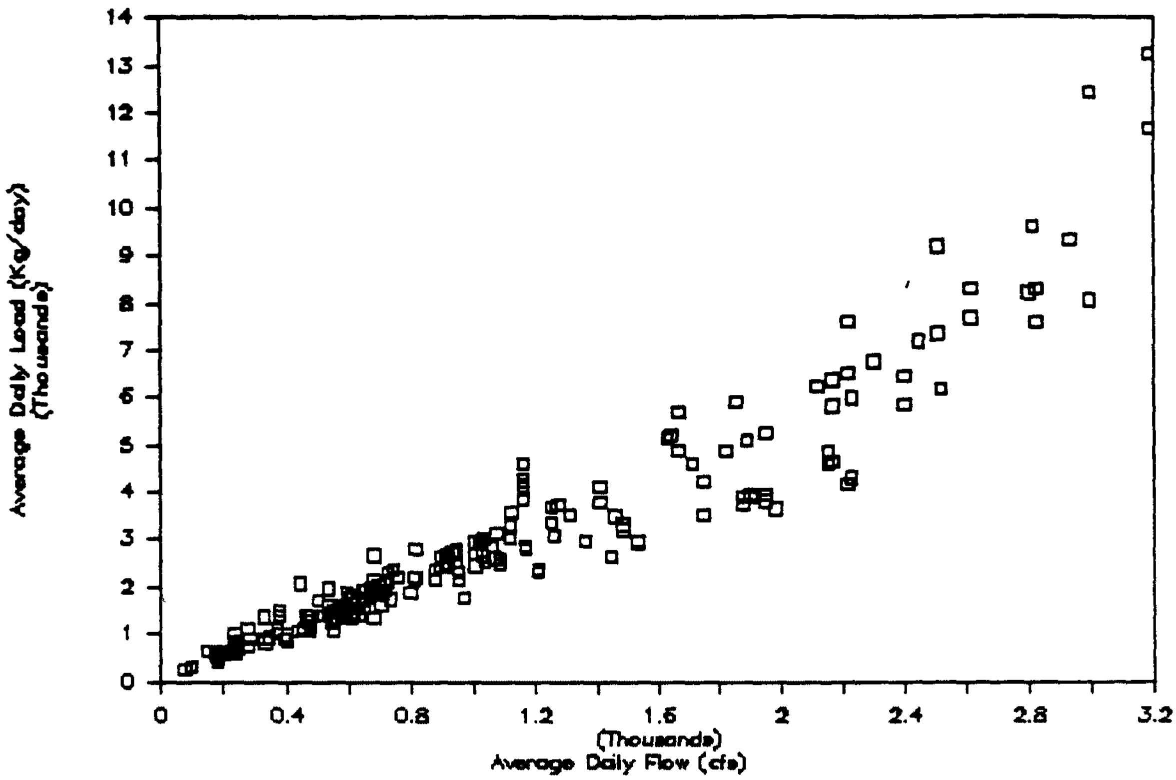
Average Daily Load of Ammonia versus Average Daily Flow in the Huron River (1984-1986).



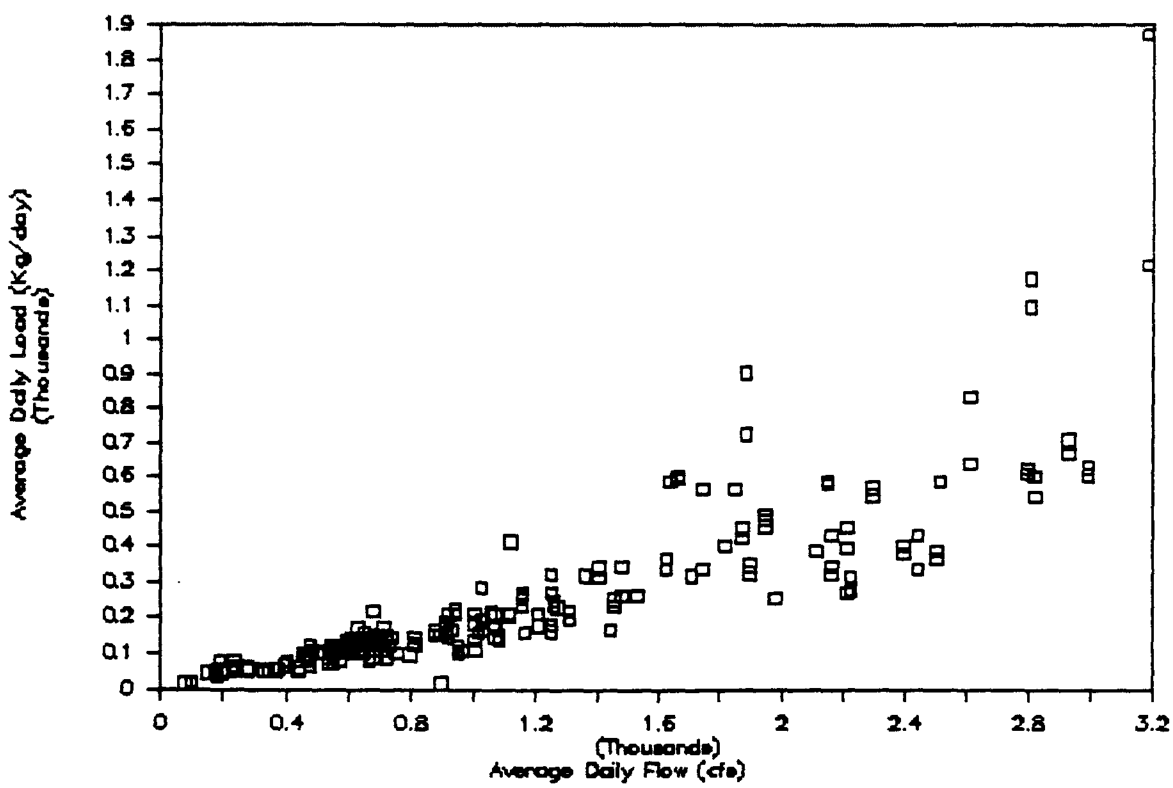
Average Daily Load of Nitrate versus Average Daily Flow in the Huron River (1984-1986).



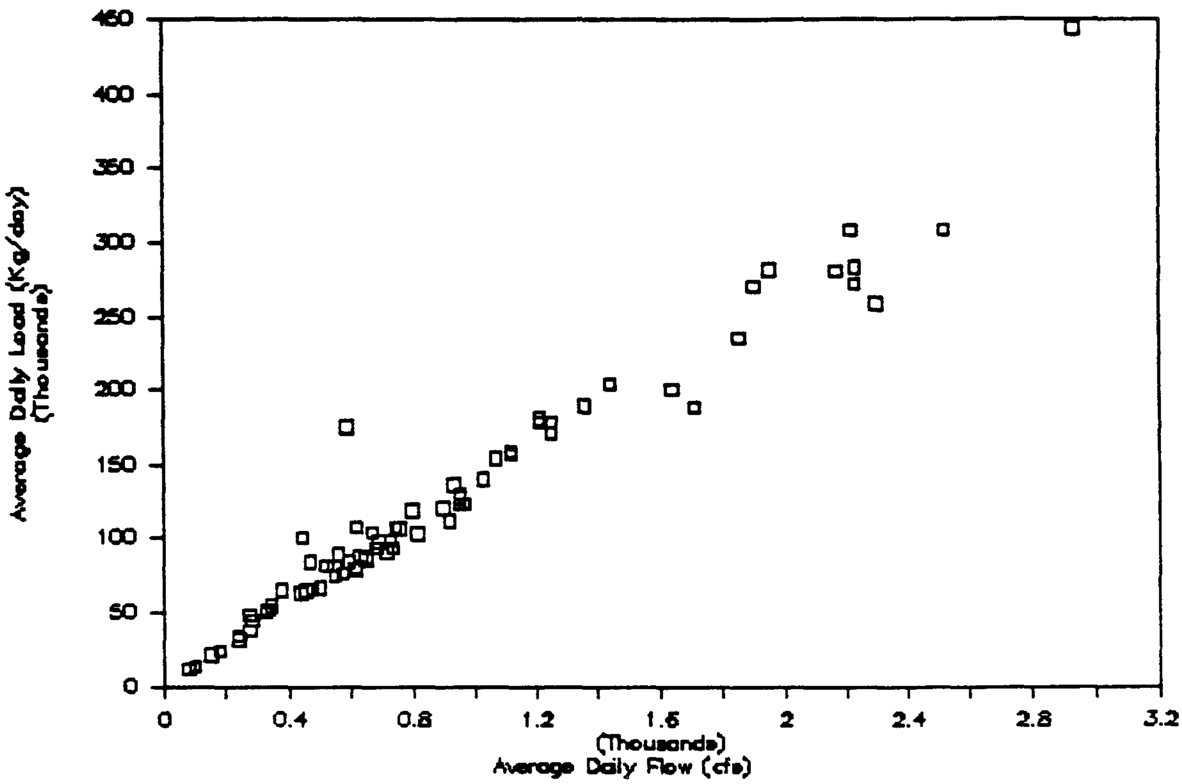
Average Daily Load of Silicate versus Average Daily Flow in the Huron River (1984-1986).



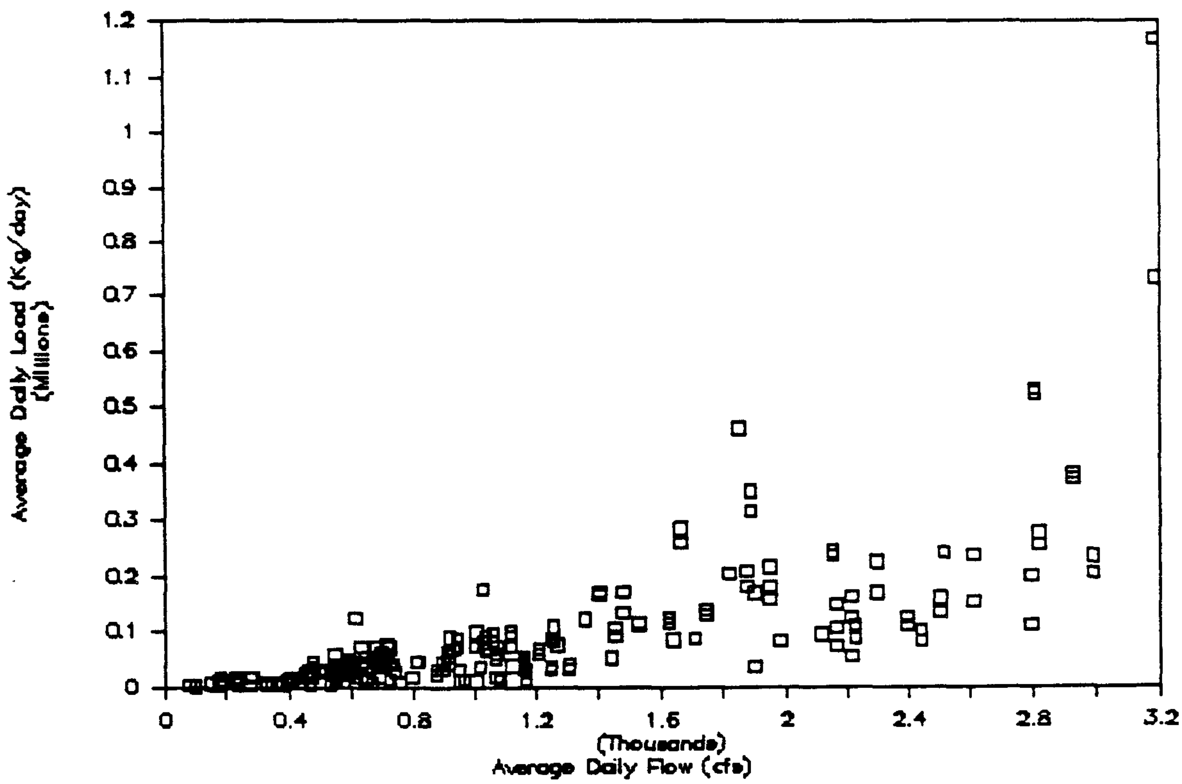
Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the Huron River (1984-1986).



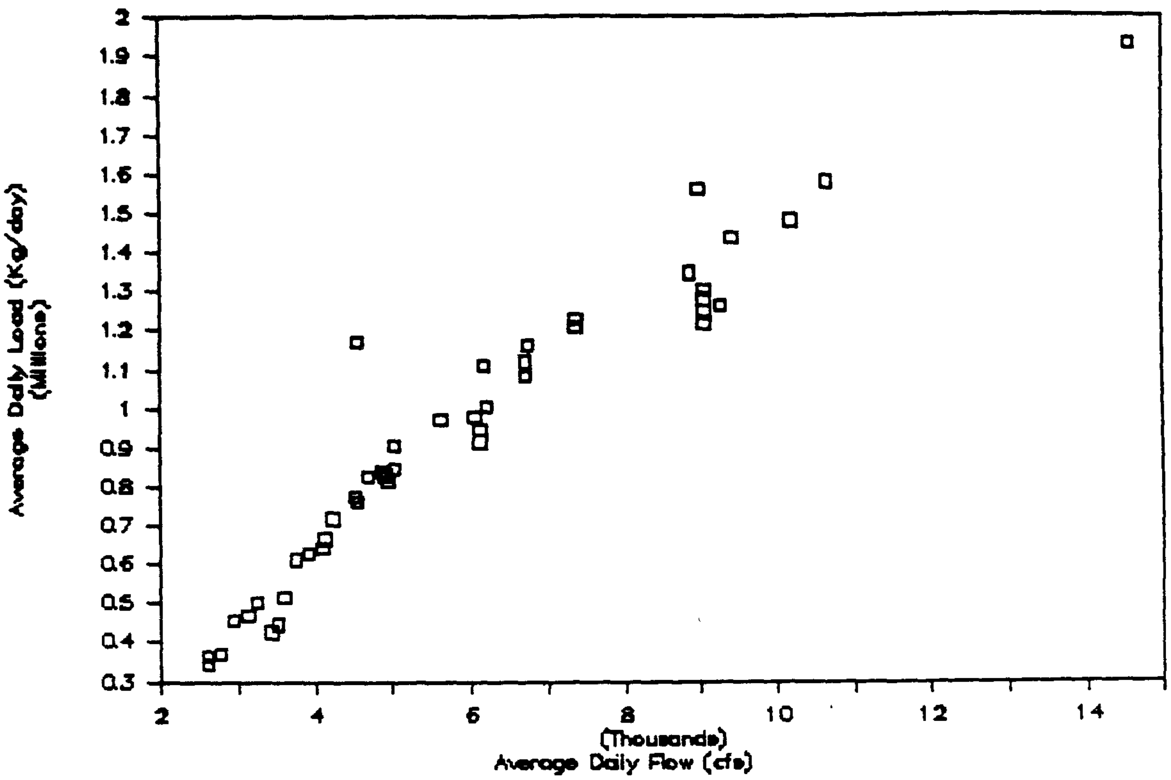
Average Daily Load of Total Phosphorus versus Average Daily Flow in the Huron River (1984-1986).



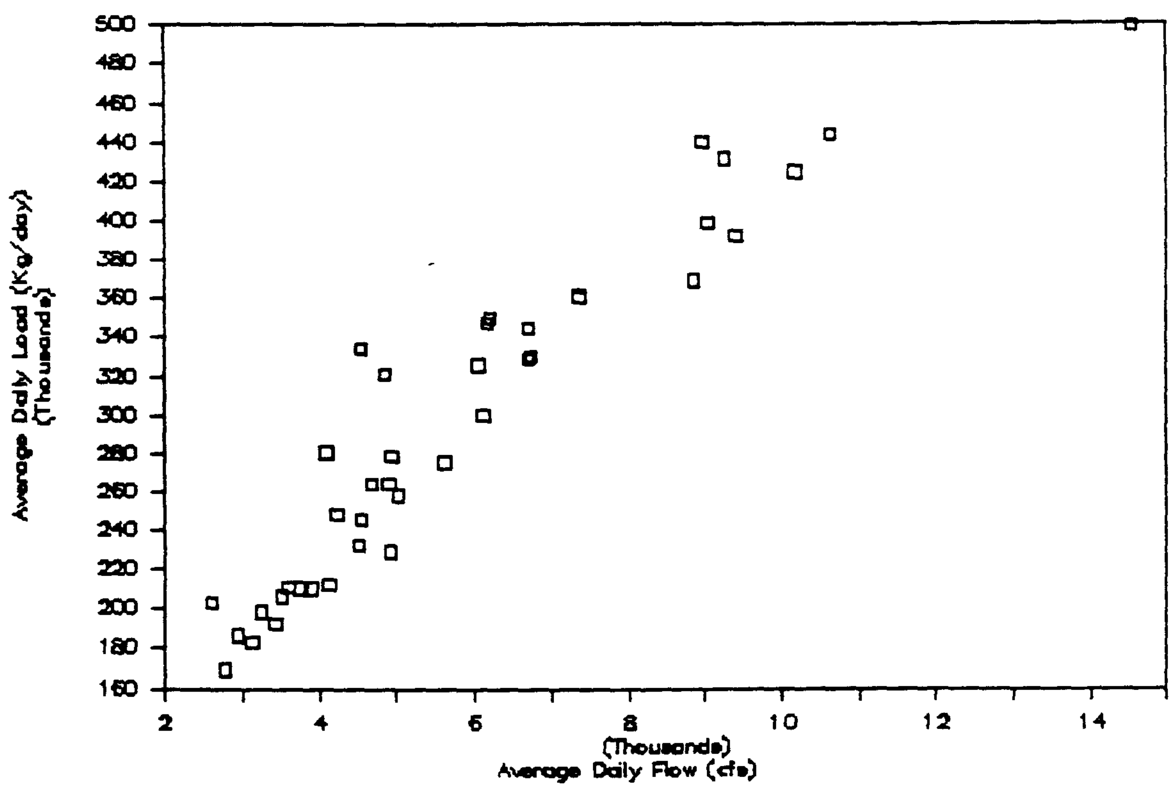
Average Daily Load of Sulfate versus Average Daily Flow in the Huron River (1984-1986).



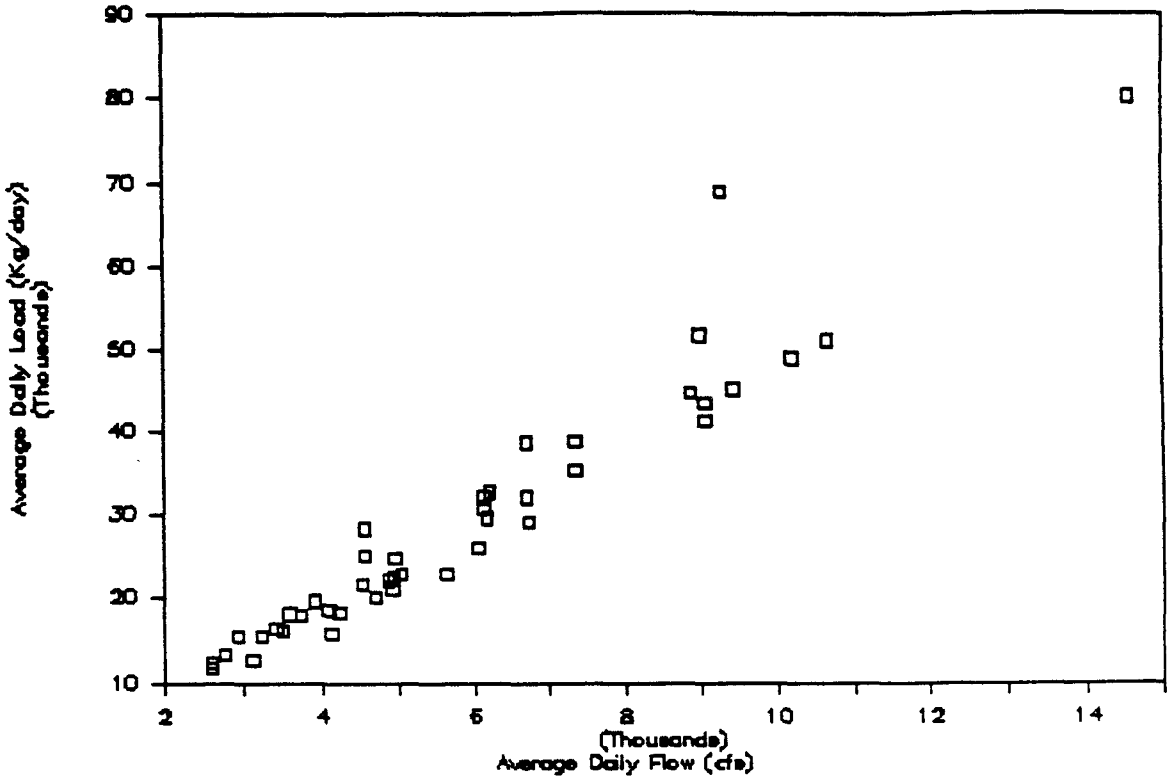
Average Daily Load of Suspended Solids versus Average Daily Flow in the Huron River (1984-1986).



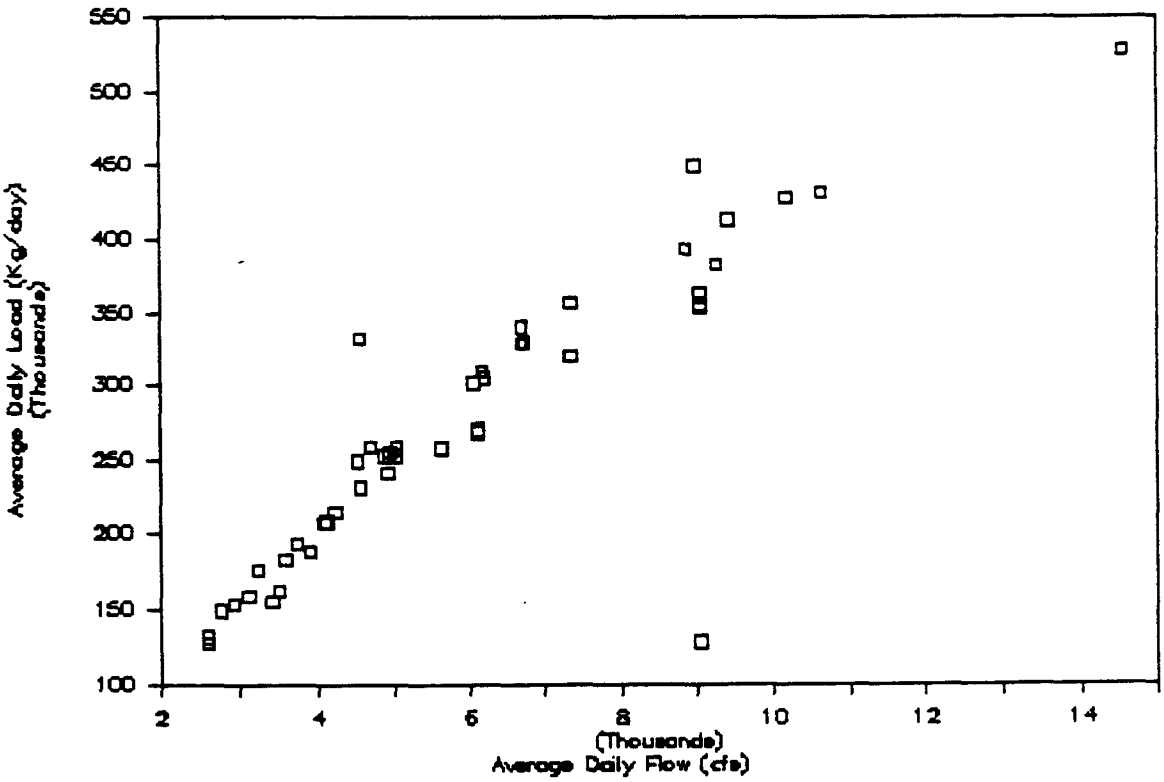
Average Daily Load of Calcium versus Average Daily Flow in the St. Joseph River (1984-1986).



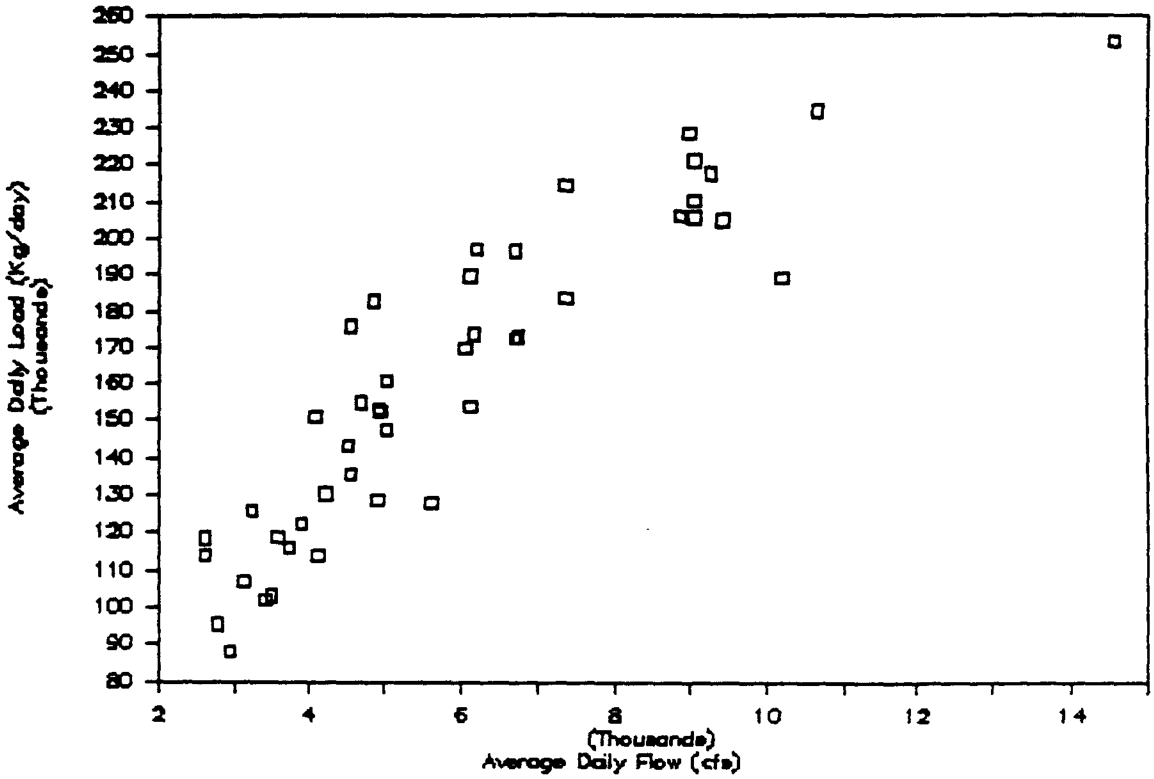
Average Daily Load of Chloride versus Average Daily Flow in the St. Joseph River (1984-1986).



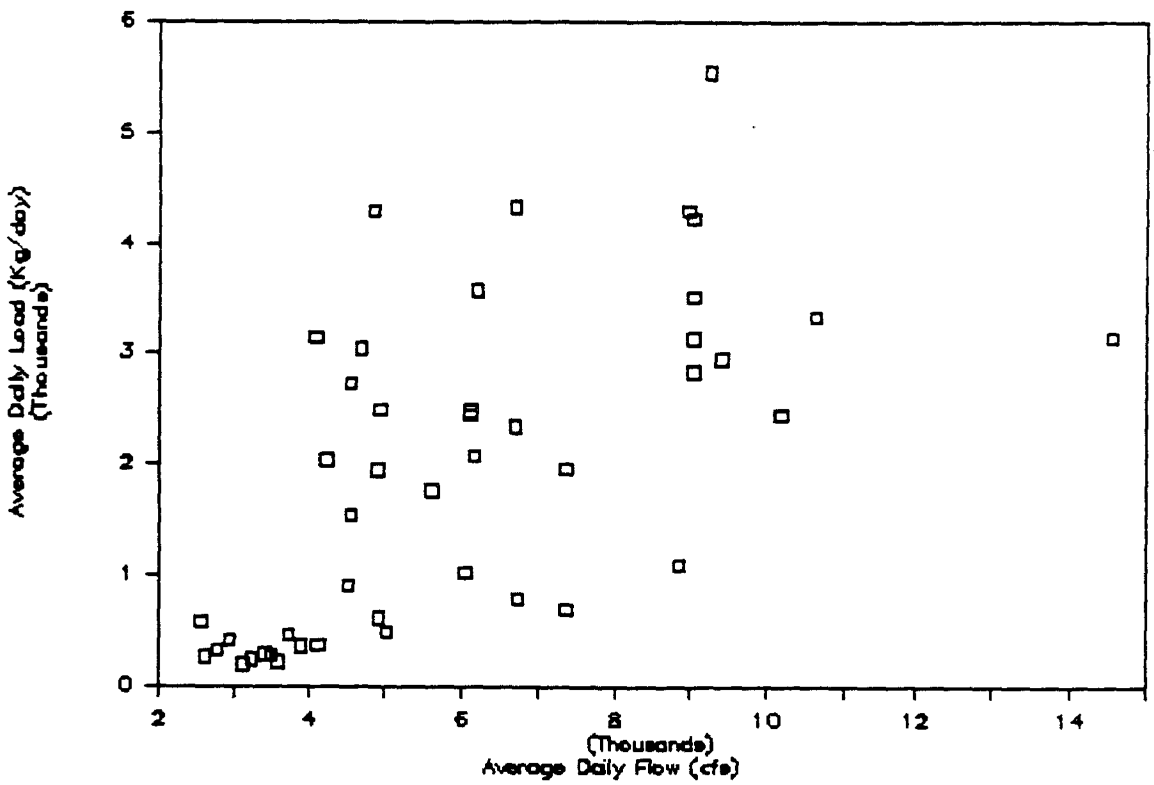
Average Daily Load of Potassium versus Average Daily Flow in the St. Joseph River (1984-1986).



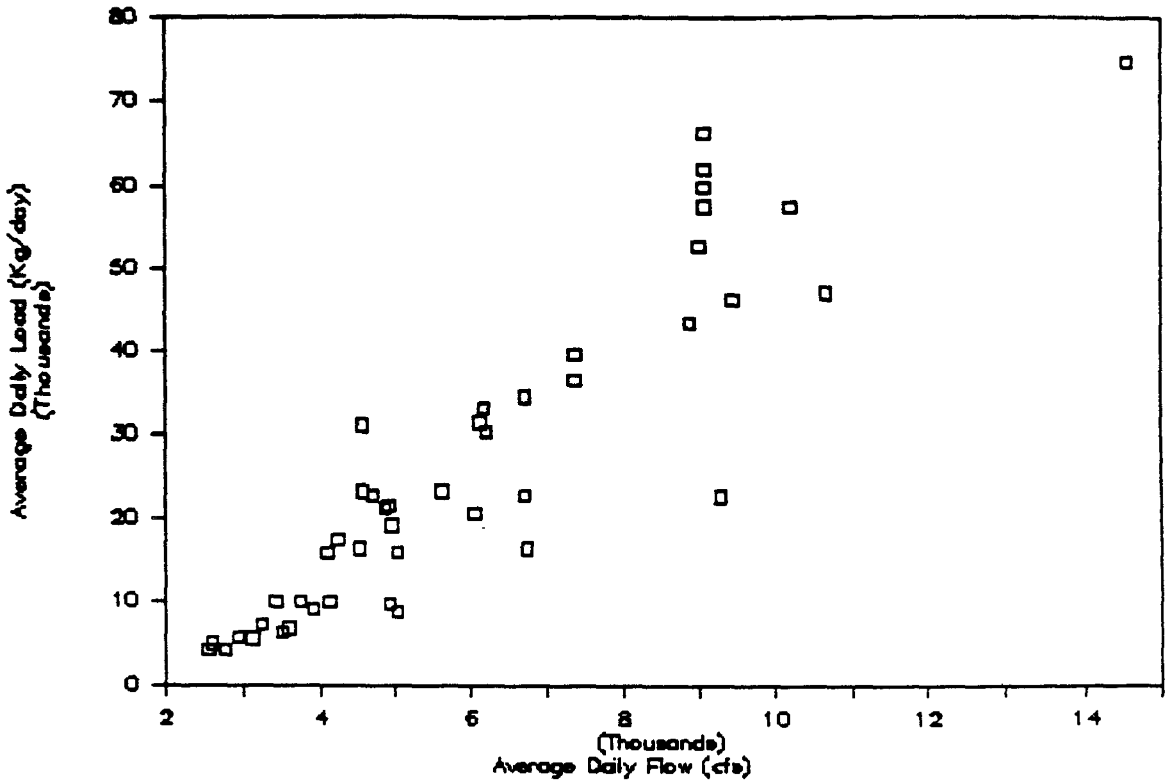
Average Daily Load of Magnesium versus Average Daily Flow in the St. Joseph River (1984-1986).



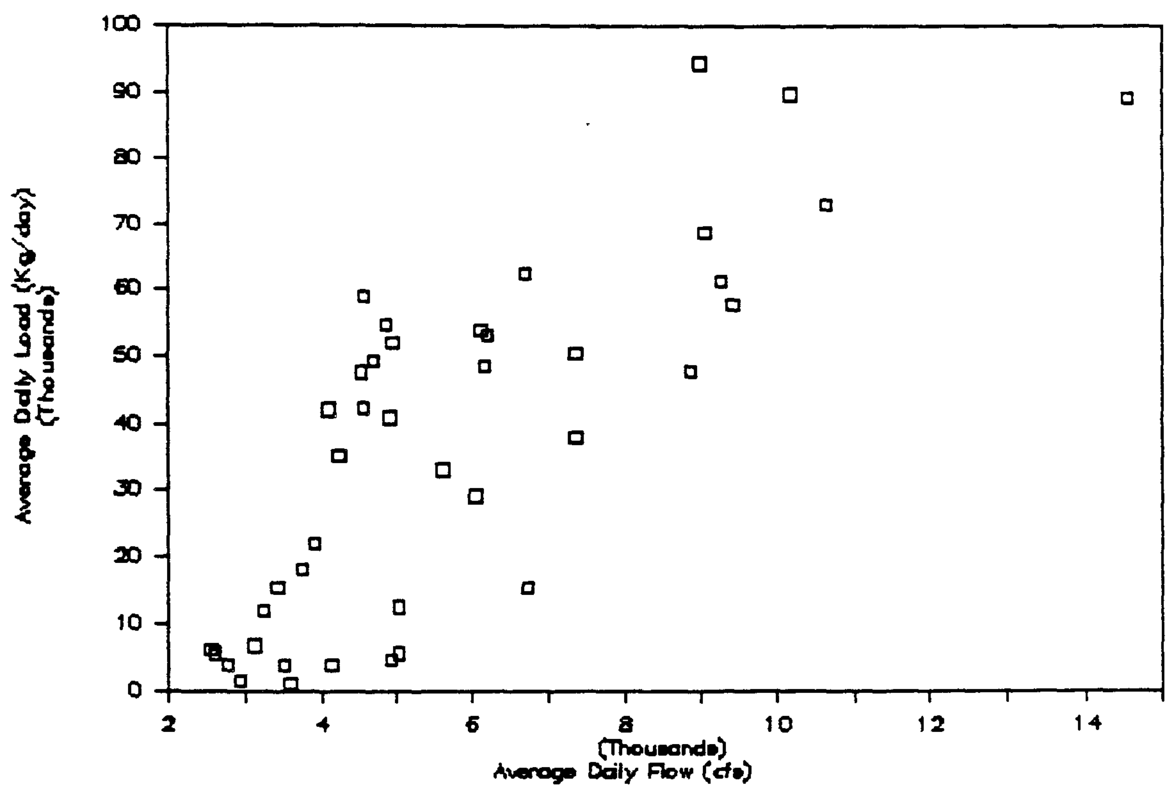
Average Daily Load of Sodium versus Average Daily Flow in the St. Joseph River (1984-1986).



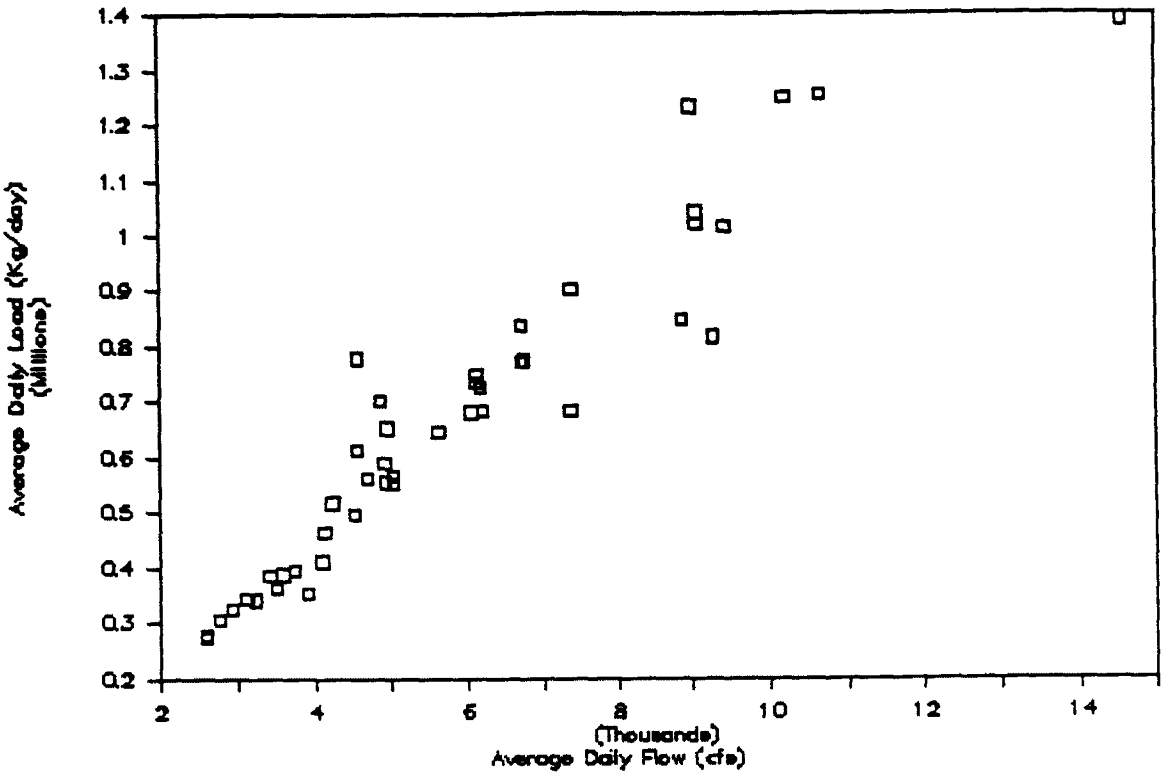
Average Daily Load of Ammonia versus Average Daily Flow in the St. Joseph River (1984-1986).



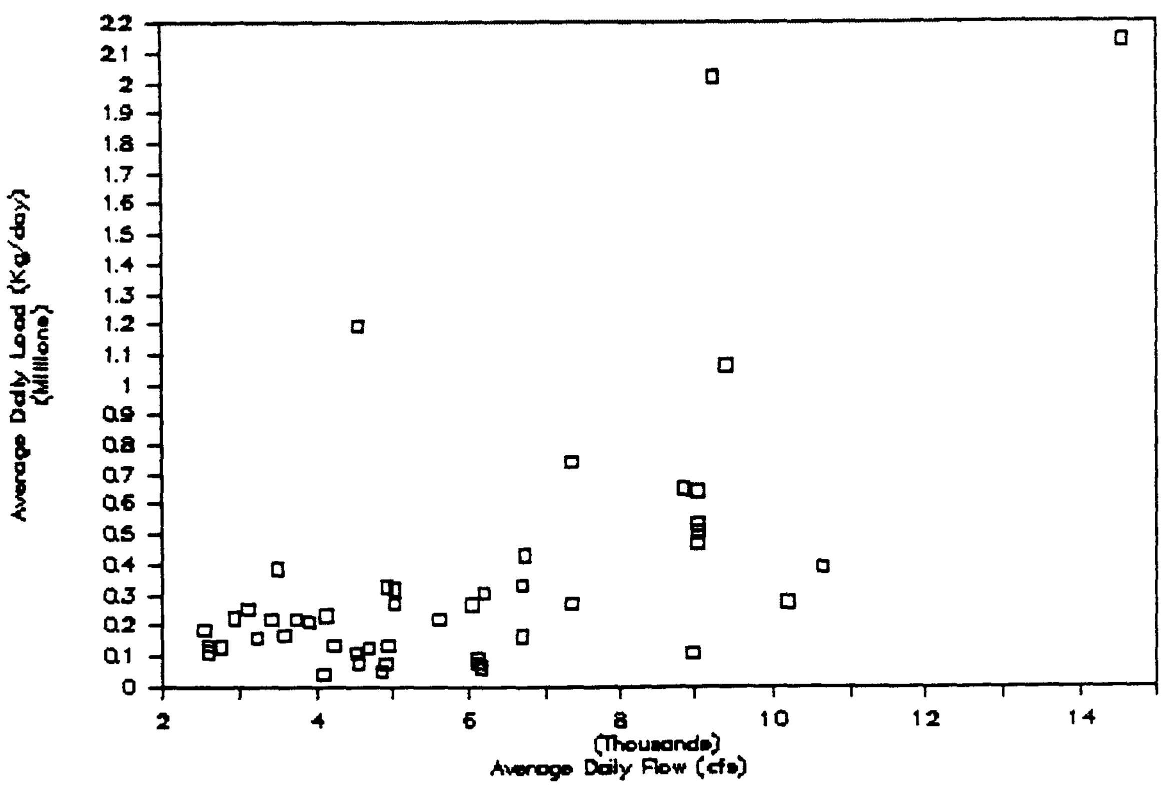
Average Daily Load of Nitrate versus Average Daily Flow in the St. Joseph River (1984-1986).



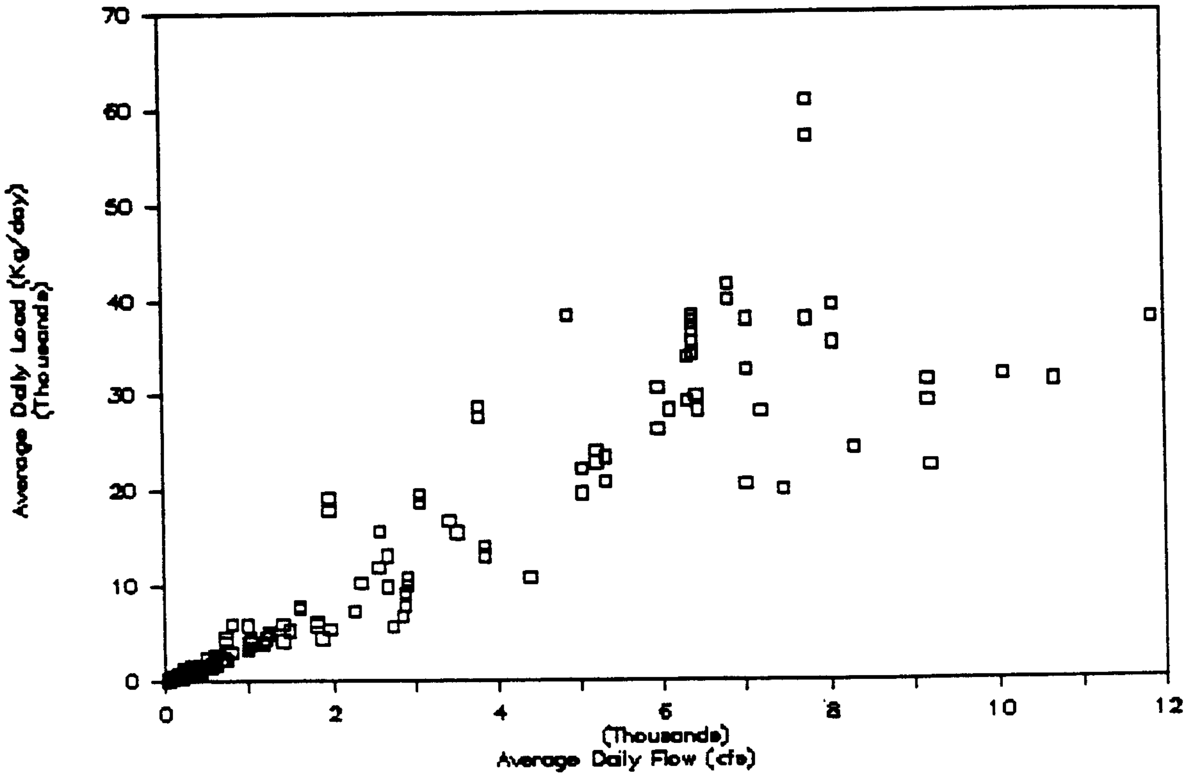
Average Daily Load of Silicate versus Average Daily Flow in the St. Joseph River (1984-1986).



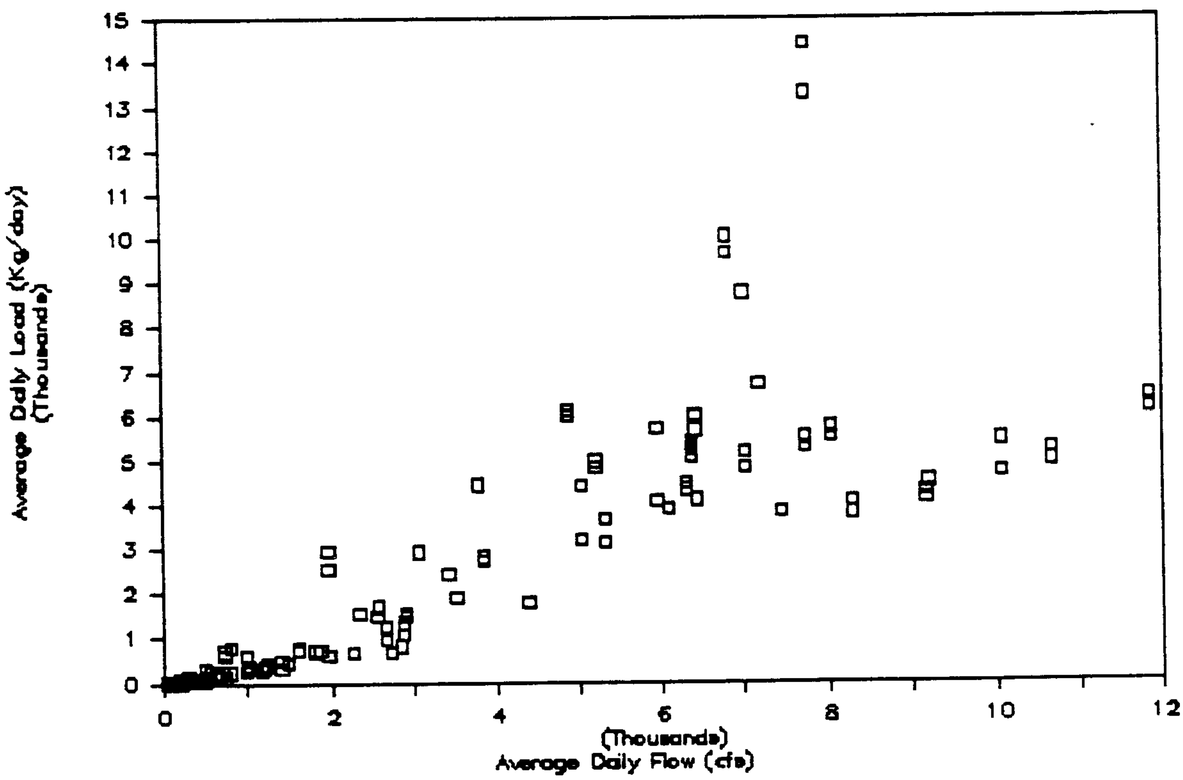
Average Daily Load of Sulfate versus Average Daily Flow in the St. Joseph River (1984-1986).



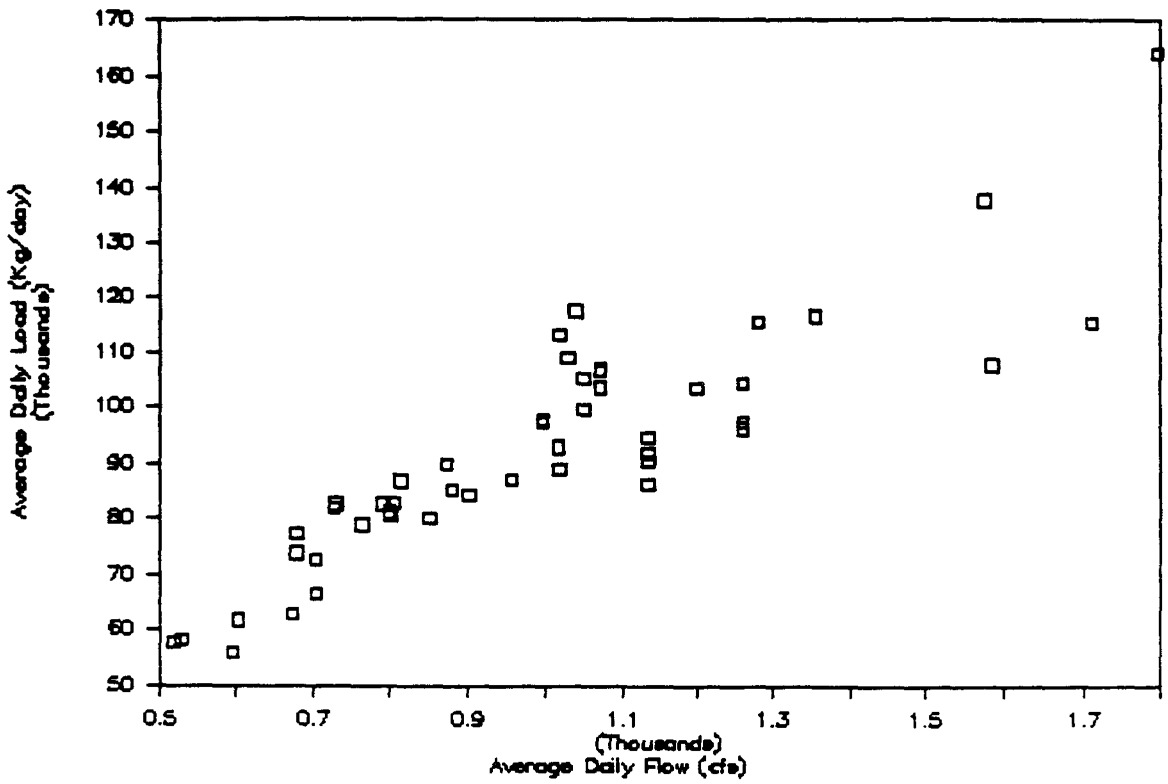
Average Daily Load of Suspended Solids versus Average Daily Flow in the St. Joseph River (1984-1986).



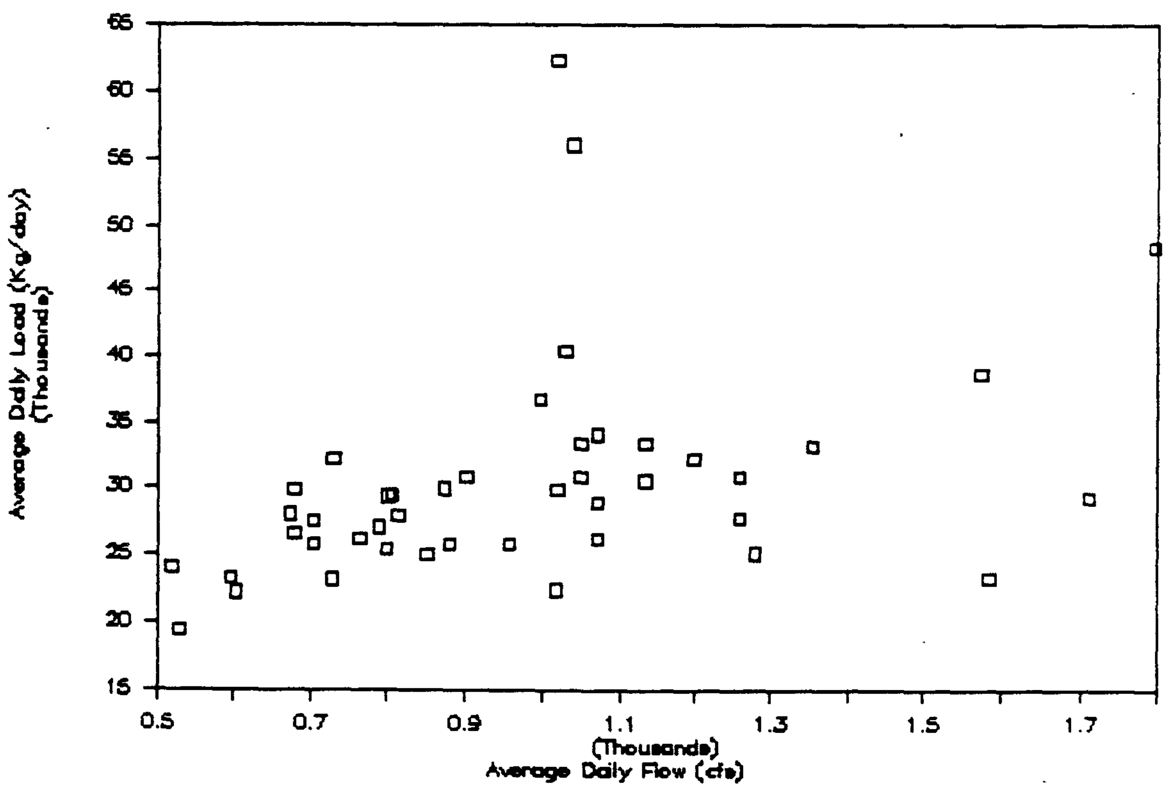
Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the St. Joseph River (1984-1986).



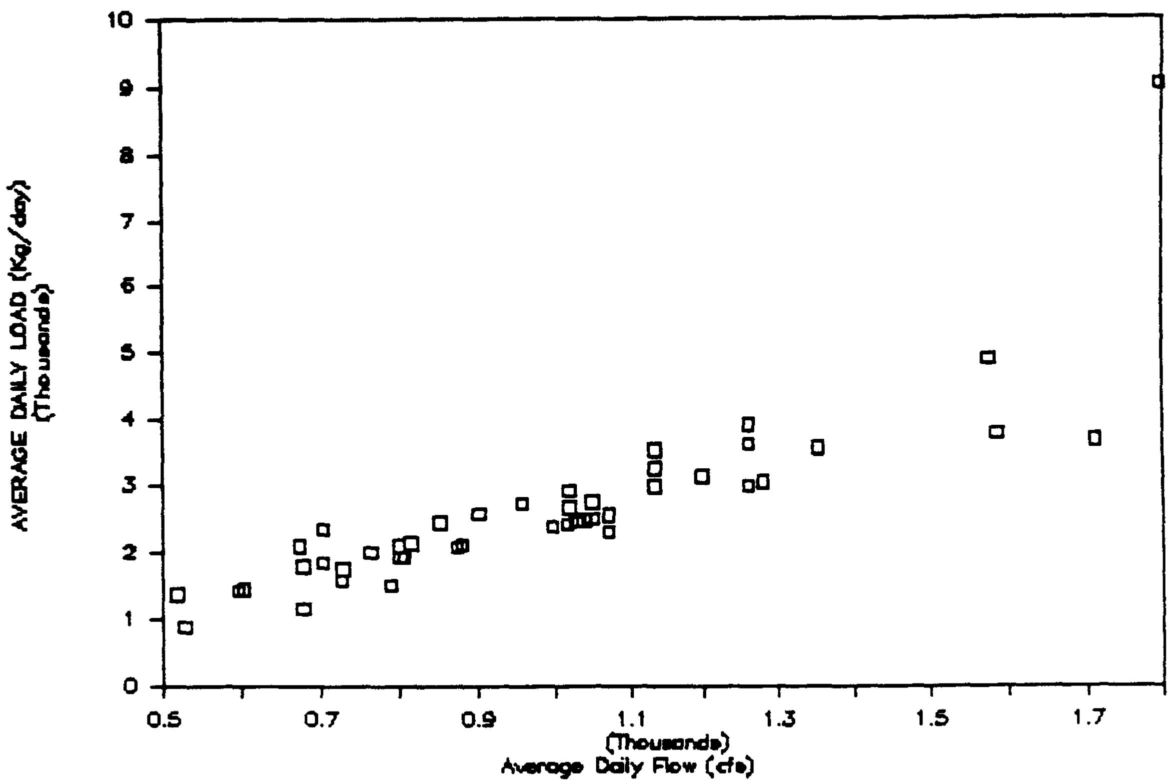
Average Daily Load of Total Phosphorus versus Average Daily Flow in the St. Joseph River (1984-1986).



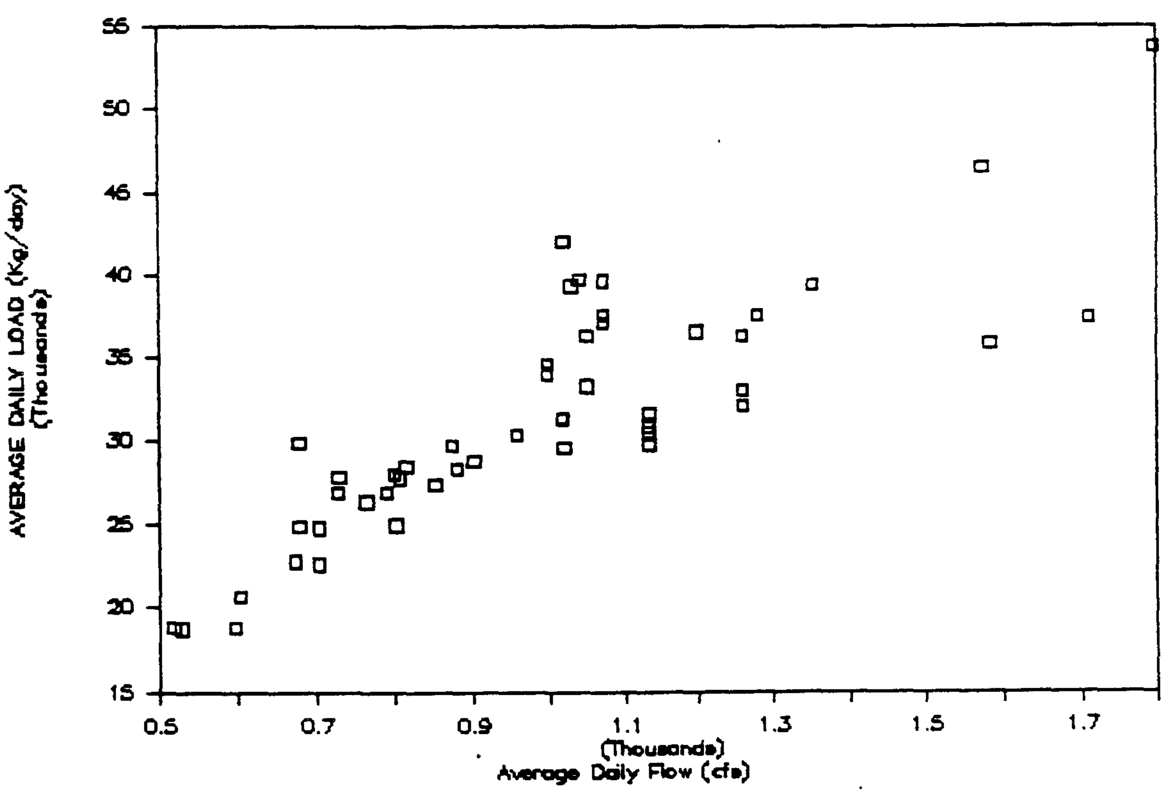
Average Daily Load of Calcium versus Average Daily Flow in the Pere Marquette River (1984).



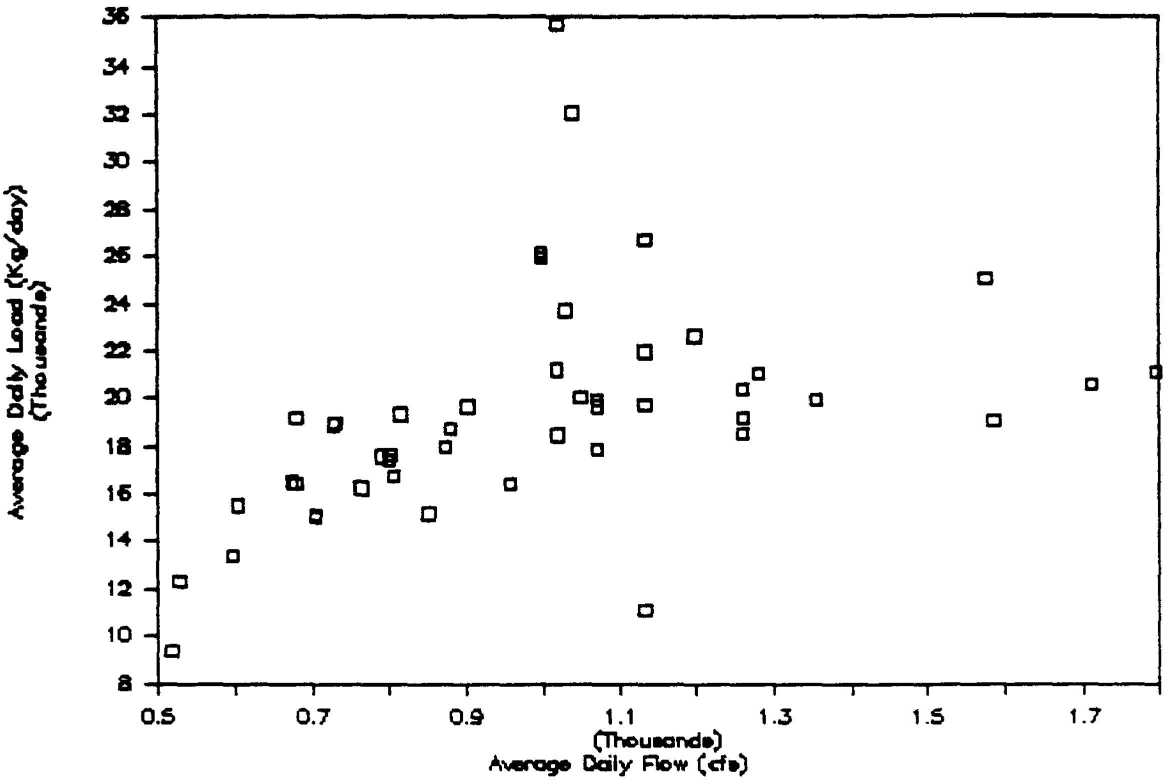
Average Daily Load of Chloride versus Average Daily Flow in the Pere Marquette River (1984).



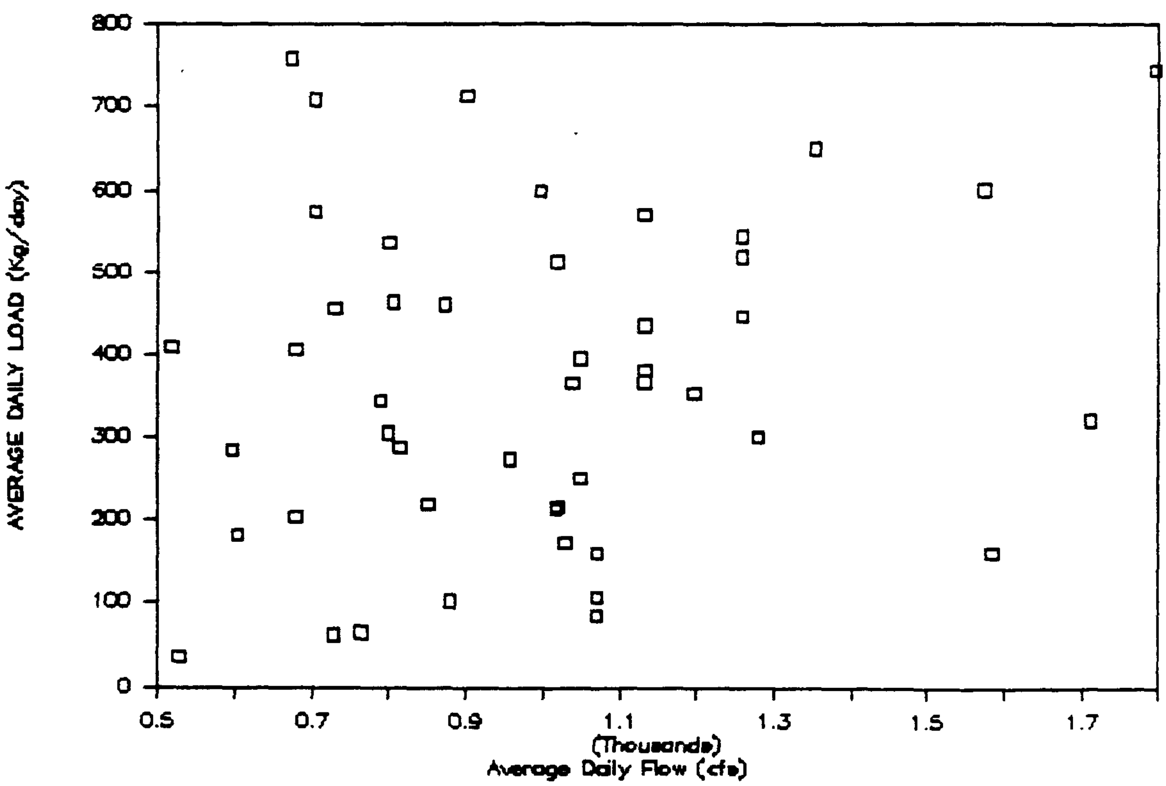
Average Daily Load of Potassium versus Average Daily Flow in the Pere Marquette River (1984).



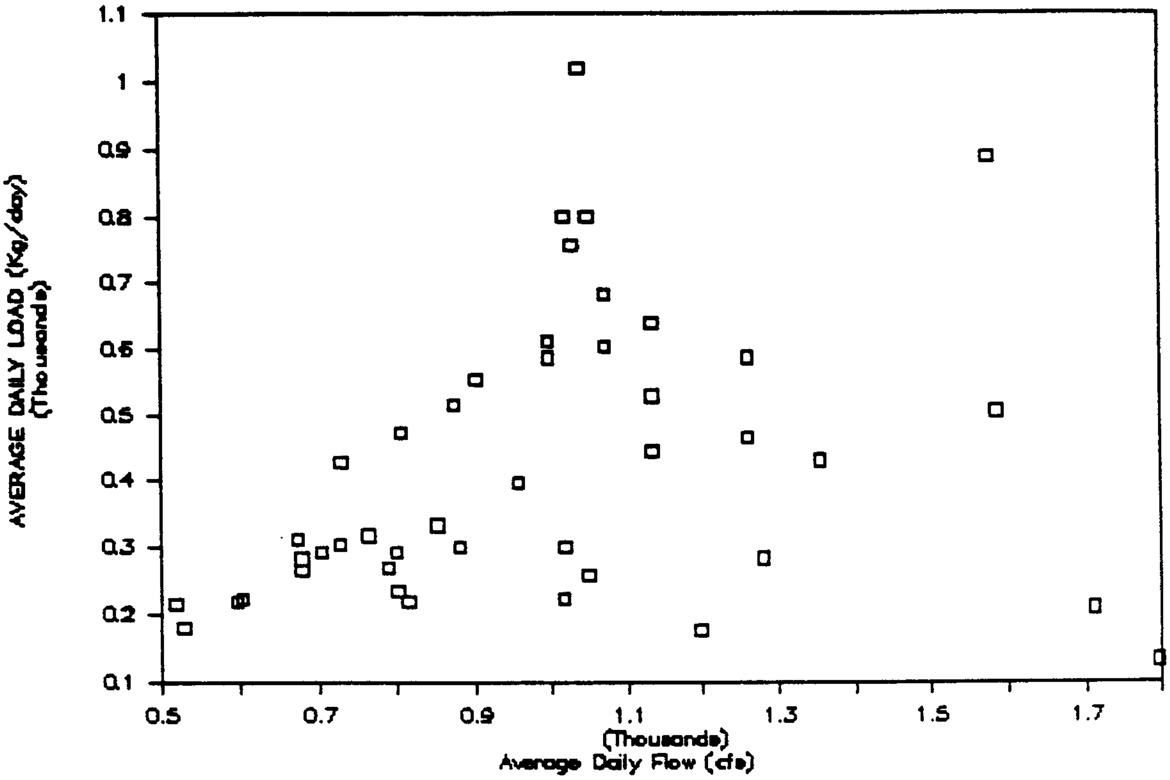
Average Daily Load of Magnesium versus Average Daily Flow in the Pere Marquette River (1984).



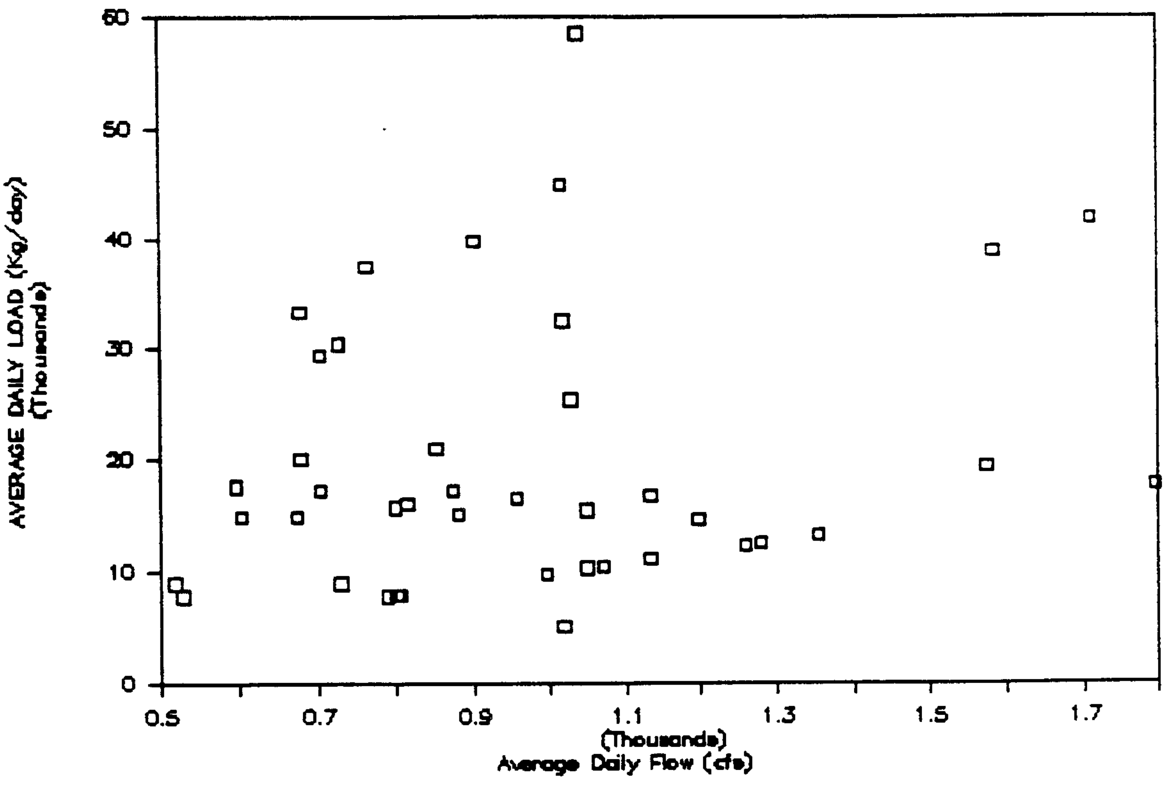
Average Daily Load of Sodium versus Average Daily Flow in the Pere Marquette River (1984).



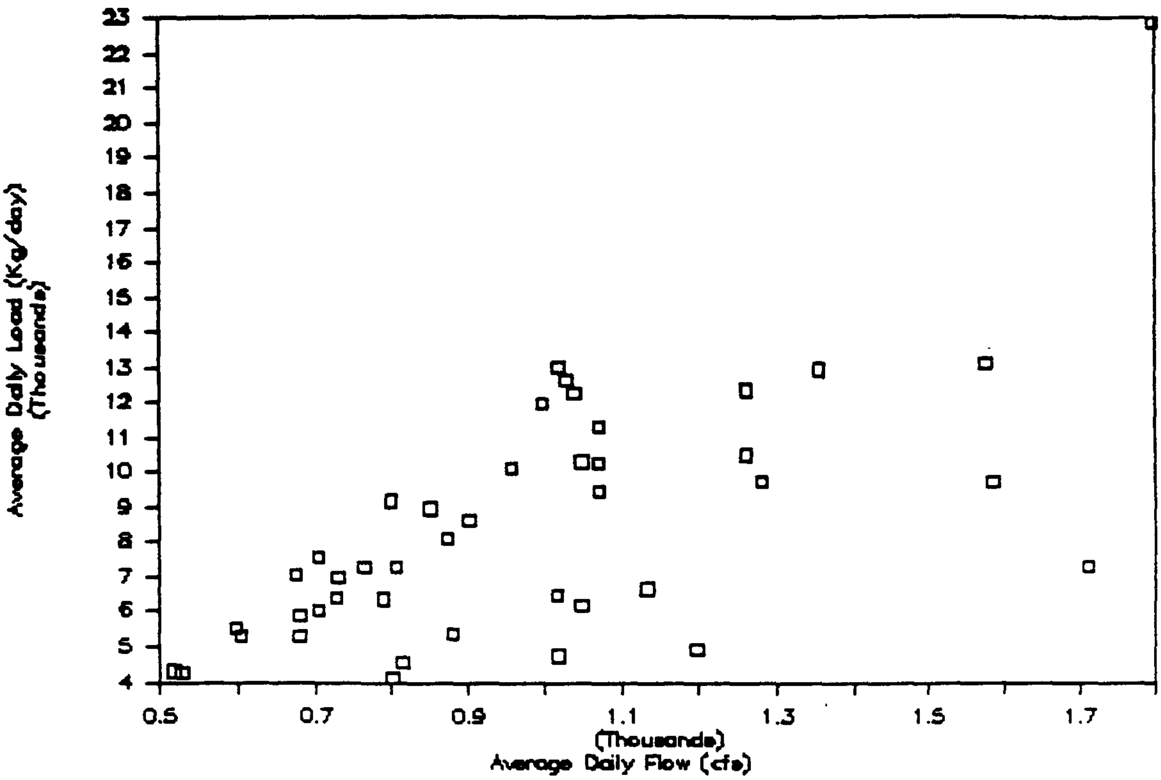
Average Daily Load of Ammonia versus Average Daily Flow in the Pere Marquette River (1984).



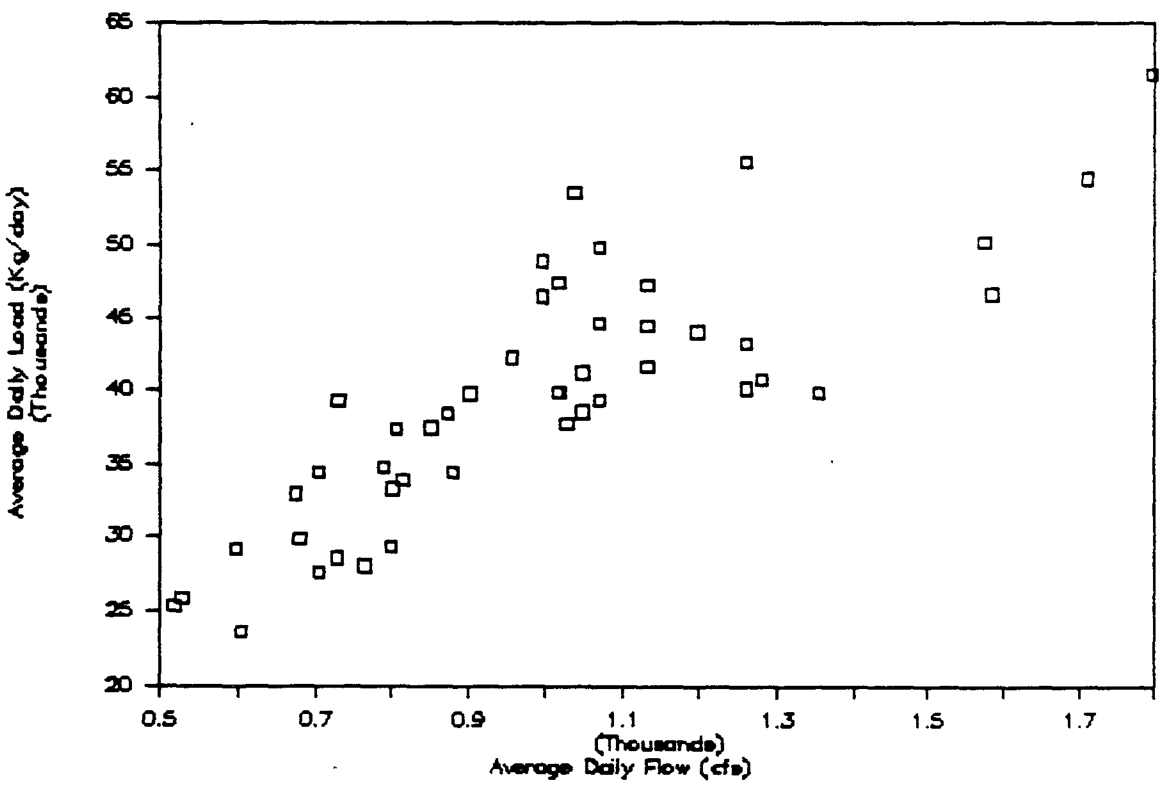
Average Daily Load of Nitrate versus Average Daily Flow in the Pere Marquette River (1984).



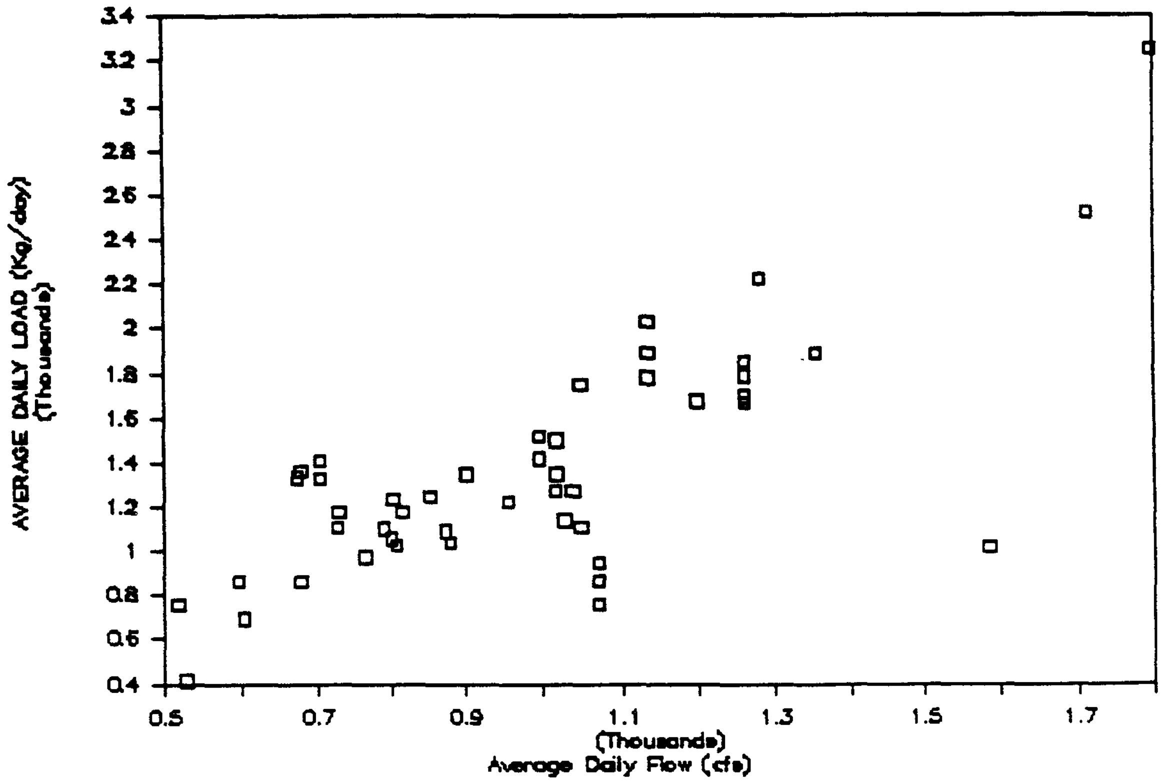
Average Daily Load of Suspended Solids versus Average Daily Flow in the Pere Marquette River (1984).



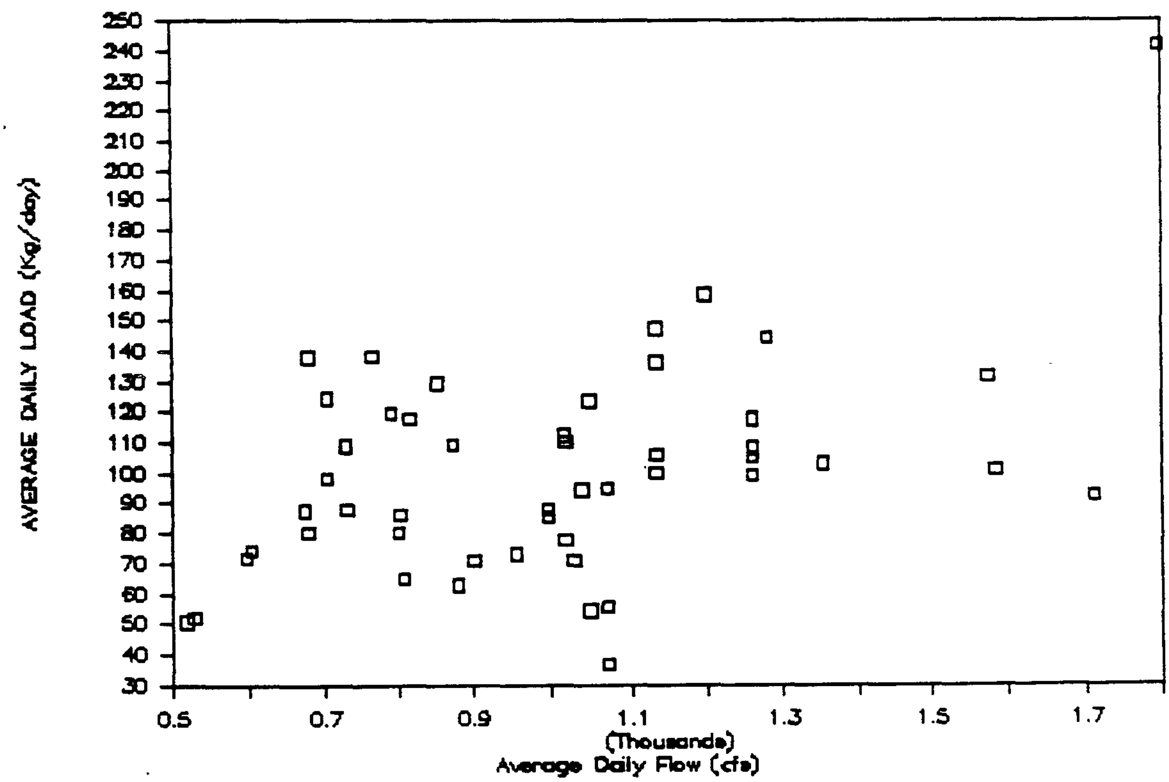
Average Daily Load of Sulfate versus Average Daily Flow in the Pere Marquette River (1984).



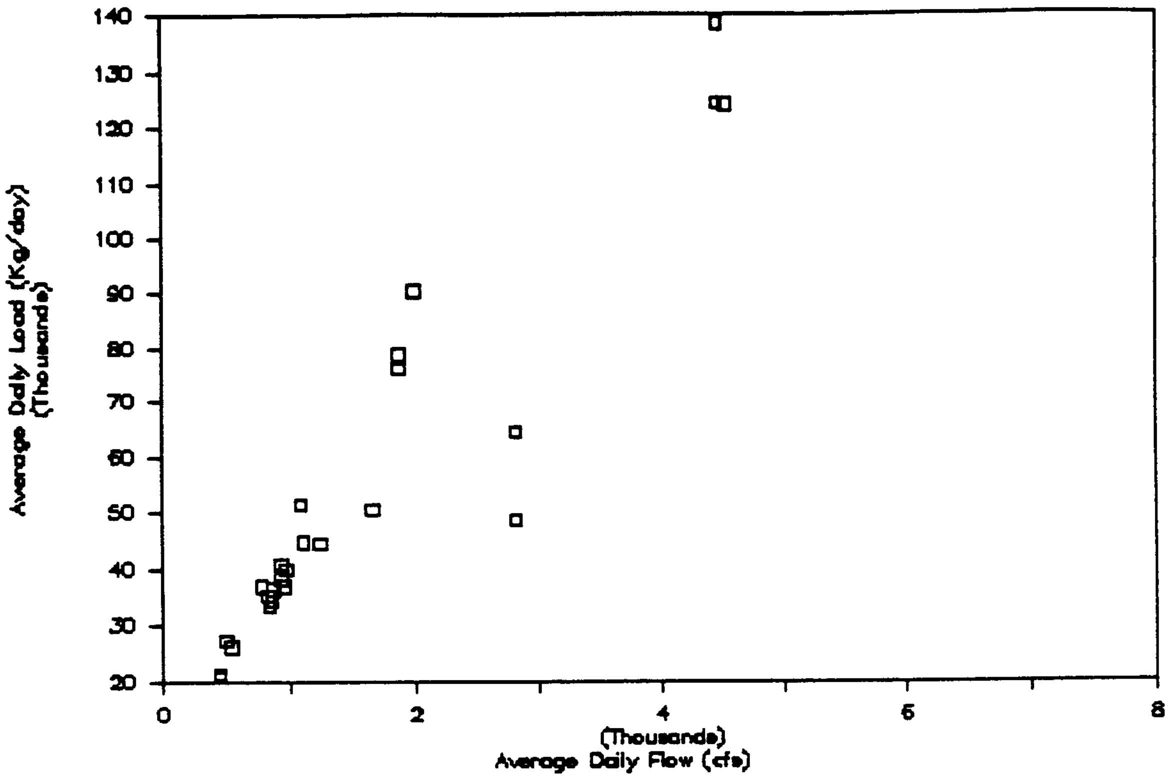
Average Daily Load of Silica versus Average Daily Flow in the Pere Marquette River (1984).



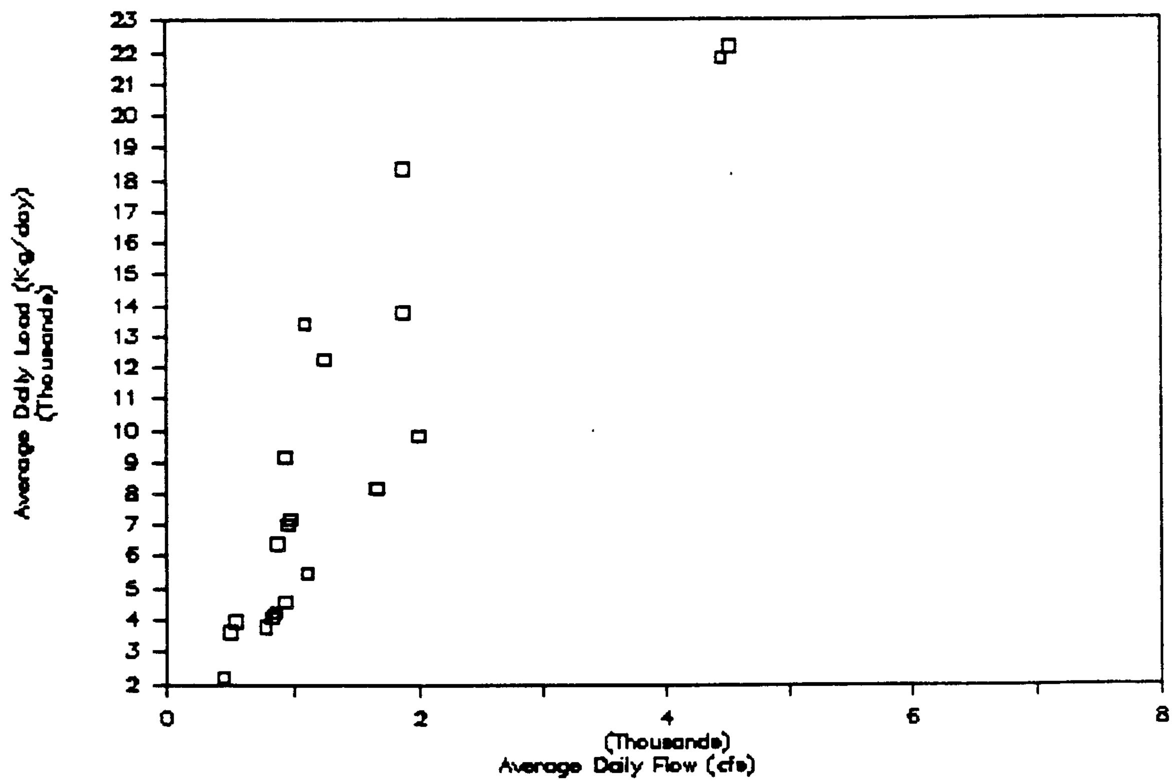
Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the Pere Marquette River (1984).



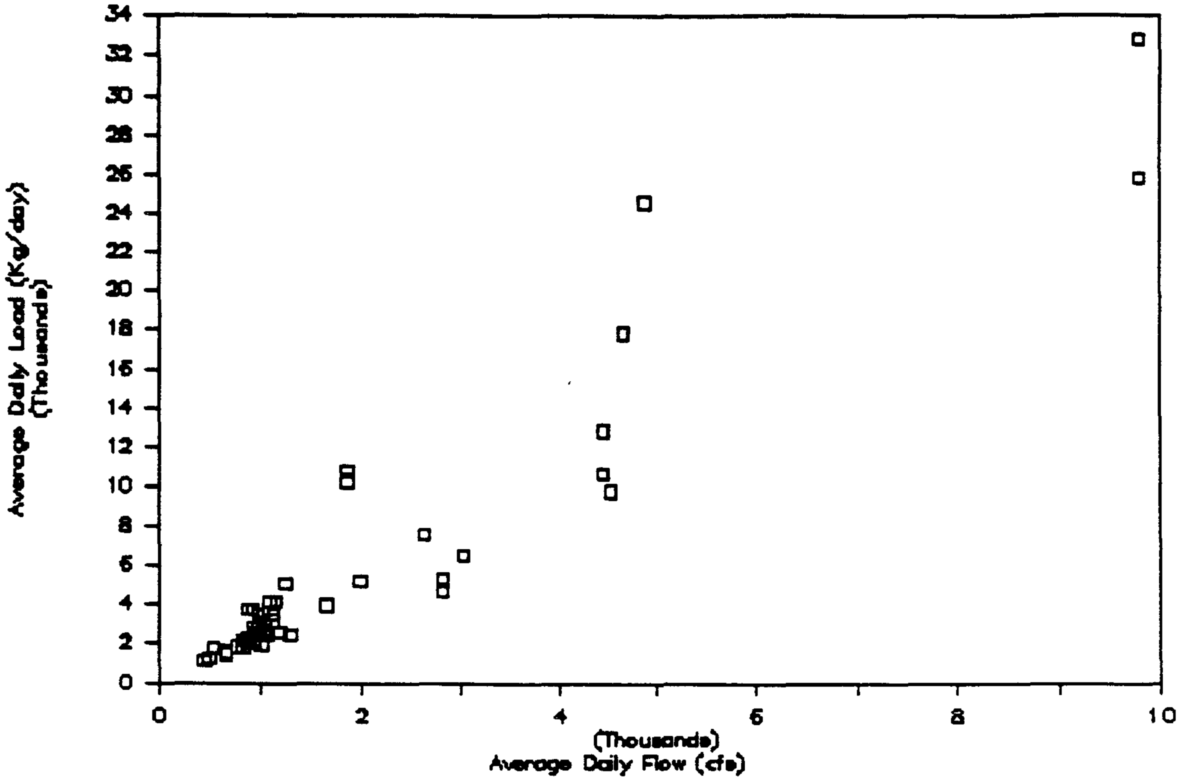
Average Daily Load of Total Phosphorus versus Average Daily Flow in the Pere Marquette River (1984).



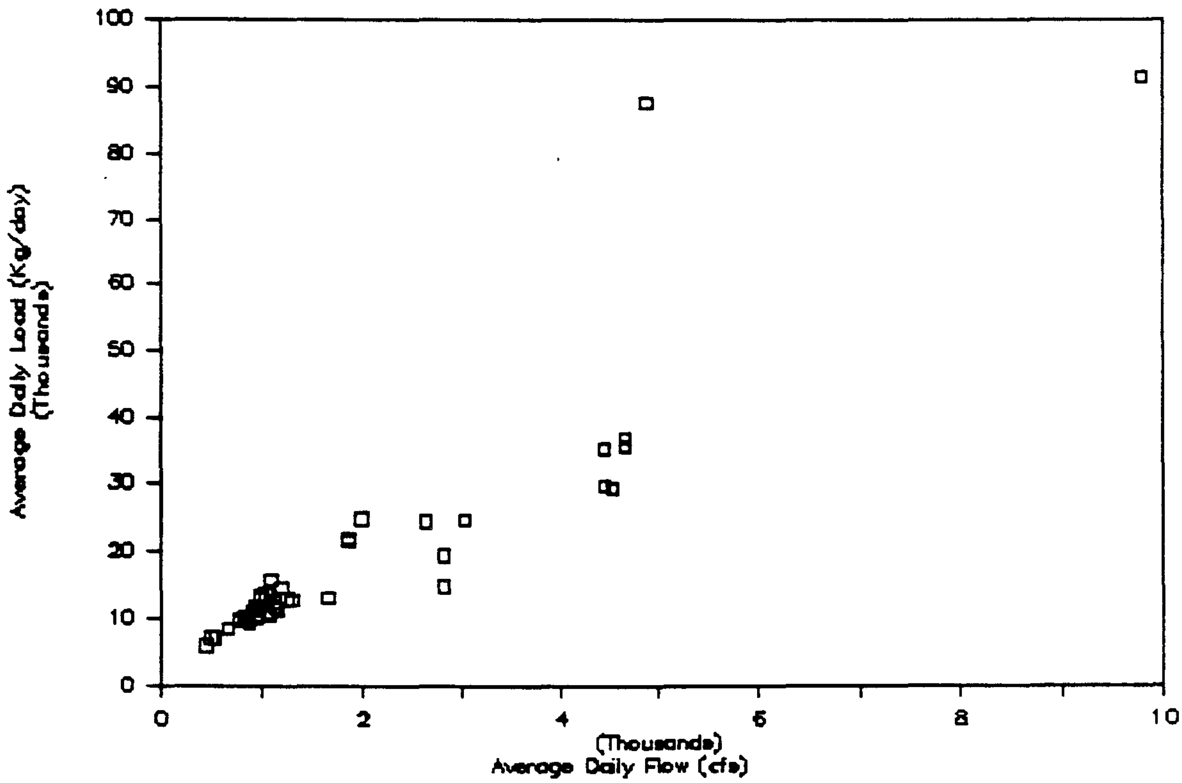
Average Daily Load of Calcium versus Average Daily Flow in the Ontonagon River (1984).



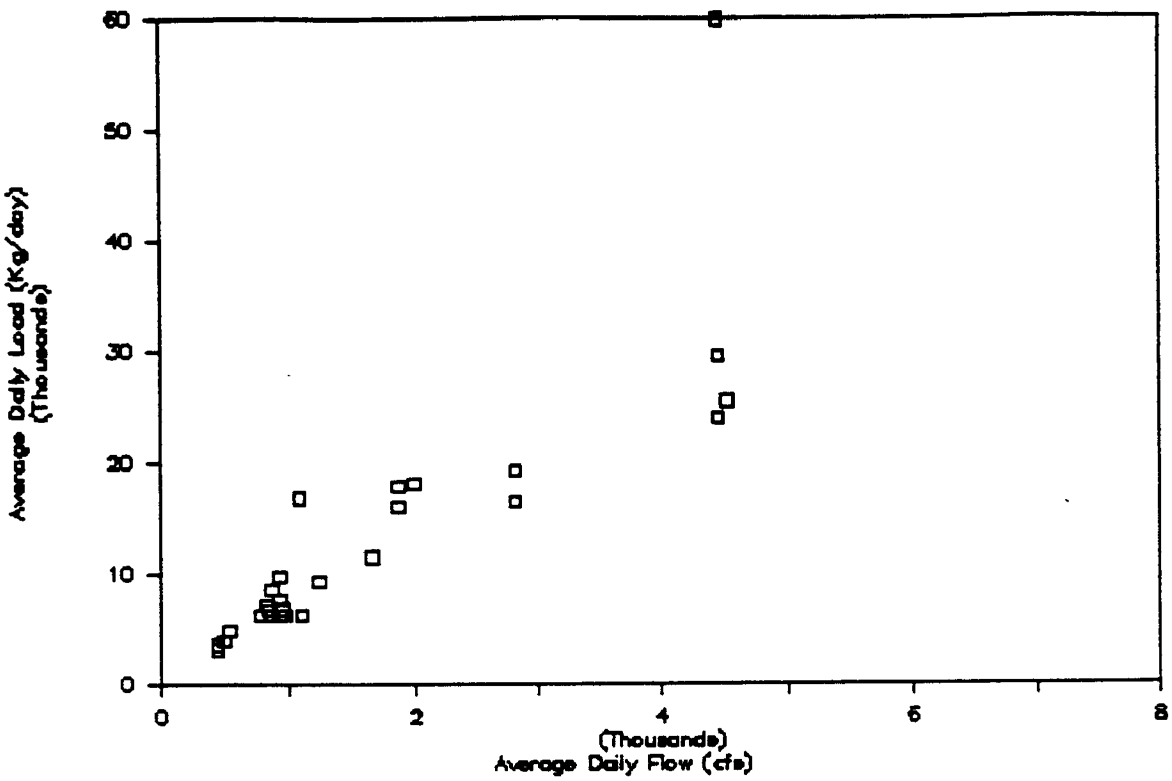
Average Daily Load of Chloride versus Average Daily Flow in the Ontonagon River (1984).



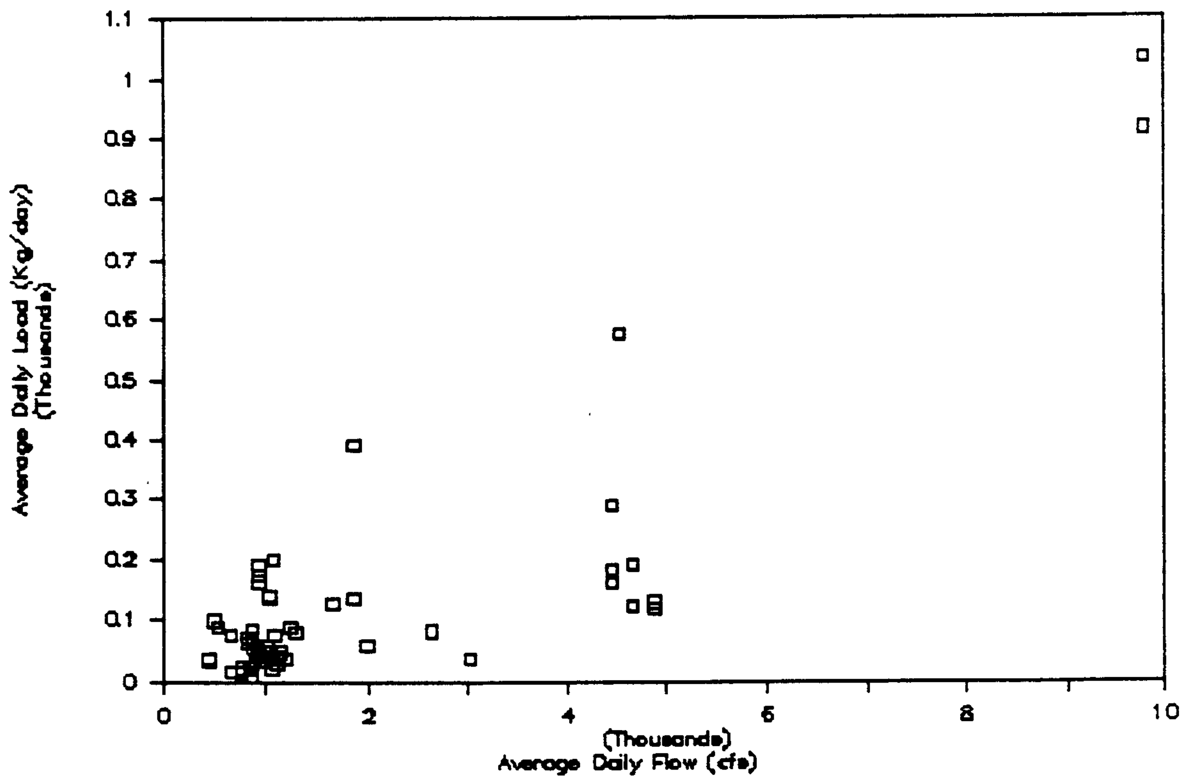
Average Daily Load of Potassium versus Average Daily Flow in the Ontonagon River (1984).



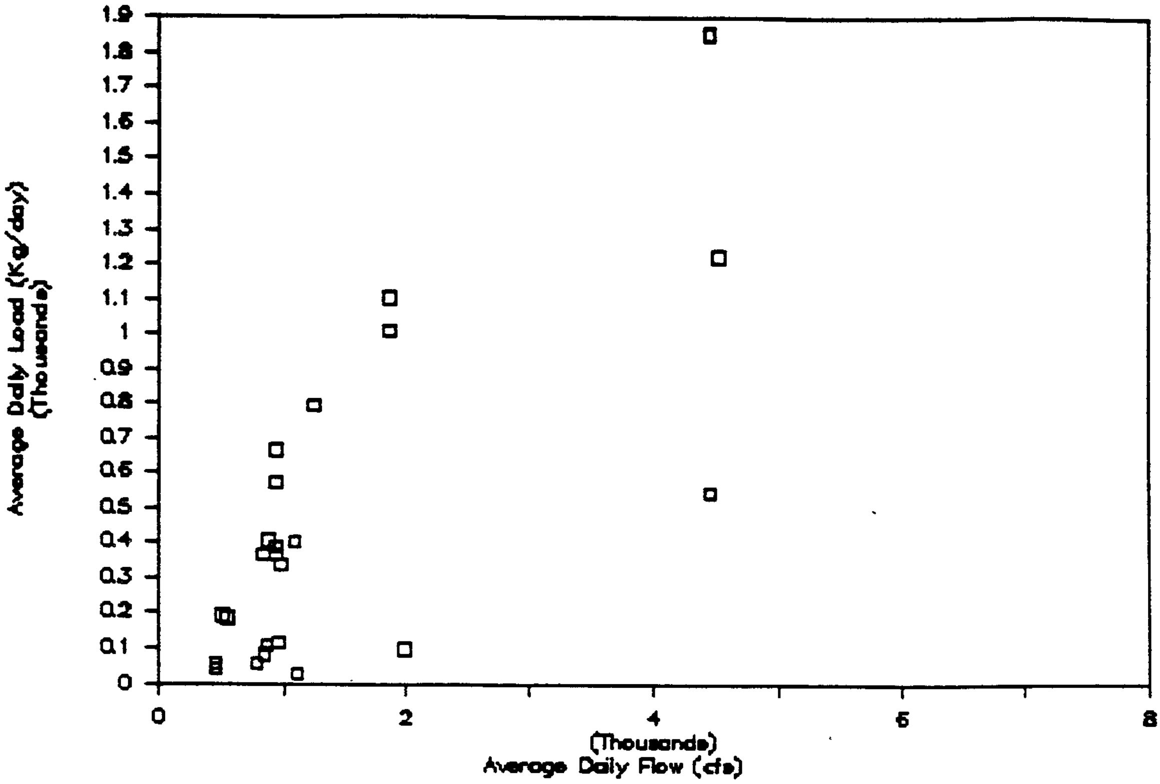
Average Daily Load of Magnesium versus Average Daily Flow in the Ontonagon River (1984).



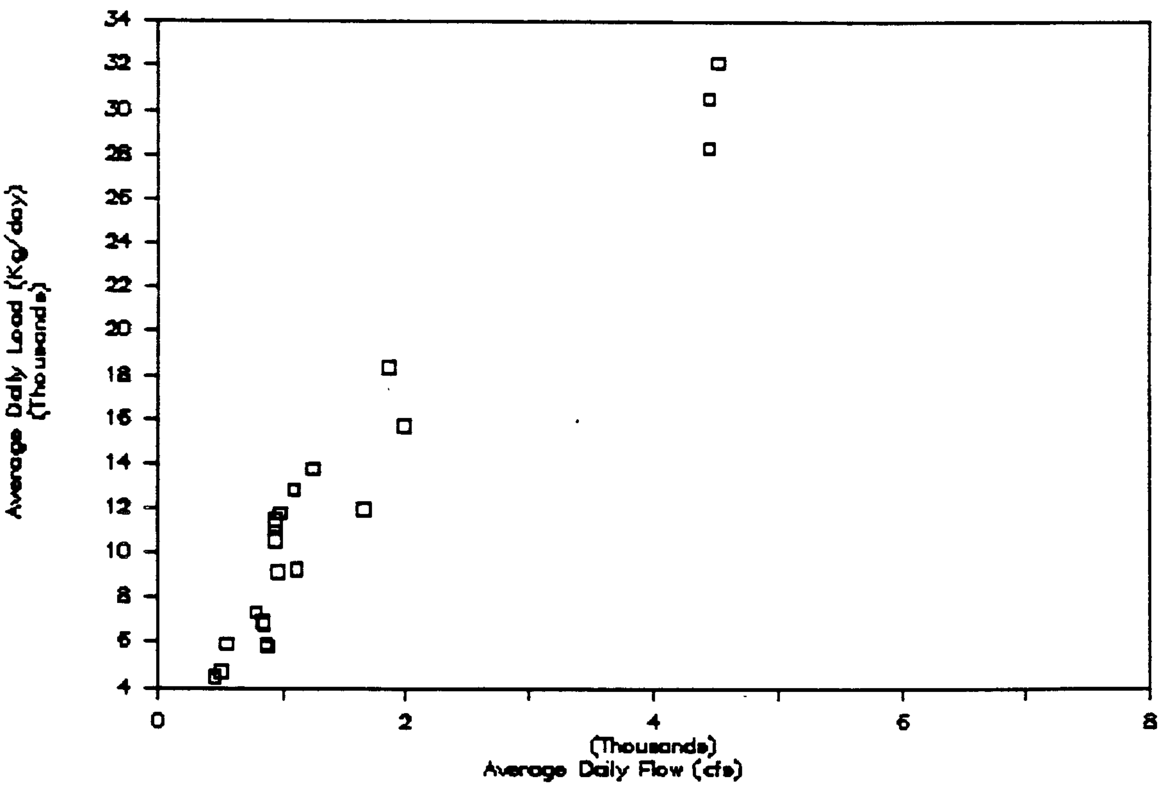
Average Daily Load of Sodium versus Average Daily Flow in the Ontonagon River (1984).



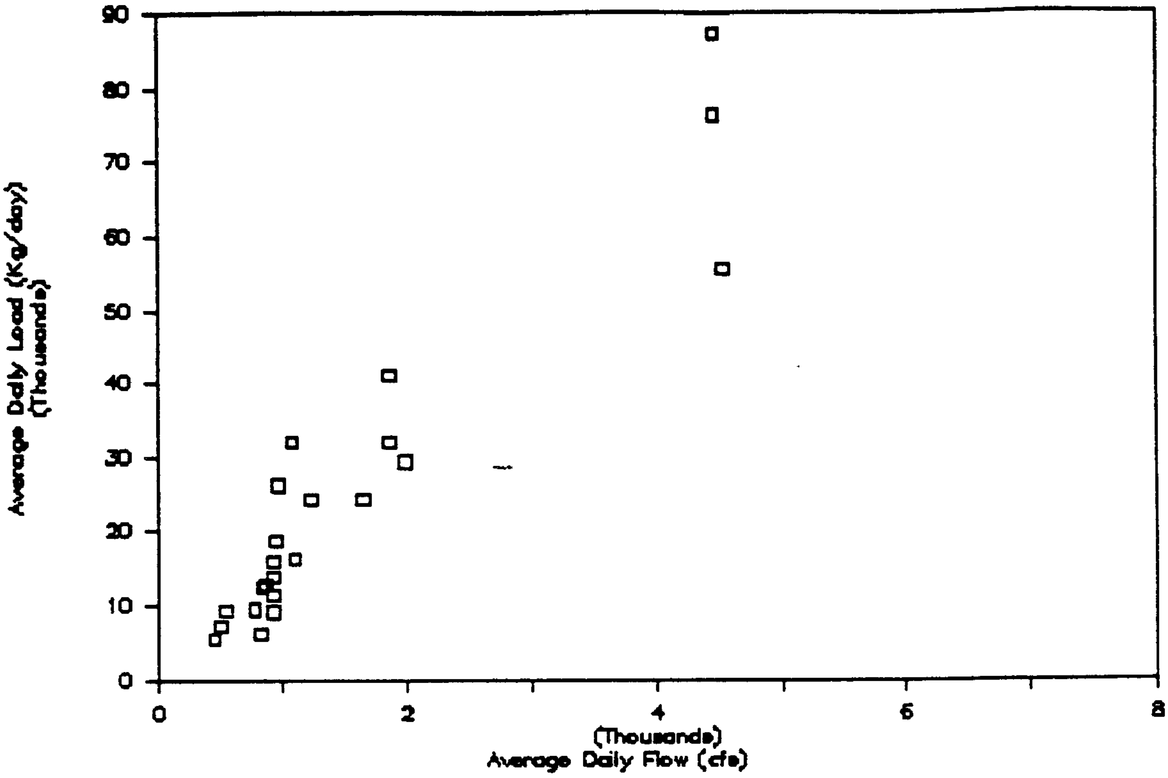
Average Daily Load of Ammonia versus Average Daily Flow in the Ontonagon River (1984).



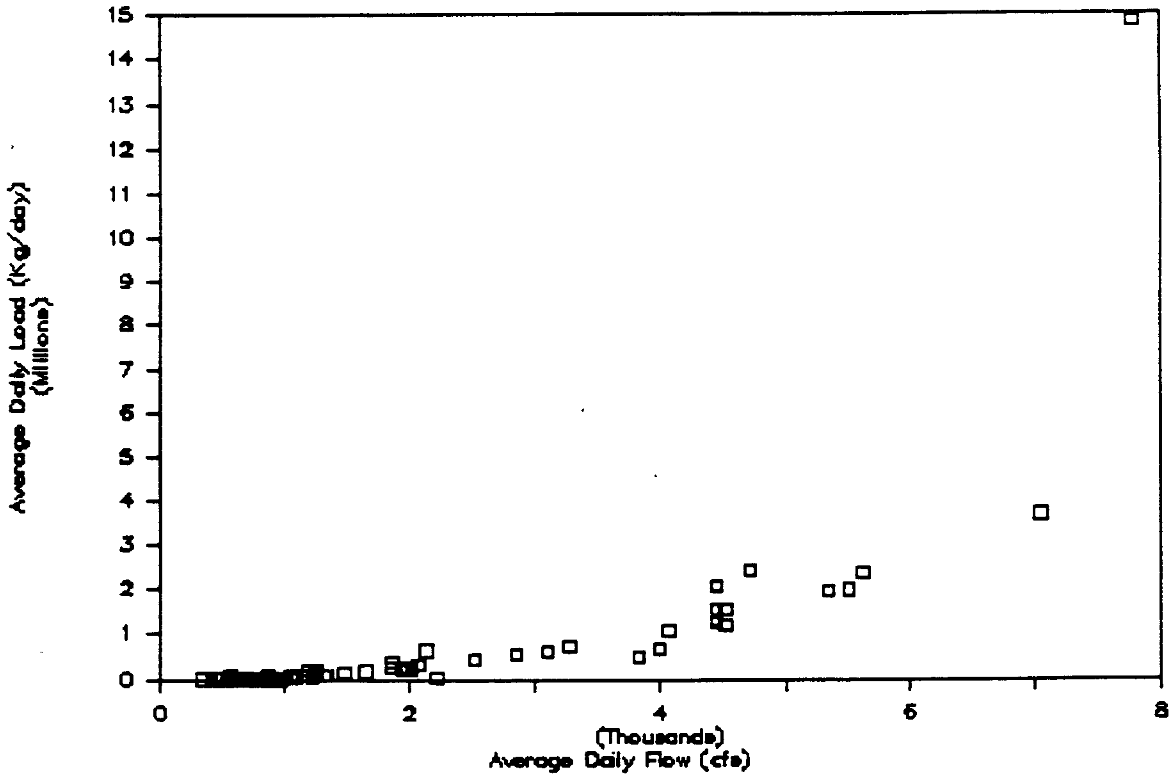
Average Daily Load of Nitrate versus Average Daily Flow in the Ontonagon River (1984).



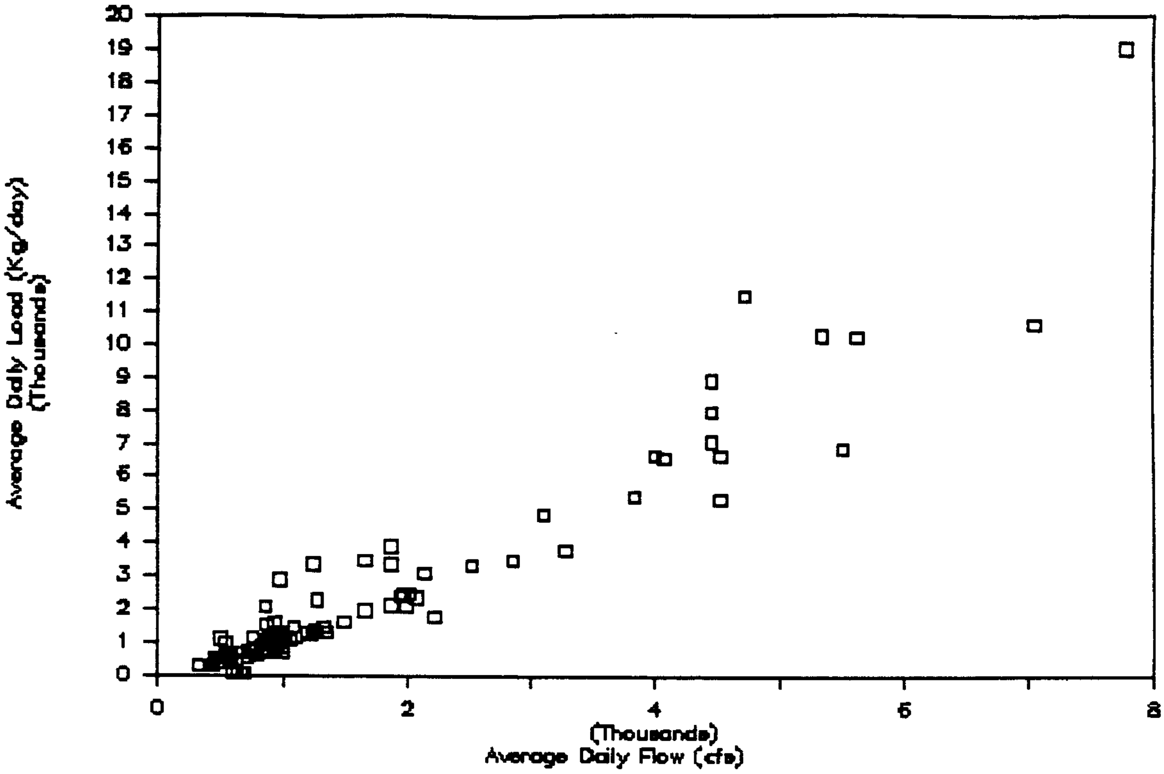
Average Daily Load of Silicon versus Average Daily Flow in the Ontonagon River (1984).



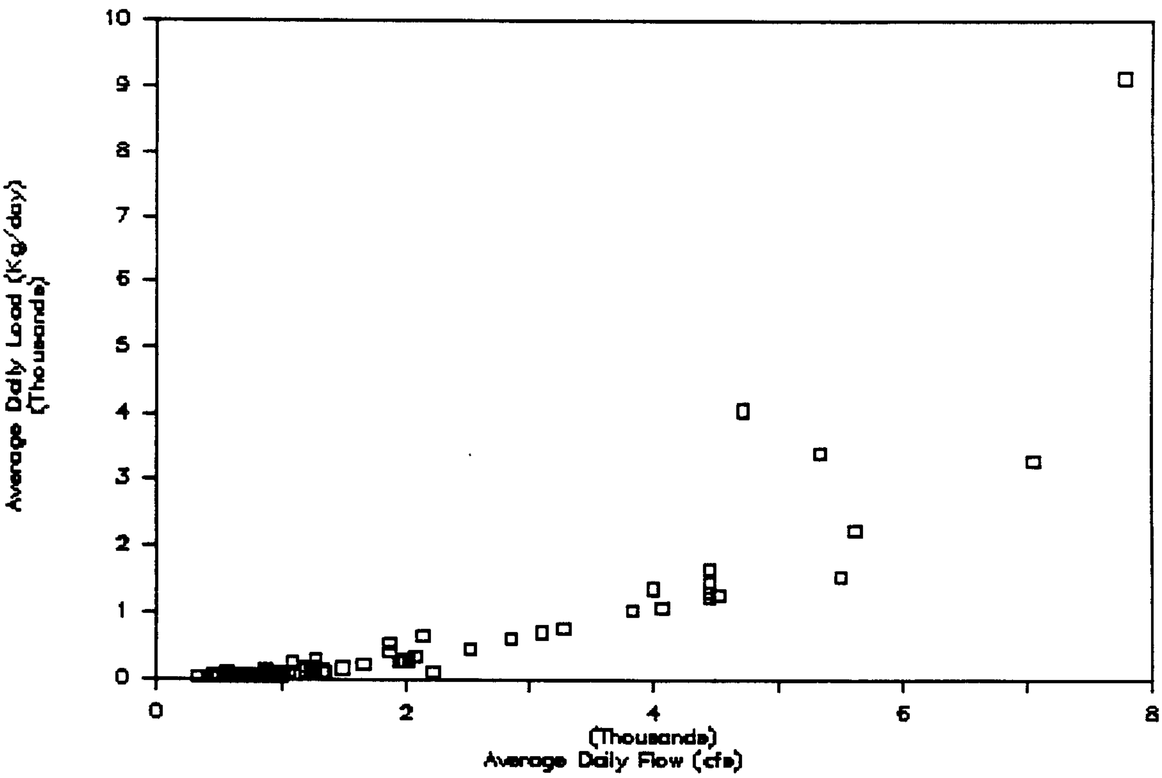
Average Daily Load of Sulfate versus Average Daily Flow in the Ontonagon River (1984).



Average Daily Load of Suspended Solids versus Average Daily Flow in the Ontonagon River (1984).



Average Daily Load of Total Kjeldahl Nitrogen versus Average Daily Flow in the Ontonagon River (1984).



Average Daily Load of Total Phosphorus versus Average Daily Flow in the Ontonagon River (1984).