METROPOLITAN COUNCIL REPORT

Water Resources Management: NONPOINT SOURCE POLLUTION TECHNICAL REPORT

MAY 1982

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Nonpoint Source Pollution Technical Report

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FOREWORD

This report was prepared by Gary L. Oberts, senior environmental planner with the Metropolitan Council. Robin G. Brown and Mark A. Ayers of the U.S. Geological Survey (USGS) assisted in data processing and analysis. The research was conducted with funds received from the U.S. Environmental Protection Agency through the 208 Water Quality Program. The USGS played a major role in this study in sample collection, data management and study result interpretation.

A technical advisory group reviewed the technical aspects of the Surface Water Management Plan.

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TABLE OF CONTENTS

APPENDICES

FIGURES

TABLES

I. SUMMARY

Nonpoint source pollution has been found to be a widespread and serious problem in the Metropolitan Area. Particularly impacted are the Region's lakes and secondary streams. These conclusions were reached after a year-long study of the character of nonpoint pollution generated in urban and rural areas.

The actual runoff monitoring program consisted of precipitation, runoff and water quality data collection at 17 sites located in both rural and urban watersheds. Subsequent modeling allowed for projection of this data in time and space over the entire Region. Additionally, the Council's natural resources program was responsible for a data collection program on 60 representative lakes during the 1980 field season.

Water quality data collected at the 17 sites show clearly that runoff from snowmelt and rainfall events is highly polluted or concentrated and that this pollution is impacting Area receiving streams. It was found that the total pollution load is primarily determined by the hydrology of the watershed, that is, runoff volume. Pollutant concentration is an important factor, but a highly concentrated runoff at a low volume actually contributes little in terms of total pollution load.

Seasons were found to be quite significant, especially for rural areas. Because quantity and quality are so intimately related, the loading behavior of watersheds is nearly identical to the hydrologic behavior of watersheds. In rural areas from 75 to 95 percent of most pollution loading occurs before the establishment of a good vegetative canopy, that is, during snowmelt and spring rainfall events. After vegetation becomes well established, runoff, and therefore loading, is negligible. Urban areas, however, respond not only to frequent snowmelt events, but also to essentially every rainfall event exceeding 0.10 inch. This results in urban area receiving waters getting numerous increments of pollution loading throughout the year. As a result of this major hydrologic difference between rural and urban areas, management approaches are different, as are pollutants of most concern.

Construction areas were found to be particularly high relative to solids and nutrients loading. Normalized loads from the two watersheds containing some construction areas were an order of magnitude larger than rural and most other urban sites. Proper management of construction site development and runoff minimizes the impact.

Limited data were also collected for the quality of precipitation. Little definitive can be said about atmospheric loading other than it appears to contribute a fair amount of nitrogen to total watershed loads, and a variable amount of phosphorus and lead. Atmospheric chloride appears to be minimal when compared to that applied on road surfaces.

The results of the 1980 lakes monitoring program showed that Metropolitan Area lakes are nearly all eutrophic, with most of these experiencing accelerated eutrophication due to loads from nonpoint sources. A one-time heavy metals sampling at surface and near bottom showed alarmingly high levels of metals occurring commonly in the sample lakes. The report concludes that reduction in nonpoint source loading is a necessary first step in a long-term lakes improvement program.

The 1980 runoff data was statistically expanded in time using the precipitation-runoff relationship and long-term U.S. Weather Bureau data. Once this hydrologic data was available, it was combined with the runoff-water quality relationships in statistical models and projected to unsampled watersheds. The results of the modeling exercise show that most watersheds are experiencing some degree of degradation from nonpoint sources, particularly from total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS) and chemical oxygen demand (COD).

The management approach found to be most reasonable for mitigating the impact of nonpoint source pollution is comprehensive stormwater management, supplemented by keeping developed urban area surfaces and drainage systems clean. A comprehensive stormwater management approach includes planning and implementation and could involve such things as detention, erosion control, farmland management and wetland preservation. In fully developed areas, retrofitting drainage systems is not economically feasible so attention has to be placed on keeping urban surfaces and drainage systems as clean as possible through accelerated housekeeping and control of organic and toxic pollutants. This report addresses preliminary management needs for each of the 44 secondary watersheds located within the Region.

This report summarizes the technical aspects of the 208 Nonpoint Source Program undertaken by the Metropolitan Council during 1980 and 1981. A companion report to this was prepared for the 1980 lakes data program (Metropolitan Council, 1981a) and supplemented by the 1981 lakes data (Metropolitan Council, 1982a). The lakes reports address the impact on the Region's 950 lakes resulting from nonpoint source pollution, while this report stresses the impact on streams and the overall nonpoint problem.

II. STUDY DESIGN

The purpose of the monitoring project undertaken in 1980 was to document the nature of the nonpoint source pollution problem in the Metropolitan Area. Essentially no in-depth analysis has ever been done on this problem in this Region. A great deal of routine data exists, but these are generally not directly applicable to nonpoint analysis because they are not related to flow events and not designed to collect representative seasonal samples.

Reference is made to a document that fully describes the runoff sampling and sample data analysis (Ayers et al., 1980). The lakes sampling that was conducted in 1980, and the results of that study, are described in detail in a Metropolitan Council report (Metropolitan Council, 1981a). These two sampling projects are summarized in this section. The 1981 lakes sampling results (Metropolitan Council, 1982a) support the 1980 conclusions; the analyses done in this technical report rely on the 1980 results.

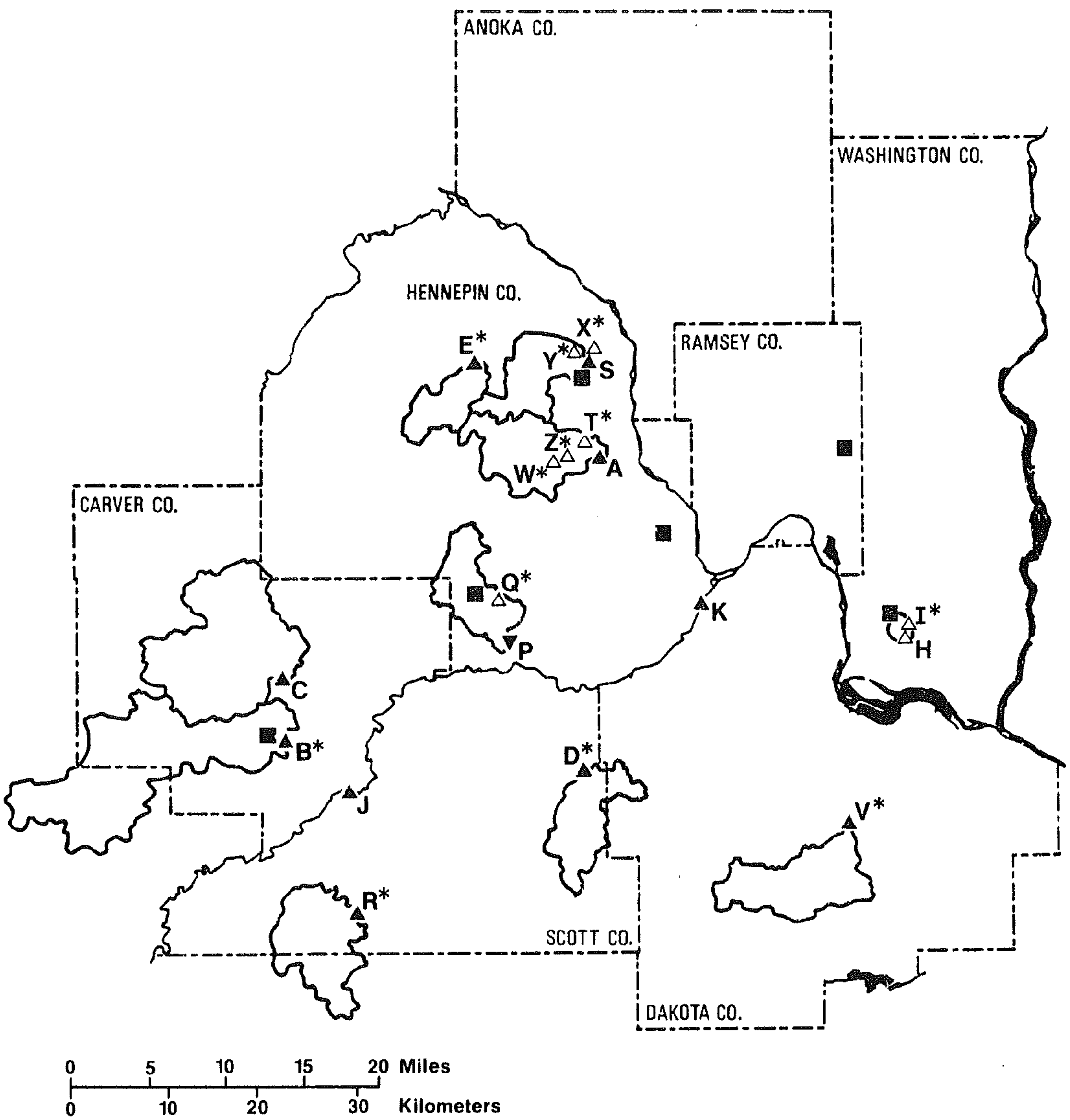
The runoff and lakes sampling program were conducted in unison because evidence seemed to indicate that the primary impact of runoff occurred on tributary streams and lakes (Metropolitan Council, 1979). The impacts of nonpoint pollution on major rivers will also be evaluated, but it is suspected that the real impacts will be most seriously felt by the smaller streams and lakes.

Table 1 summarizes the land use characteristics of the 17 runoff monitoring sites shown in Figure 1. Sites J and K, shown in Figure 1, were located on the Minnesota River for purposes of the point versus nonpont analysis; these sites will not be discussed with the other 17 sites. Table 2 gives some of the watershed characteristics of the monitored watersheds compiled from topographic maps and field visits. These 17 sites were chosen to represent the types of areas contributing to the nonpoint source problem in the Metropolitan Area. The agricultural sites have large drainage areas because the field-by-field variability and the management differences in each of the watersheds made separate field monitoring infeasible. Rather, an attempt was made to choose characteristic agricultural areas and monitor the in-stream responses to runoff. In the urban area, it was believed that monitoring storm sewers that drain areas characteristic of urban land uses would yield the best information when combined with several mainstem sites that integrate many land uses. It should be noted that most of the urban storm sewer watersheds are not homogeneous in land use, but are "representative" with one type of land use dominating in a mixed-use area. The other thing to note about the storm sewer watersheds is that the combined sewer areas of the central cities were not monitored. The Metropolitan Waste Control Commission (MWCC) has spent much money documenting the problems of the combined sewer overflow (CSO) areas and it was decided that our limited monitoring funds would be best spent in previously unmonitored areas. The monitoring results and program conclusions of the CSO program will be used in our final analyses.

Table 1
LAND USE CHARACTERISTICS OF THE RUNOFF MONITORING SITES
(For details see Ayers et al., 1980)

Site (Site letter, rural or urban)	Character
Bevens Creek (B,r)	Over 70 percent in farms; principally dairy or feedlot operations with support crops; headwaters largely wetlands; loamy soils.
Carver Creek (C,r)	Similar to Bevens except for higher wetlands and lakes concentrations.
Credit River (D,r)	25 to 50 percent in cash-crop farming; bottom of watershed in open space; many wetlands; loamy soils.
Elm Creek (E,r)	Under 25 percent farms; watershed in transition from agricultural to urban; generally bad practices on land; hobby farms; low gradient, many wetlands.
Raven Stream Tributary (R,r)	Similar to Bevens and Carver without lakes; fewer wetlands; agricultural activity same.
S. Fork Vermillion River (V,r)	Over 70 percent in farms; well-drained, sandy soils; few wetlands; highly irrigated; cash-cropping.
Bassett Creek (B,u)	Mainstem station on highly urbanized watershed; good detention pond system and many wetlands.
Shingle Creek (S,u)	Mainstem station in area urbanized later and at lower density than Bassett; fewer wetlands and lakes in system.
Purgatory Creek (P,u)	Mainstem station below Staring Lake; rapidly urbanizing; lakes, wetlands and detention storage common.
80th Street (H,u)	Storm sewer draining last of eight detention facilities in high-density subdivison in Cottage Grove.
Iverson Avenue (I,u)	Small basin draining new construction area of subdivision.
Estates Avenue (X,u)	Storm sewer draining medium- to high-density residential area of Brooklyn Park; one to 20 years old.
Yates Avenue (Y,u)	Storm sewer draining residential area in Brooklyn Park except mixed with multifamily and commercial.
Hwy. 100 (T,u)	Storm sewer draining high-density residential area of Golden Valley; major highway bisecting watershed; developed 20 to 40 years ago.
Wesley Park (W,u)	Storm sewer draining medium-density residential area of Golden Valley developed 10 to 20 years ago; partially curbed and guttered.
Sandburg Road (Z,u)	Storm sewer draining light industrial park in Golden Valley; high volume of truck traffic.
PDQ-Valley View Road (Q,u)	Storm sewer draining mixed medium-density residential and multifamily in Eden Prairie; some construction activity.

Figure 1. LOCATIONS OF RUNOFF AND RAIN QUALITY SAMPLING SITES



KEY TO LETTER CODE:

A - BASSETT CREEK
B - BEVENS CREEK
C - CARVER CREEK
D - CREDIT RIVER
E - ELM CREEK
H - 80th STREET
I - IVERSON AVE.
J - UPPER MINN. R.
K - LOWER MINN. R.
P - PURGATORY CR.
Q - PDQ
R - RAVEN STREAM
S - SHINGLE CREEK
T - HIGHWAY 100
V - VERMILLION R.
W - WESLEY PARK
X - ESTATES
Y - YATES
Z - SANDBURG RD.

KEY TO SYMBOLIZATION:

▼ - RUNOFF SAMPLING SITE
▲ - RUNOFF SAMPLING SITE WITH GAUGE
■ - AUTOMATIC WET/DRY PRECIPITATION SAMPLER
* - TIPPING-BUCKET RAIN GAUGE

▲ - MAINSTEM SAMPLING SITE
△ - STORM SEWER SAMPLING SITE

Table 2
MONITORED WATERSHED CHARACTERISTICS

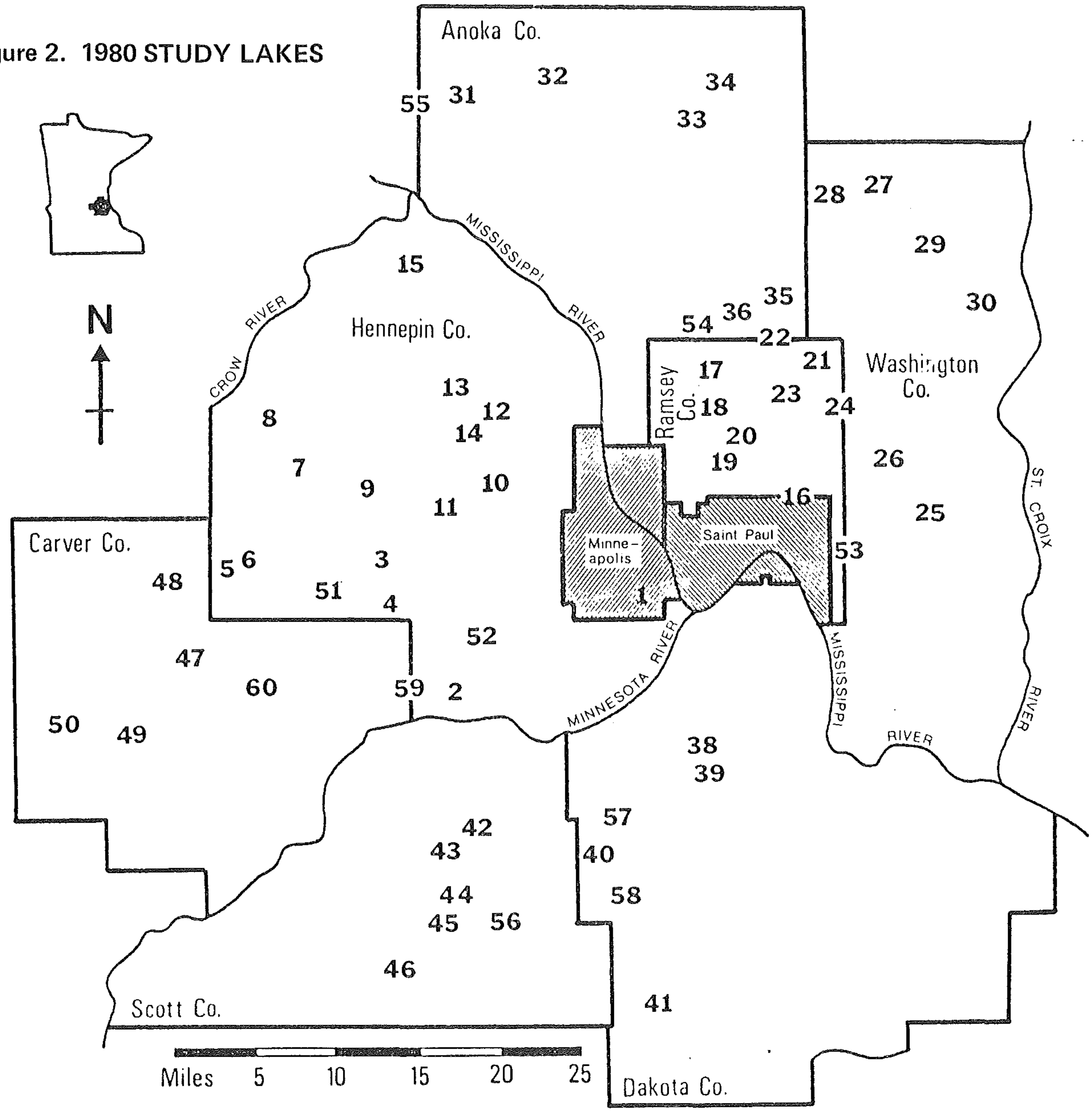
	Channel Slope ft/mi (intermittent)	Storm Sewer Slope, ft/mi	Watershed Relief, ft.	Drainage (Storm-Sewer) Density, ft/acre	Wetland Area, acres (%)	Surface Water Area, acres (%)	Overall Impervious Area %	Effective Impervious Area %	Average Overland Flow, ft.	Area, Sq. Mi. (acres)
Shingle Creek Mainstem	6.4	-	189	2.81	1209(8.2)	675 (4.6)	15.5	12.2	2600-4000	22.9 (14656)
Yates Ave	-	10.0	7	55.2	0 (0)	0 (0)	23	13.3	450	0.35 (224)
Estates Dr.	-	22.5	16	50.3	0 (0)	0 (0)	29	16.5	500	0.22 (141)
Bassett Creek Mainstem	9.9(18.3)	-	305	2.76(3.67)	1674(8.1)	1306(6.4)	13	8.4	2500-4000	31.7 (20288)
Hwy. 100	-	85.2	45	36.0	1.2(0.3)	0 (0)	35	26.3	750	0.47 (301)
Sandburg Rd	-	33.8	45	35.8	0 (0)	0 (0)	70	53.7	1000	0.12 (77)
Wesley Park	-	43.2	60	56.0	9.2(4)	0 (0)	22	15.3	500	0.33 (211)
Purgatory Creek Mainstem	12.2	-	215	3.51	2228(14.5)	754(4.9)	7	5.0	2500-4000	24.0 (15360)
PDQ	-	103.2	95	33.0	0 (0)	0 (0)	11	8.0	500	0.13 (83.2)
80th St. (Cottage Grove)	-	44.9	160	40.3	15.2(1.5)	0 (0)	16	11.2	500	1.55 (992)
Iverson	-	24.1	60	22.0	0 (0)	0 (0)	16	11.0	375	0.15 (96)
Elm Creek	8.9	-	165	4.21	1482(16.3)	18(0.2)	3	2.1	2000	14.3(9152)
Bevens Creek	4.1	-	126	2.41	1500(5.2)	400(0.8)	1.7	1.2	3500	82.9(53056)
Carver Creek	4.3	-	160	1.87	4007(9.6)	3867(9.3)	2	1.3	2400	65.2(41728)
Credit R.	13.4	-	240	3.42	1671(11)	456(3)	2	1.5	2000-5280	23.2(14848)
S.Br. Verm. R.	8.8	-	198	2.11	797(4)	8(0)	1.5	1.0	2600	30.8(19712)
Raven Trib.	So.9.0, No.7.8	-	135	3.27	1200(5.8)	60(0.2)	1.5	1.0	3300	32.4(20736)

As stated previously, the nonpoint runoff monitoring effort was undertaken to collect samples during periods of rainfall and snowmelt runoff. Several samples were taken across runoff hydrographs to best represent varying conditions during such an event. Up to 35 different chemical, physical and biological analyses were performed on each sample gathered (Ayers et al., 1980). Only the most frequently run analyses will be summarized in this report. All other data will be reported in the USGS published data summary (Payne et al., 1982). Flow at the sites was continually monitored on a 5- or 15-minute USGS punch-tape and precipitation was recorded with a tipping-bucket gage with 0.01-inch sensitivity. At the beginning of the sampling season, every one of the snowmelt events was successfully sampled, so very good snowmelt loading data exists. During the precipitation season, as many events as possible were collected and analyzed, with numbers of sampled events per station ranging from 15 to 35. More than 16,000 individual pieces of runoff quality data were collected, not counting the flow data or the rainfall data.

Figure 2 identifies the 60 lakes sampled from June to September, 1980. The 60 lakes were chosen to represent the approximately 950 lakes occurring in the Region. Lakes were selected based on their surrounding land use, morphometry and/or special interest. Forty of the lakes were sampled monthly and 20 were sampled bimonthly for nutrients, transparency and biological character. Additionally, the Minnesota Department of Transportation (MnDOT) performed analyses for 13 heavy metals, suspended solids and chlorides on surface and near-bottom samples taken during August. The MWCC provided invaluable assistance in actual field sampling and equipment, and Hennepin County Soil and Water Conservation District personnel assisted by collecting samples from the lakes in Hennepin County. Details of the lakes study are available in another Council report (1981b), but a short summary occurs in Section V of this report.

Data analyses for both the runoff and the lakes sampling began as soon as data became available from the MWCC lab. (Laboratory procedures are described in Appendix A.) Individual loads for each rainfall and snowmelt runoff event were compiled, as well as baseflow and atmospheric loading. These data were then used to generate probable runoff loadings to lakes and combined with the in-lake sampling to arrive at conclusions on lake response to nonpoint source inputs. The quality and quantity data collected from the monitoring program were also used in models to project the total nonpoint load for the Metropolitan Area for various periods, such as annual, seasonal or a particular frequency event. This information was then compared with point source loadings and used as input data to evaluate point versus nonpoint loading to our major rivers. This analysis will ultimately lead to a recommendation(s) on how limited financial resources can best be spent to improve the water quality of the Region. All of the study results are covered in subsequent sections of this report.

Figure 2. 1980 STUDY LAKES



Study Lake No.	Lake Name	Study Lake No.	Lake Name	Study Lake No.	Lake Name
1	Nokomis	21	Bald Eagle	41	Chub
2	Staring	22	Otter	42	Prior (upper)
3	Minnetonka (lower)	23	Birch	43	Spring
4	Christmas	24	White Bear	44	Fish
5	Whaletail	25	Elmo	45	Cynthia
6	Long	26	DeMontreville	46	Cedar
7	Independence	27	Forest	47	Waconia
8	Sarah	28	Clear	48	Swede
9	Wolsfeld	29	Big Marine	49	Rice
10	Medicine	30	Square	50	Eagle
11	Parkers	31	Pickerel	51	Minnetonka (upper)
12	Eagle	32	George	52	Bryant
13	Fish	33	Coon	53	Tanners
14	Bass	34	Linwood	54	Golden
15	Diamond	35	Centerville	55	East Twin
16	Phalen	36	Reshanau	56	McMahon
17	Turtle	37	Laddie	57	Crystal
18	Snail	38	Thomas	58	Marion
19	Owasso	39	Farquhar	59	Riley
20	Wabasso	40	Orchard	60	Pierson

III. SAMPLING PROGRAM RESULTS

his section will describe the findings of the previously mentioned sampling program. The section is intended to identify the character of the nonpoint pollution problem using data collected from variable runoff events.

CONCENTRATIONS

Analysis of pollutant concentrations is particularly important since it can be directly related to guidelines of the Minnesota Pollution Control Agency (MPCA) for water quality in streams and rivers. Guidelines for water quality are set according to low flow conditions and are generally oriented toward analysis of point source impacts on the various receiving water bodies. This is a point to keep in mind throughout the discussion of water quality guidelines, that is, direct application of water quality guidelines is difficult since guidelines development circumstances differ from those occurring when nonpoint sources are contributing. This is particularly pertinent to pollutants like TSS which have guidelines only for effluent discharges. The 30 mg/l TSS guideline is used in this report as an in-stream guideline, not as a guideline for runoff before it reaches a receiving water.

PESTICIDES

Before the various observations for each station are discussed, the results of a small pesticides sampling program are presented. Very few pesticide samples were run because the laboratory cost of pesticide scans is almost prohibitive.

The real objective of the small program was to establish at a few locations whether or not residual pesticides were in the runoff and, if so, at what levels. Table 3 lists the standard pesticide analyses that were performed on the samples. Samples were taken at seven of the sites (Bevens, Vermillion, 80th, Raven, Carver, Credit and Bassett) during the heavy rains of June 5 through June 7, and during a rainy period from Aug. 8 through Aug. 11. The June sampling followed shortly the application period for many of the pesticides and occurred when little or no vegetative cover was present, while the August period would have been at a time when residues from the spring applications were low and vegetative cover was abundant.

Table 3
STANDARD PESTICIDE ANALYSES PERFORMED ON SAMPLES

Herbicides (H)		Insecticides (I)	
Alachlor	Prometone	Aldrin	Ethion
Ametryne	Prometryne	Chlordane	Heptachlor Epoxide
Atratone	Propazine	DDD	Heptachlor
Atrazine	Silvex	DDE	Lindane
Cyanazine	Simazine	DDT	Malathion
Cyprazine	Simetone	Diazinon	Methyl Parathion
2,4 - D	Simetryne	Dieldrin	Methyl Trithion
2,4 - DP	2,4,5, - T	Endosulfan	Methoxychlor
		Endrin	Mirex
		Ethyl Parathion	Perthane
		Ethyl Trithion	Toxaphene

Table 4 gives the results of the pesticide sampling. Only seven of the pesticides were detected in the samples; absence from Table 4 means that the pesticides were either not present or were below the limits for detection. It is obvious from the table that washoff of pesticides did occur quite readily in the June event. The fields were essentially bare with summer growth just becoming established. In brief, the June storm could not have occurred at a worse time in the year. EPA-recommended water quality criteria for those pesticides in Table 4 exist only for 2,4-D and dieldrin. The levels of 2,4-D detected were well below EPA's recommendation of 100 ug/l, but dieldrin (a strong chlorinated insecticide) limits were exceeded for the human health recommendation of 0.0071 ng/l (ng=10^{-9} gram).

Significant conclusions and recommendations on the preceding findings are not possible because of the limited data that were collected. Suffice it to say, however, that pesticides are moving from the fields and that incorporation of pesticides into the soil and proper timing of application are essential if mobilization and transport are to be minimized. A conservation tillage approach, which roughs up the soil while leaving sufficient surface residue to dissipate rainfall energy, is probably the best approach to prevent conditions such as those of early June 1980 from generating serious pesticide pollution loads.

SITE ANALYSES

Water quality guidelines (Table 5) are included at this point to provide a basis against which to compare the flow-weighted mean concentration data collected during 1980 (Table 6). It is emphasized that MPCA water quality standards are point-source-oriented and ignore such things as runoff concentrations during events and accumulation of pollutants due to nonpoint contributions. The following analyses are made using statistical tabulations of the year's runoff and snowmelt events.

Carver Creek contributed its highest COD concentrations during the mid-March melt event when levels reached 148 mg/l. The highest TSS concentration of 272 mg/l was reached during the June 6 rainfall at a period when fields were exposed (Figure 3). Volatile suspended solids (VSS), on the average, made up over half of the total suspended solids. Nutrient levels again were at their highest level in the mid-March melt, with TP hitting 3.1 mg/l and TKN reaching 6.54 mg/l. All other pollutant levels were generally quite low, with Cl and heavy metal concentrations minimal. Fecal coliform and streptococci levels (several thousand colonies per 100 ml) were normal for agricultural runoff.

Figure 3 shows a pattern typical of rural areas in the spring and early summer. Flow is not depicted but it generally follows the TSS line. A several-day event occurs when the snow melts or when a rainfall occurs. During this period of the year, the ground is generally bare with little, if any, vegetative canopy to reduce raindrop energy and bind topsoil. Snowmelt flows over frozen surfaces, and depressions or wetlands cannot allow infiltration or nutrient uptake because of frozen conditions. The total runoff event takes several days to run its course, typified by a slow rise and fall for snowmelt, and a more rapid rise for rainfall.

Figure 3. WATER QUALITY DATA—CARVER CREEK

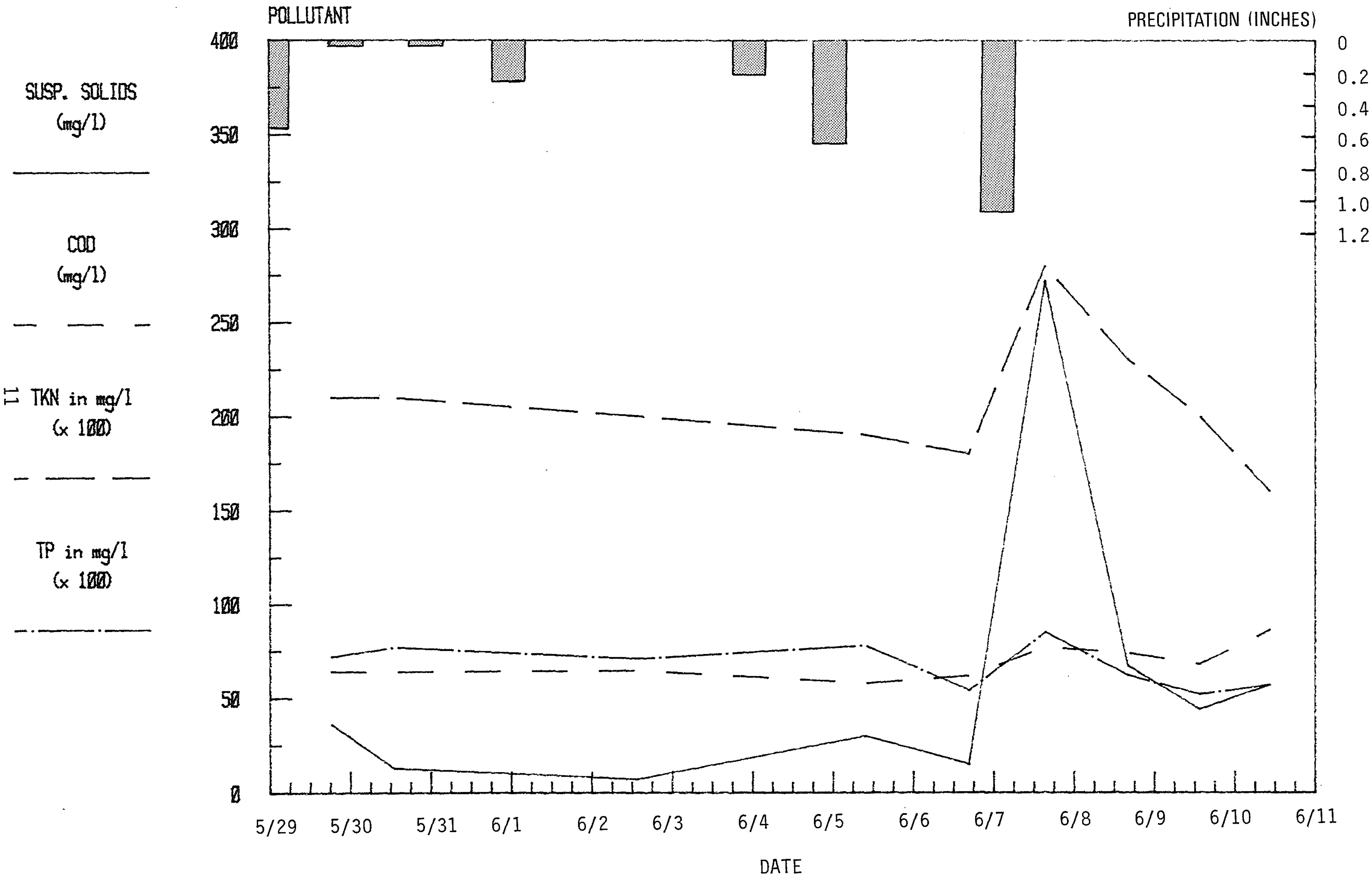


Table 4
PESTICIDE RESULTS

Pesticide Detected (ug/l)

Station	Date	Alachlor	Atrazine	Diazinon	Dieldrin	2,4-D	Prometone	Prometryne
Vermillion	June 5, 1980	0.73	18.0	ND	ND	ND	ND	0.2
Bassett	June 5, 1980	0.14	0.2	ND	ND	ND	0.1	ND
Carver	June 5, 1980	0.68	0.3	ND	ND	ND	ND	ND
80th St.	June 5, 1980	0.17	0.2	ND	ND	ND	ND	0.1
Bevens	June 5, 1980	ND	ND	ND	ND	0.6	ND	ND
Credit	June 6, 1980	0.57	0.7	ND	ND	ND	ND	ND
Raven	June 6, 1980	0.03	0.8	ND	ND	ND	ND	ND
Vermillion	June 6, 1980	ND	ND	0.01	0.01	ND	ND	ND
Bevens	June 7, 1980	1.84	4.4	0.1	ND	ND	0.1	0.1
Credit	June 7, 1980	2.05	2.0	ND	ND	ND	0.1	ND
Raven	June 7, 1980	3.60	1.0	ND	ND	ND	ND	ND
80th St.	August 8, 1980	ND	ND	0.38	ND	ND	ND	ND
Vermillion	August 8, 1980	ND	ND	ND	ND	0.02	ND	ND
Vermillion	August 8, 1980	0.03	0.2	ND	ND	ND	ND	ND

ND = not detected.

Table 5
RECOMMENDED WATER QUALITY GUIDELINES FOR NONPOINT SOURCE POLLUTION

Constituent	Guideline (mg/l)	Source
Fecal coliform (2)	200 MPN/100 ml	MPCA, Secondary Effluent Standard
Total phosphorus (1) (in-stream)	0.10	CAC, TAG
Chemical oxygen demand (1)	50.00	CAC, TAG
Un-ionized ammonia (2)	0.04	MPCA Water Quality Standard
Total suspended solids (1)	30.00	MPCA Secondary Effluent Standard
Total nitrogen (1)	2.00	CAC, TAG
Chloride (3)	100.00	MPCA Water Quality Standard
Copper (2), Cadmium (4) (total)	0.01	MPCA Water Quality Standard
Zinc (total) (4)	5.00	MPCA Water Quality Standard
Chromium (2), Lead (4) (total)	0.05	MPCA Water Quality Standard
Iron (4) (total)	0.30	MPCA Water Quality Standard
Nickel (total)	0.10	EPA Water Quality Criteria

(1) In-stream water quality standards not available from MPCA, so staff recommendation was made based on EPA criterion (TP), or level thought to be indicative of good quality (COD, TN).

(2) State standard for all waters classified 2B, 2C or unclassified.

(3) State standard for all waters classified 3B or unclassified; 50 mg/l for all 2A and 3A waters.

(4) State standard for all waters classified as domestic comsumption waters (1A, 1B, 1C, 1D).

CAC - Citizens Advisory Committee.

TAG - Technical Advisory Group.

Table 6
FLOW-WEIGHTED MEANS AND RANGES

Flow-Weighted Mean
Range
Number of Samples

	mg/l							ug/l			
Site	TSS	VSS*	COD	TKN	N/N	TP	Cl	Pb	Zn*	Cr*	Fecal Coliform* (MPN/100 ml)
Carver	33 1- 272 36	19 2- 64 24	82 50- 148 30	3.03 1.64- 6.54 36	0.74 0.10- 4.6 34	0.85 0.49- 3.1 36	38 22.0- 558 16	4.9 0- 12 6	23 10- 40 6	73 3- 200 3	5,472 400- 9,800 8
Bevens	44 7-4,560 90	30 1- 590 62	75 51- 586 53	3.44 1.52-22.0 91	2.92 0.05-10.0 78	0.78 0.27- 5.1 91	46 18.0- 160 18	--	87 12- 450 7	69 2- 150 4	16,230 1,430- 53,000 9
Raven	46 2- 504 21	13 0- 108 14	78 25- 116 19	4.02 .80- 8.4 21	3.81 0.50- 9.5 21	0.74 0.04- 1.1 21	19 8.0- 31 12	4.3 3- 14 4	22 10- 30 4	1.8 1- 4 4	1,992 300- 4,600 3
Credit	32 1- 496 21	15 0- 96 14	72 35- 157 19	2.99 1.20- 6.0 23	0.64 0.05- 1.6 22	0.72 0.05- 1.3 23	14 7.0- 28 12	6.5 4- 14 2	15 10- 20 2	10 1- 20 2	3,622 50- 7,500 4
Elm	10 2- 374 103	9 0- 36 89	65 45- 157 32	2.08 1.20- 5.4 115	0.27 0.05- 1.35 58	0.35 0.11- 2.23 116	36 16.0- 99 22	4.9 1- 12 7	11.8 5- 19 5	1 1- 1 3	4,142 80- 15,500 8
Vermillion	103 0-6,900 115	40 1- 812 98	41 2- 676 39	1.91 0.14-20.6 118	3.07 0.95- 5.3 115	0.35 0.01- 8.7 117	9.4 4.0- 16 24	46.8 0- 165 9	88 10- 320 8	33 1- 140 6	25,126 44-120,000 7
80th St.	44 4-1,672 37	29 3- 188 18	73 25- 263 6	2.53 0.60-31.0 38	0.75 0.10- 1.75 27	0.66 0.15- 3.05 38	23 1.0-1,700 17	43.8 3-9,100 28	55 5- 110 11	12.5 2- 41 8	4,975 2,500- 7,800 4
Bassett	64 0- 720 127	18 1- 112 101	45 6- 152 65	1.81 0.30- 4.7 127	0.38 0.05- 0.9 120	0.31 0.05- 1.1 127	46 27.0- 305 33	17.6 0- 520 87	61 10- 500 42	4.1 1- 12 8	7,372 96- 50,000 9
Shingle	48 2-1,490 147	26 0- 408 109	44 9- 786 64	2.04 0.40- 9.6 153	0.30 0.05- 3.2 133	0.27 0.01- 1.3 151	73 8.0- 530 36	46 1- 760 90	58 10- 250 36	15 1- 47 8	7,117 1,520- 19,700 7

* Figures not flow-weighted

Table 6 Continued
FLOW-WEIGHTED MEANS AND RANGES

Flow-Weighted Mean
Range
Number of Samples

Site	TSS	VSS	COD	TKN	N/N	TP	Cl	Pb	Zn*	Cr*	Fecal Coliform* (MPN/100 ml)
	mg/l							ug/l			
Purgatory	23	17	55	1.53	0.05	0.10	44	4.8	17.7	1.5	40
	0- 236	2- 60	30- 150	1.00- 7.0	0.05- 0.9	0.04- 0.7	48.0- 98	0- 22	6- 30	1- 2	10- 70
	27	17	22	27	8	27	10	11	6	2	3
Iverson	740	244	38	1.24	0.07	0.62	0.5	20.0	235	255	6,197
	17-26,610	0-2,640	1- 597	1.00-29.2	0.05- 2.45	0.20-13.1	1.0- 66	8- 310	28- 530	9-1,120	10- 22,300
	124	89	58	118	88	118	27	55	24	8	7
PDQ	768	89	146	5.07	0.72	1.39	29	136.0	141	31.4	13,282
	17- 8,210	5- 860	32-1,505	0.50-22.8	0.05- 3.1	0.12- 8.4	0.5-3,600	5-1,260	25- 620	1- 270	990- 25,000
	103	72	56	107	88	107	21	82	52	17	6
Wesley	161	31	68	2.36	0.66	0.67	93***	109.0	85	5.2	31,000
	4- 1,302	2- 132	4- 248	0.15-17.6	0.10- 2.8	0.25- 2.5	2.0- 810	0- 780	20- 300	1- 12	--
	88	55	43	80	65	80	16	63	40	4	1
Sandburg	337	48	138	2.52	0.42	0.63	110	190.0	185	--	28,622
	7- 4,388	6- 262	10- 850	0.40-16.0	0.05- 2.4	0.07- 4.3	2.5-4,200	3-1,500	20- 810	--	10-110,000
	174	132	93	173	140	173	53	147	100	--	5
Hwy. 100**	184	33	112	3.16	0.47	0.56	243***	276.0	122	25	28,267
	0- 1,212	2- 142	1-1,500	0.40-23.8	0.05- 2.5	0.03-12.0	3.0-3,300	2-1,670	10- 770	2- 240	2,200-161,000
	187	159	70	179	144	183	11	159	123	21	12
Estates**	83	30	79	2.71	0.60	0.57	69	178	114	25	28,861
	1- 2,400	0- 346	2- 536	0.22-11.4	0.10- 5.0	0.04- 3.2	0.5-5,600	1-2,400	12- 930	1- 210	1,550-210,000
	197	131	102	186	145	186	56	146	84	20	14
Yates	133	19	90	3.60	0.79	0.63	82	231	198	20.7	6,518
	2- 758	3- 65	24- 879	0.60-28.6	0.05- 4.5	0.10- 3.85	1.0-9,700	15-1,800	20-2,200	1- 160	1,710- 17,600
	83	41	48	86	64	86	33	70	37	10	6

* Figures not flow-weighted

** Determined without summer baseflow.

*** Winter data only.

Bevens Creek responded quite differently from neighboring Carver Creek to the north. Bevens Creek contains far fewer wetlands and lakes (Table 2) than Carver Creek and, hence, responds much faster and with higher concentrations (Figure 4). Mean COD concentrations at Bevens were 75 mg/l, with a high of 586 mg/l occurring during the June runoff event; levels during the mid-March melt event were also in the several hundred mg/l range. The mean TSS of 44 mg/l surpasses the MPCA effluent standard; a peak TSS concentration of 4,560 mg/l occurred during the early June event (Figure 4). Baseflow TSS concentrations varied from about 10 to 40 mg/l, so the impact again of rain on exposed fields is evident. Volatile suspended solids composed only about 35 percent of the total suspended solids.

Mean nitrogen levels also exceeded those of Carver Creek, with mean TKN and dissolved N/N equaling 3.44 mg/l and 2.92 mg/l, respectively (versus Carver's 3.03 and 0.74, respectively). Mean TP levels were about the same. Peak levels of nutrients hit unbelievably high values of 5.1 mg/l TP, 22 mg/l TKN and 10 mg/l N/N in March and June. In some respects, Bevens Creek responds like an urban watershed in that it has low baseflow concentrations, but reacts quickly and with high concentrations to runoff events early in the year. Concentrations of Cl and heavy metals, as with Carver Creek, are low. Mean concentrations for fecal coliform and streptococci were 16,230 colonies (most probable number or MPN) per 100 ml and 11,782 MPN/100 ml, much higher than those of Carver Creek. Peaks for coliform reached 53,000 MPN/100 ml and for streptococci 38,000 MPN/100 ml. On several occasions animal access to streams was noted in the Bevens Creek watershed. This undoubtedly adds to the bacterial content of the stream, as well as to the sediment, nutrient, and oxygen-demanding load.

Figure 5 is an annual load graph depicting Bevens Creek for the entire year of 1980. This is put in the report to show the significance of the snowmelt (mid-March) and spring (early June) events. Notice that even though concentration fluctuates quite markedly, flow increases only during these two periods; as a result of the flow increase, load also increases, pointing out the significance of flows. In other words, a highly concentrated runoff with little flow will usually not result in a large load, whereas a large runoff quantity, even with a low concentration, will result in a large load. This basic behavioral characteristic was seen throughout the sampling program at all sites.

Raven Stream Tributary was not a particularly heavily loaded stream, but it did have its high periods, again in mid-March and June. COD and TSS means were 78 and 46 mg/l, respectively, with the COD high reaching 116 mg/l in March and TSS reaching 504 mg/l in June. The mean VSS value was 13 mg/l, or about one-third of the TSS mean. Nutrient highs were again reached in March and June when TP, TKN and dissolved N/N reached 1.1 mg/l, 8.4 mg/l, and 9.5 mg/l. As with Carver Creek, levels of Cl, metals and bacteria were low. Reference to Table 2 again shows that this watershed has a fair amount of wetlands and this has been shown to improve water quality (see Appendix H).

The south fork of the Vermillion River acted very much like Bevens Creek in its reaction to rainfall and its high runoff concentrations; Vermillion, also like Bevens, has very few wetlands or lakes. Figure 6 shows the same period as Figures 4 and 5 for comparison with those watersheds. Mean COD and TSS concentrations of 41 mg/l and 103 mg/l indicate the general inorganic nature of solids being moved; peak COD and TSS values, however, were higher than Bevens, with concentrations reaching 676 mg/l COD and 6,920 mg/l TSS (the highest single agricultural observation) again in March and June. The trend of high March COD

Figure 4. WATER QUALITY DATA—BEVENS CREEK

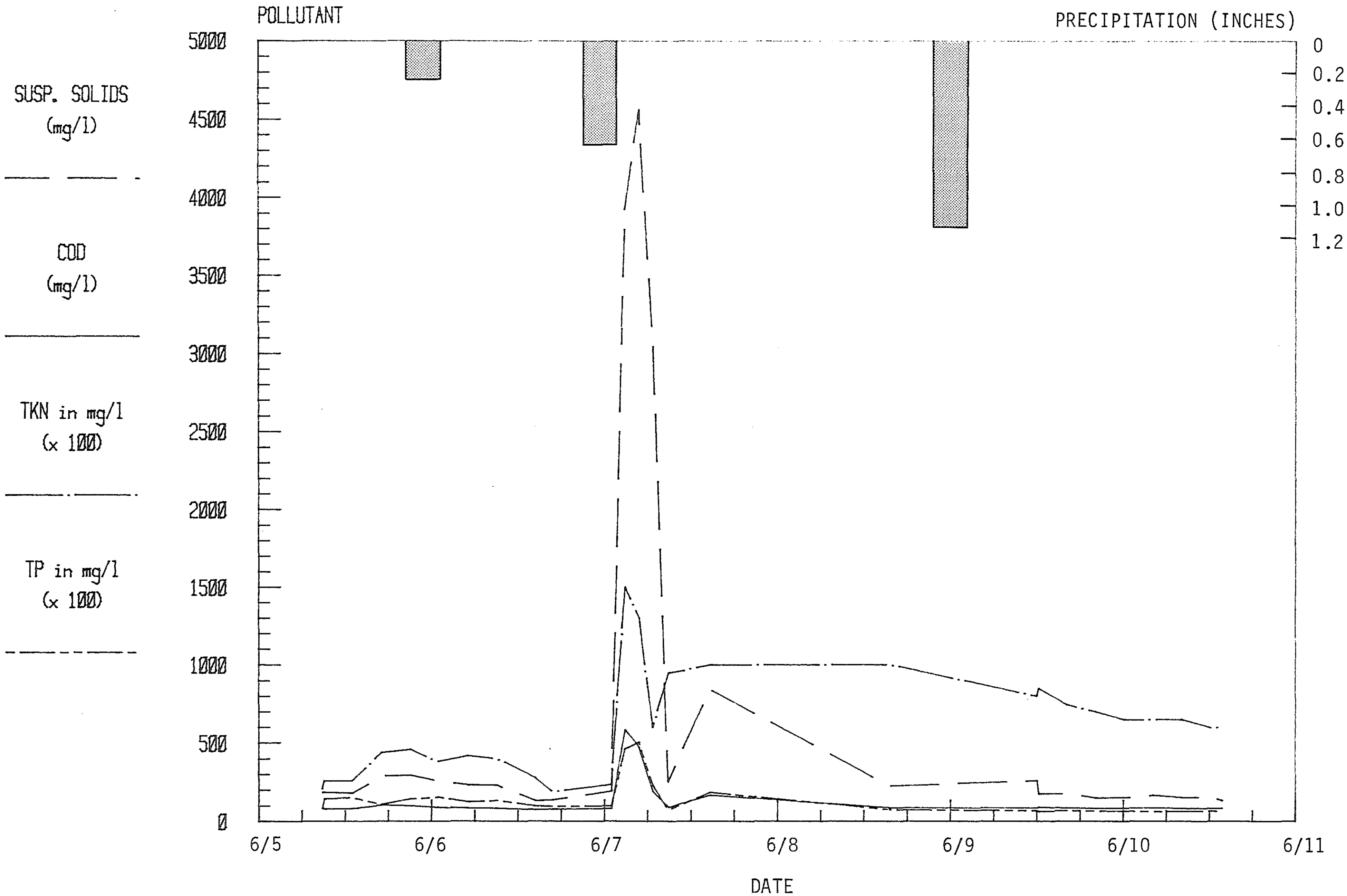


Figure 5. ANNUAL LOAD GRAPH FOR TOTAL PHOSPHORUS AT BEVENS CREEK, 1980

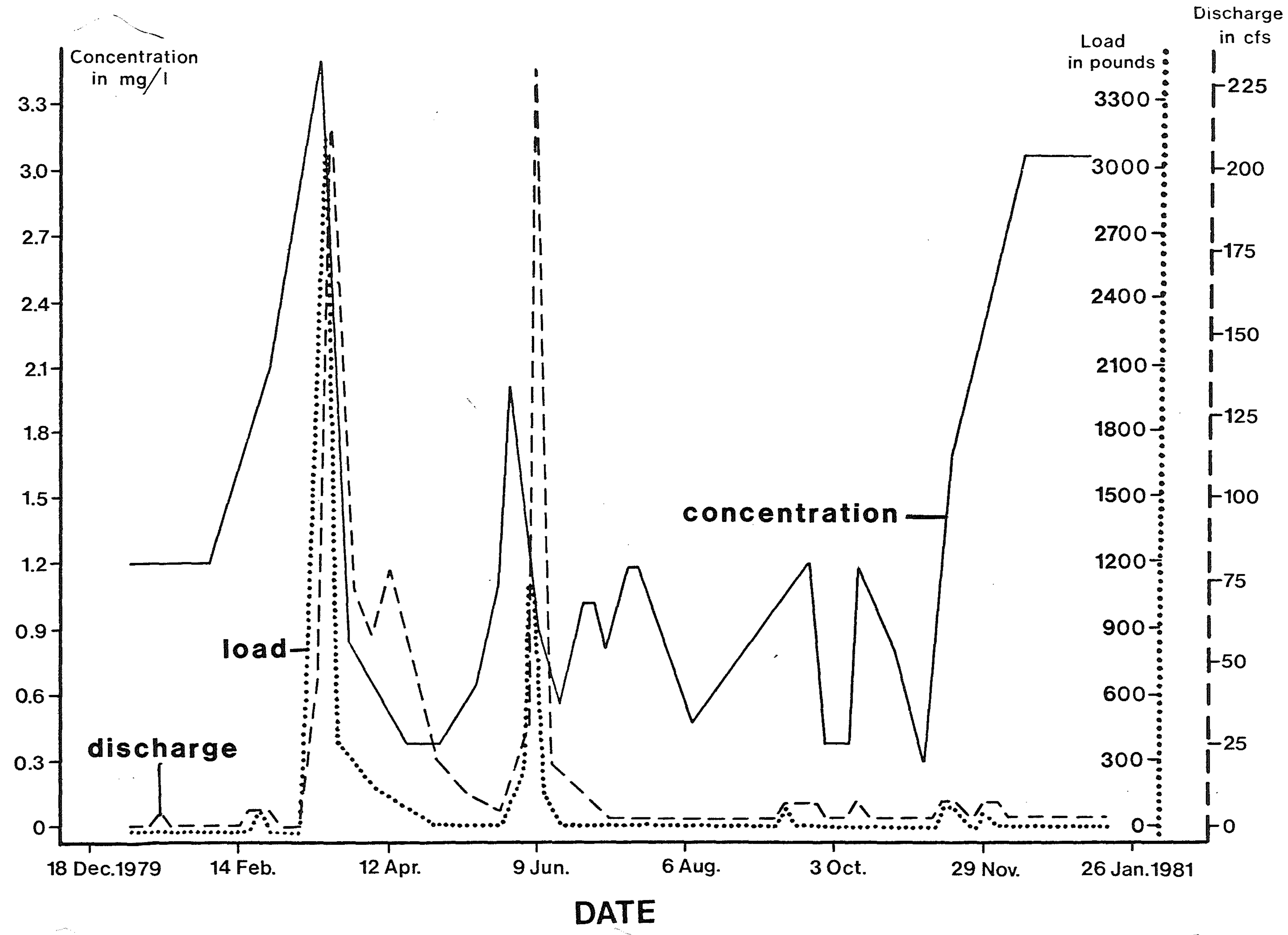
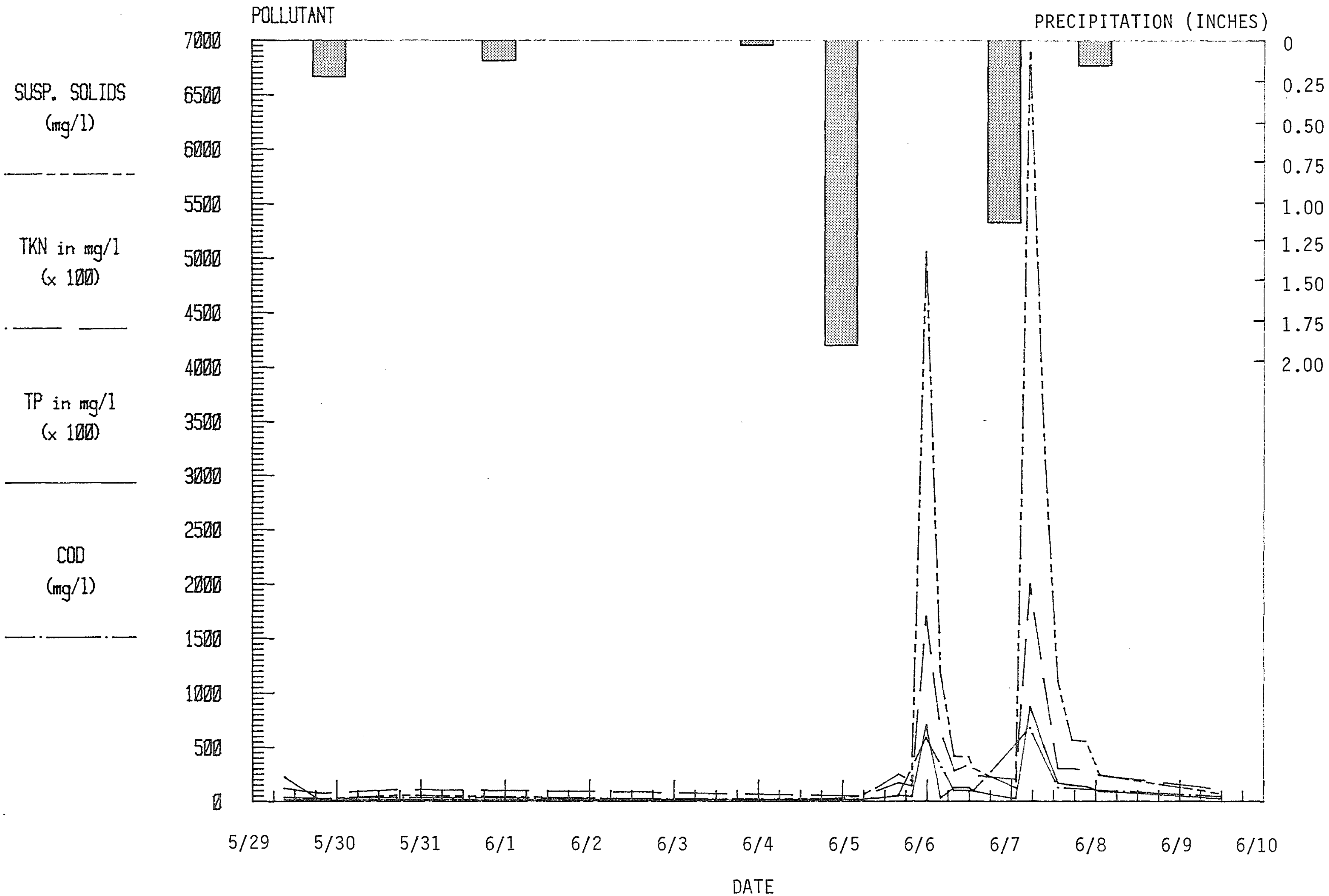


Figure 6. WATER Q LITY DATA—S. FORK VERMILLION RIVER



concentrations and high June TSS concentrations continues to be evident in the agricultural sites. The low VSS mean of 40 mg/l, relative to the TSS mean, again indicates the low organic solids content. Nutrient values were exceptionally high, with peak TP at 8.7 mg/l in June, TKN at 20.6 mg/l in June and N/N at 5.3 in the January baseflow. This notes the first time in our analysis that a pollutant concentration reached its peak during a period other than mid-March or early June. This is quite significant in the sense that several very intense storms did occur after early June, but the streams basically responded quite slowly (see Figure 5) and generally did not reach peak concentrations. This illustrates the importance of a cover crop that shields the soil and dissipates raindrop energy. The atypical peak of soluble N/N in January at the Vermillion site is explainable because of the tile drainage, high level of nitrogen fertilizer application, and general lack of wetlands in the watershed; nitrogen merely infiltrated and moved through the soil into the stream at a high concentration. The Cl and metals again were low, but mean fecal coliform and streptococci levels were the highest of any of the agricultural sites at 25,126 MPN/100 ml coliform and 33,055 MPN/100 ml streptococci. Peaks reached 120,000 and 97,000 respectively. These high levels are usually indicative of much animal access to the stream and runoff from feedlots.

The fifth agricultural site, the Credit River, responded slowly to events and generally at low concentrations. No particularly high levels were reached, with the exception of 496 mg/l TSS in June. All other values were moderate, behaving in a similar manner to Carver Creek.

Elm Creek contributed some of the lowest concentrations of all of the agricultural sites and it responded most slowly. Mean COD and TSS concentrations were 65 mg/l and 10 mg/l respectively, with VSS averaging a very low 9 mg/l. Very few elevated levels of pollutants were observed (Figure 7). The Elm Creek watershed, because of its low gradient and relatively high wetland content, is dominated by soluble and fines-associated loadings as is evident by the COD:TSS values and the soluble nutrient concentrations (Payne et al., 1982). Chloride and metals again were low and fecal coliform normal, but one high fecal streptococci value (157,000 MPN/100 ml) raised the mean to a high value of 21,401 MPN/100 ml.

In summary for the agricultural sites, Bevens and Vermillion contributed the highest concentrations and responded most quickly to events. High COD values in the melt and high TSS values in the June event support a phenomenon to be discussed in the snowmelt loading section of significant dissolved COD levels and low TSS levels occurring during spring melt and the opposite during rainfall. The need was again seen for establishing some kind of a cover crop or residue to hold back melt runoff and dissipate rainfall and runoff energy. Increased infiltration also was shown to be very important, as was maintenance of wetlands and open water to trap and retain pollutants. Proximity of pastures and feedlots or access of animals to the stream channel, or perhaps feedlot practices, would seem to be responsible for increased bacteria levels in the various streams, particularly Bevens and Vermillion. Hydrographs respond slowly to most events and last for several days.

The urban storm sewer sites that were monitored all responded quickly and at high concentrations to snowmelt and precipitation events. Figure 8 is a typical example of a loading versus time graph from an urban site. Several things are important about this figure. In most cases, baseflow is maintained until a melt or storm, at which time a rapid increase in flow occurs. During this

Figure 7. WATER QUALITY DATA—ELM CREEK

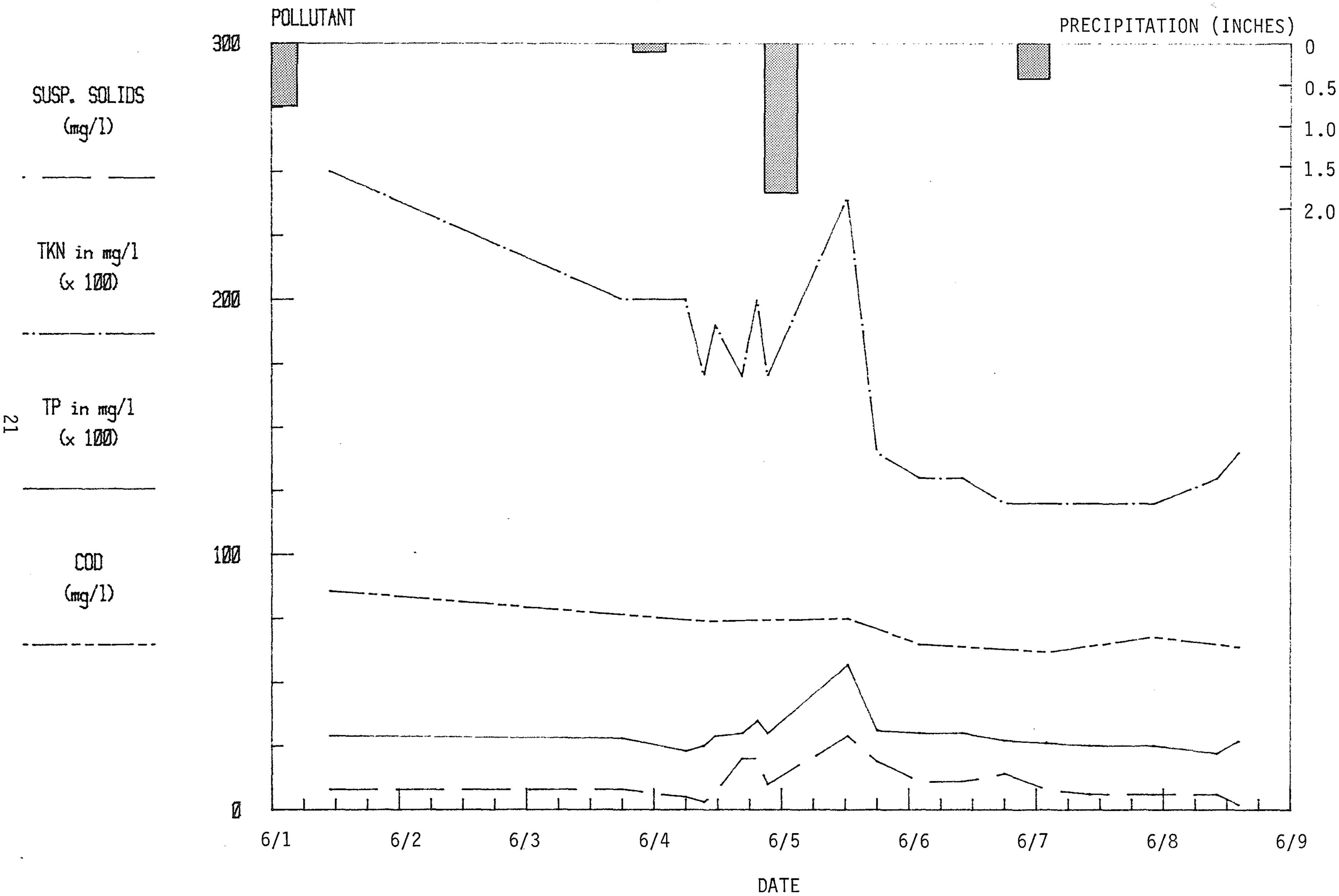
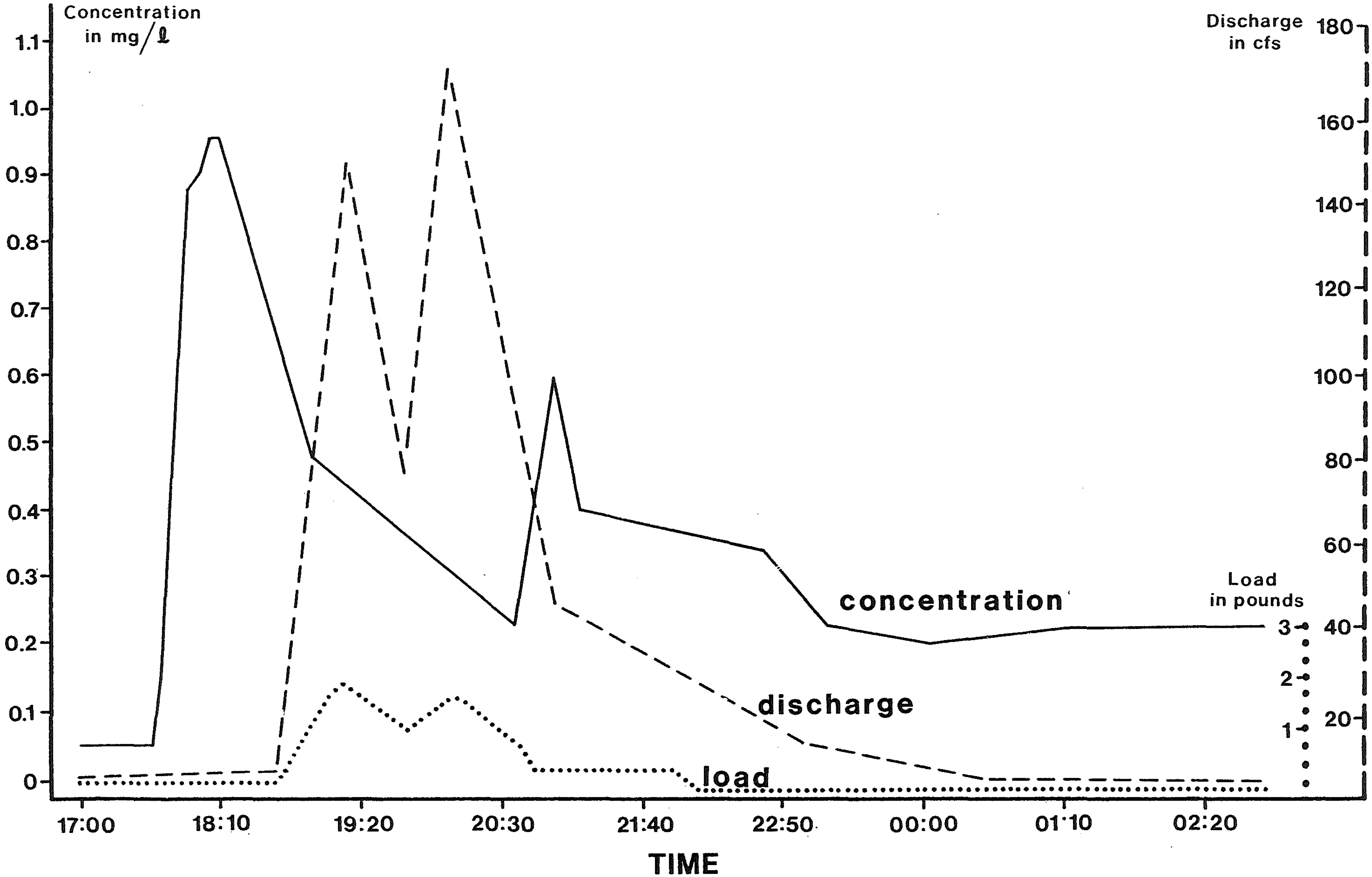


Figure 8. LOAD GRAPH FOR TOTAL PHOSPHORUS AT HWY. 100 (JUNE 18 EVENT)

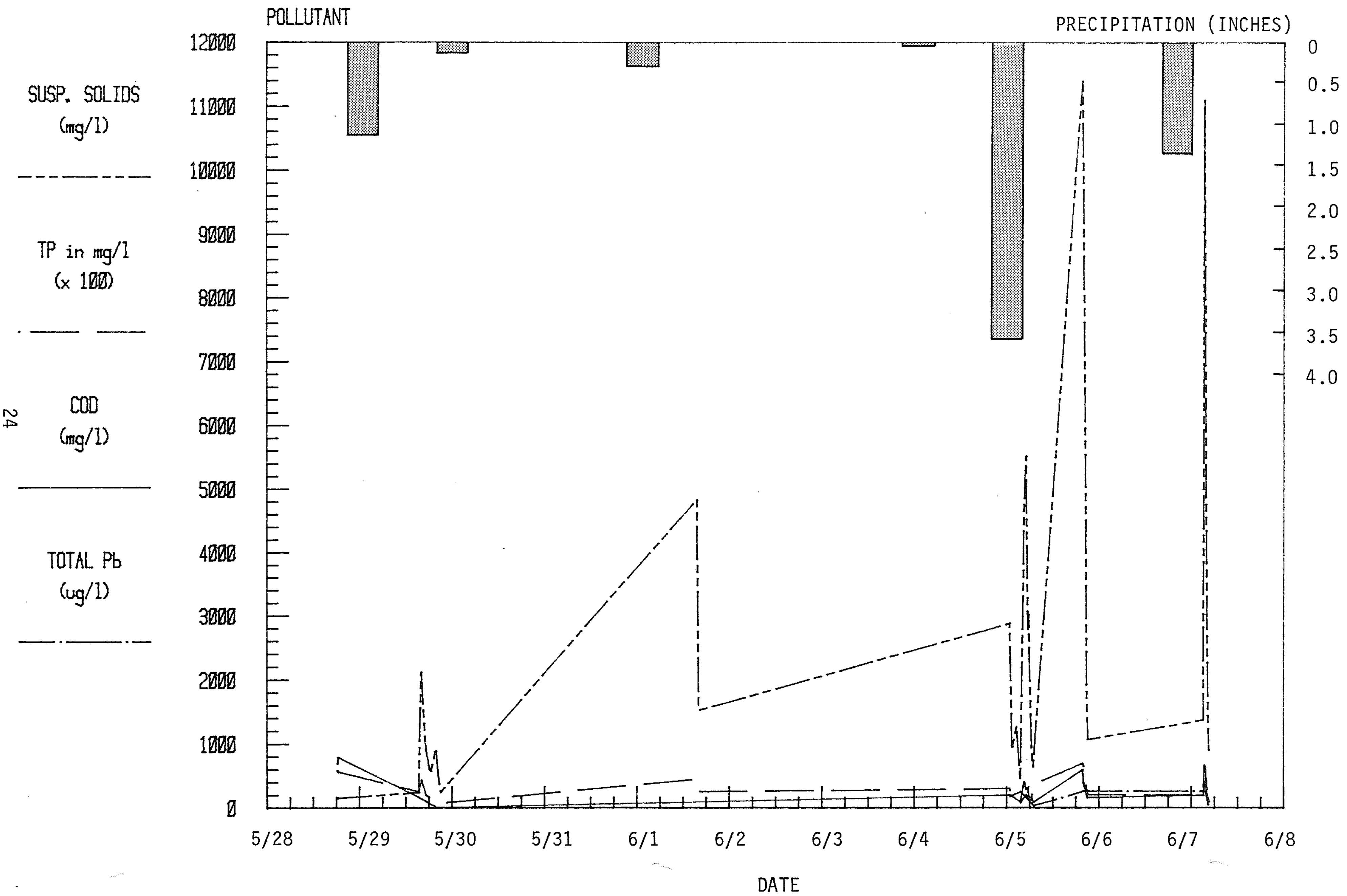


rapid increase or slightly preceding it, there is an equally sharp rise in concentration caused by the initial washing off of accumulated surficial material. Available material eventually diminishes and the concentration graph shows this as the recessional limb. The concentration eventually reaches baseflow again when flows drop and pollutant mobilization ceases. Notice, however, that the load contributed by this twin peak event is determined by the flow, not by the concentration. The load graph responds according to the two flow peaks rather than to the concentration peak. This phenomenon, evident in almost every event, shows that the "first flush" of pollutants does not exist as postulated in several pieces of literature. A first slug of highly concentrated material at a very low flow does occur, but diverting or storing this component eliminates less than five percent of the true load associated with the event. This behavior will be important when management techniques are discussed.

The Iverson and 80th Street sites make an interesting comparison in concentrations. The Iverson site is at the inflow of a detention facility in a construction zone for high-density residences (Orrin Thompson's Pinetree Pond Subdivision, Cottage Grove) and 80th Street is an outlet from the last of eight wet and dry detention facilities in the same subdivision. Solids concentrations into Iverson after construction reached full-swing in March can be characterized as extraordinarily high (Figure 9). Although the project was intended to sample the Iverson pond outflow, shortages of time and personnel prevented this from occurring. Visual observation by USGS sampling personnel, however, indicated that the pond seldom had outflow and did so only near the peaks of the largest storms. When it did flow, the outgoing water was generally of better visual quality than inflow. The 80th Street site verified that the detention system at the subdivision did perform its task; again, the outflows from the eighth pond were reduced and much slower to react, and the concentrations were quite low (see Table 6).

The flow-weighted mean TSS concentration at Iverson was a very high 740 mg/l, with peak values hitting 26,610 and 11,000 (twice) in July when the ground was bare and construction activity at its peak. The VSS during these peak flows was only 200 and 700 mg/l, respectively, indicating that the material moving was almost exclusively inorganic soils. COD values were similarly low, reaching only the 600 mg/l range when TSS peaked, and averaging only 38 mg/l. Nutrient values also hit a few phenomenal highs during the summer construction season. A TP reading of 13 mg/l was reached in August and readings of 4-7 mg/l were quite common. Two TKN peaks of 29 mg/l and 26 mg/l are noteworthy during August and September events. These high nutrient values are expected to have occurred as black topsoil and sod were put in place and homeowners attempted to establish lawns with heavy doses of fertilizer. Some nutrient inputs are also associated with the soils and the organic debris found in residential areas. Of the heavy metals, only Fe and Mn were particularly high, but again this is expected because of the movement of soil. Reference to Table 5 readily shows how far over recommended guidelines such Iverson concentrations were. Again, once the highly concentrated, largely soil-laden runoff hit the detention facility, the particulates generally settled and the water infiltrated into the sandy soils. Settleability tests run on Iverson runoff showed greater than 90 percent settling of TSS in 24 hours under laboratory conditions (Appendix I).

Figure 9. WATER QUALITY DATA—IVERSON AV.



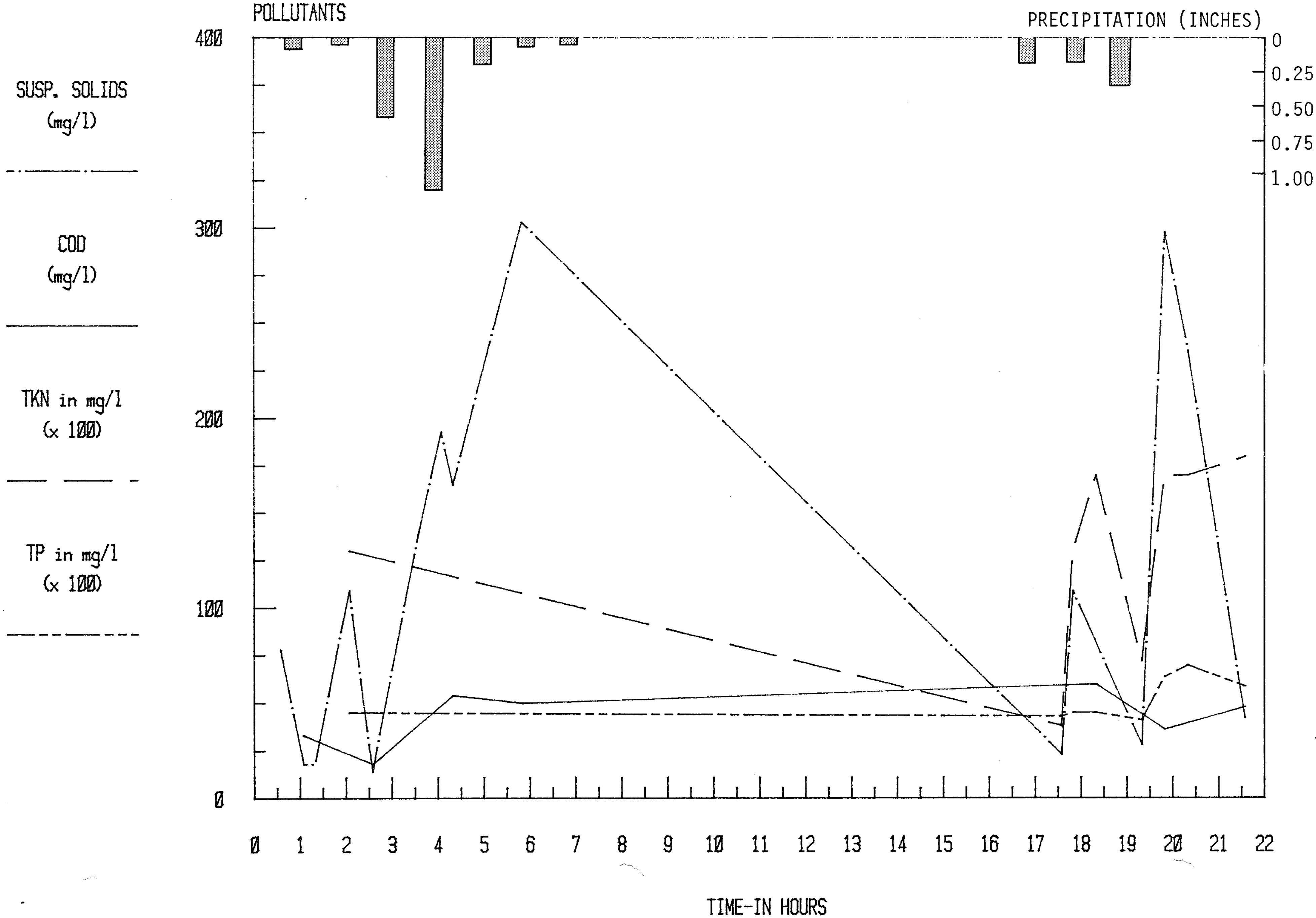
The 80th Street site was a marked contrast to Iverson. Mean TSS was only 44 mg/l and the peak TSS was 1,672 during a July storm. Mean VSS was only 29 mg/l, again indicating a strong inorganic soil enrichment in the fine-sized range; the COD mean was a low 73 mg/l. Nutrient levels leaving the detention facility were low and not out of range expected for settled stormwater. In summary, the concentration and flow data at the Pinetree Pond Subdivision show that extremely high concentrations generated in an area of active construction can be mitigated with a well designed detention system. Outflow from such a system in a high density residential area was less frequent and surprisingly cleaner than that from urban areas without detention ponds.

Five other urban subwatersheds of varying residential densities were monitored to determine pollution character of the urban area's largest land use. A site was established on Valley View Road in Eden Prairie adjacent to a PDQ parking lot. The PDQ site drained a rather steep area containing medium-density and some multifamily residences. The watershed contained a fair amount of grass swale drainage prior to discharge to storm sewers, and some construction (nine acres) immediately upstream of the sampling location. A mean TSS value of 768 mg/l (the highest of any of the 17 sites) was observed, with a peak of 8,200 mg/l occurring in July. These figures are believed to be the result of construction under way at the lower end of the watershed during the summer season. This construction activity greatly masked what otherwise would probably have been rather low loading values; the grass swale drainage appeared to be contributing quite clean water. Low VSS and high Fe values confirm that soils were the contributors to the high TSS rather than organic materials (grass, leaves), as was observed at other residential sites. The mean and high COD readings were 146 and 1,505 mg/l, again slightly higher than expected. Bacterial levels were in the several thousand MPN/100 ml, most probably from pet populations. High nutrient spikes of TP at 8.4 mg/l and TKN in the 20s mg/l were measured during July storms. These high values were suspected to be the result of the disturbed construction area and normal residential debris (grass clippings, fertilizer, pet droppings). A high Pb reading of 1,260 ug/l occurred during a May event preceded by a long, dry spell.

The Wesley Park site in Golden Valley drained a watershed essentially identical to that at PDQ, but pollutant concentrations were quite low in comparison because of the construction activity in the PDQ watershed. Wesley's TSS mean was 161 mg/l, with a peak value of 1,300 mg/l in July. The relatively high TP mean of 0.67 mg/l is indicative of an urban residential area with a large area of grass (clippings, fertilizer). Every other concentration was low except for the one bacteria value, which again suggests the effect of residential area pets. Figure 10 is indicative of the runoff character of the Wesley site, that is, quickly responding and multi-peaked. As with all of the urban sites, every snowmelt and rainfall over 0.1 inch generated a hydrograph and concentration graph similar to Figure 10.

The site adjacent to Hwy. 100 in Golden Valley monitored a relatively old, high-density urban landscape that contained a major highway and a typical commercialized intersection. The watershed also contained a small, wet detention pond that was believed responsible for affecting flow and quality in several events. The mean TSS concentration was a surprisingly low 184 mg/l, with peak TSS reaching only 1,212. Mean VSS was 33 mg/l. Mean and peak COD were 112 and 1,500 mg/l, in the expected range for such an urban area. All nutrients were very low, Cl was very high (winter mean at 243 mg/l); and all bacterial measurements were high. Metals again were surprisingly low with mean Pb at 276 ug/l (the only flow-weighted metal), Cr at 25 ug/l, Zn at 122 ug/l, Cu at 35 ug/l,

Figure 10. WATER QUALITY DATA—WESLEY PARK



Cd at 4 ug/l, and Ni at 31 ug/l. Overall, concentrations at the site were quite surprisingly low. It is believed that the small detention facility at the upper end of the watershed was helpful, as well as the fact that some of the highway runoff discharged over the shoulder and through some grass swales before reaching inlets to the storm sewer. A significant infiltrating baseflow also diluted flow to a certain extent; the loading analysis will show whether or not this made a difference. Figure 8 depicted this site and is fairly indicative of snowmelt and rainfall events from this watershed.

Two similar watersheds in Brooklyn Park were chosen to see the differences in residential densities. The Estates Av. site drains a quite high-density, single-family residential area typical of the suburban Twin Cities. The Yates Av. site drains a watershed with a large number of multifamily residences interspersed with single-family residences similar to Estates. In both cases traffic volumes are quite high. The finding in Brooklyn Park is that both sites have mean TSS, VSS and COD values generally in the same range, with Yates slightly higher for TSS and COD. The values for Estates and Yates, respectively, are TSS at 83 and 133 mg/l, VSS at 30 and 19 mg/l, and COD at 79 and 90 mg/l. Peak values at Estates for TSS and VSS, however, were about three times higher than Yates. COD was 50 percent higher at Yates. Nutrient levels again were all higher at Yates, with Yates having peak values about 50 percent higher for TP and TKN. The mean Cl at the sites was 69 mg/l for Estates and 133 mg/l for Yates. The winter-only means for these sites, however, were 200 mg/l for Estates and 266 mg/l for Yates. These high values are undoubtedly the result of Brooklyn Park's use of a high salt, anti-skid mixture (ratio 2 sand to 1 salt). Although the city takes extra care in its application of salt, the high values recorded are indications that much Cl is moving from the Brooklyn Park streets. Mean metal concentrations are in the range expected for urban areas, with Pb at 150-250 ug/l, Zn at 100-200 ug/l, and the others below 100 ug/l. Peaks for metals did reach into the 2,000 ug/l range occasionally for Pb and Zn. Again, bacteria levels reached several thousand colonies, with Estate (single-family residences) greatly exceeding Yates.

The final storm sewer site was located at Sandburg Av. in Golden Valley, draining a light industrial park. Truck traffic was extremely high and parking/loading areas and rooftop surfaces meant a great deal of impervious surface. There are no curbs, and trucks often park on, or even over, the street sides. The mean TSS was 337 mg/l (moderately high), with a peak of 4,388 in July. The COD mean of 138 mg/l again is moderately high, as is the peak value of 850 mg/l reached twice in the spring. Volatile solids were very low, indicating the inorganic nature of the TSS. Nutrients were normal, the only exception being several TKN peaks in the 16 mg/l range during the spring. Metals were high, as expected, but one exceptional reading was made when Cr reached 830,000 ug/l on March 20; no explanation is readily available for a reading this high, and its validity is suspect. Lead and Zn peaks did reach 1,500 ug/l and 810 ug/l, respectively. The winter mean Cl value was 404 mg/l, indicative of high road salting in the area and of trucks parking and dropping salt carried in from the highways. As with the other urban sites, Sandburg responded to every snowmelt and precipitation event exceeding 0.10 inch.

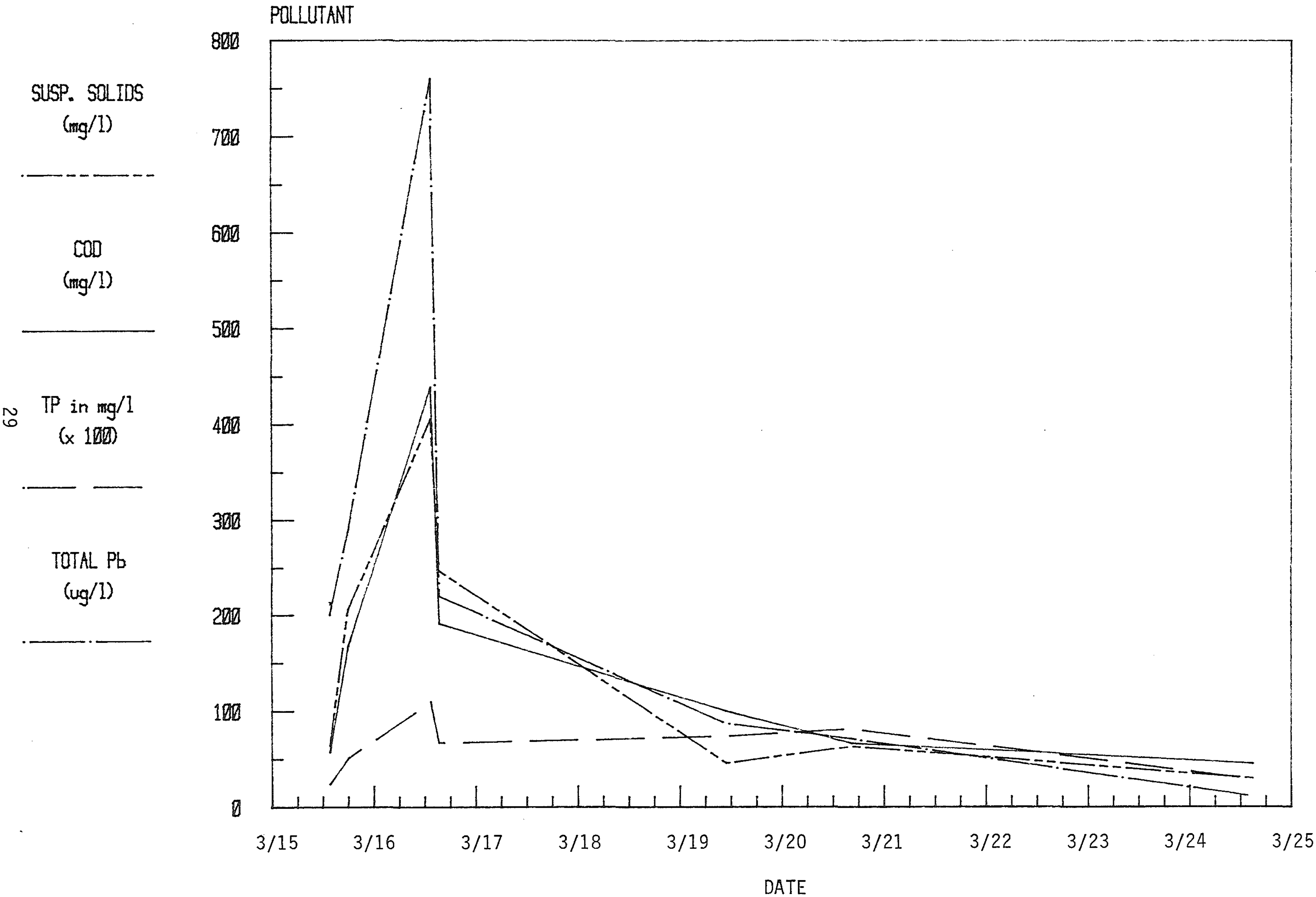
The mainstem sites reflect the fact that pollutant transformations and reductions take place as water enters a stream and proceeds down the drainageway. Water quality improves generally as a watershed increases in size because settling occurs, organisms have a chance to consume organic material, aeration and reoxygenation occur, pH conditions change and groundwater dilution or recharge occurs.

The first mainstem site discussed was 80th St., presented earlier. The next is the Purgatory Creek site, just downstream of Staring Lake in Eden Prairie. This location was selected early in the project when a joint study of the watershed was discussed with Riley-Purgatory Creek Watershed District; the district was going to monitor inflowing values. Funding from the district did not materialize, but the Purgatory station turned out to be one of the most informative stations because it showed the flow and pollution dampening that can occur with an in-channel lake. The area in the lower end of the Purgatory Creek watershed was undergoing a tremendous amount of development during the study. The PDQ site, with its small amount of development near the station, is quite reflective of the land use and development occurring in this lower end. Table 6 shows that mean and peak concentrations for every pollutant listed were significantly lower for the Purgatory site than for the representative PDQ site. Of special note also is the TSS mean of 23 mg/l which falls short of the next two mainstem sites (Bassett and Shingle) which are not immediately downstream from a lake. The implications of this finding for Staring Lake, however, are apparent. The lake is very eutrophic and very shallow, likely having filled in as the watershed developed and dumped its sediment load in this convenient place. On the positive side, the Purgatory site shows that in-line detention facilities work extremely well in improving both suspended and dissolved water quality.

The Bassett Creek site drains the largest watershed of all the urban mainstem sites (31.7 square miles), yet has slightly better quality than Shingle Creek. This fact bears more importance when the dense urban land use of Bassett is compared to the relatively newer and less dense uses in Shingle. Again, as with other sites, detention facilities, lakes and wetlands in the watershed have had their effect on water quality. Most of Bassett's means and peaks are less than Shingle's. Bassett Creek does exceed Shingle in TSS, Zn and bacteria means. Comparison with Wesley, Hwy. 100 and Sandburg, all of which occur in the Bassett Creek watershed, shows again the water quality concentration improvements that occur as drainage area increases.

The final mainstem site is on Shingle Creek in Brooklyn Park. The watershed in the vicinity of the site is fairly deficient in wetlands and detention areas, and the channel has been straightened over most of its length. Both the Estates and Yates sites drain to Shingle Creek (Estates just dowstream of the Shingle site) and are very representative of the land uses and densities in the watershed. Notice again, however, that the concentrations of the tributary sites are greater than the mainstem site, with few exceptions. The Shingle channel was dredged in the winter of 1979-80 and probably has not yet restabilized. Of particular note at the Shingle site are the high mean and ranges of the three metals noted relative to the other mainstem sites. Although these are less than the contributing subwatersheds, they are quite a bit higher than Bassett and Purgatory. The metals affinity for adsorption to fine-grained particles probably explains why these values are higher in the altered channel of Shingle Creek. Figure 11 shows the major melt period in mid-March for the Shingle Creek site. Of particular note is the relatively fast pollutant peaks that result as compared to the rural events (Figures 3-7) which last for several days. The impervious surfaces and storm sewers draining to Shingle Creek and the lack of detention storage tend to speed up pollutant delivery.

Figure 11. WAT⁻⁻ QUALITY DATA—SHINGLE CREEK



PROBABILITY ANALYSIS

An analysis was performed on the water quality data to determine by site the probability that a guideline concentration is exceeded. The methodology followed is that contained in the preliminary documents summarizing the Nationwide Urban Runoff Program (NURP) (U.S. EPA, 1982). The data presented in the following graphs (Figures 12-16) are wet weather data, representing statistical analyses of mean event concentrations (MEC). For purposes of determining these data, rainfall events were considered singly even if they span more than one day; snowmelt events were considered on a daily basis because of the diurnal melt-freeze cycle that typifies such events.

The probability data for urban areas can generally be evaluated for total wet and dry exceedance during the nonwinter seasons by taking the product of the wet weather frequency (Figures 12-16) and the probability that it is raining, defined as the ratio of the mean duration of storms to the mean interval between storm midpoints. This value for the Metropolitan Area is approximately .075 (6.3 hours/84.0 hours). For rural areas, the above procedure is not accurate because of the slow or nonexistent hydrologic response to rainfall once the vegetation becomes established (see Figure 5). The exceedance probabilities for wet and dry totals in rural areas, therefore, are far less than urban areas which respond to essentially every rainfall event. For the winter season, there is usually no runoff from snowmelt at temperatures lower than about 20^{o}F in the urban areas (due to salt) or 32^{o}F in the rural areas. Typically, several short melt events occur throughout the winter, and one major melt occurs in early spring. The probabilities presented in Figures 12-16 would apply during these melt periods.

Figures 12-14 are the probabilities for TSS for the urban storm sewer, urban mainstem and rural mainstem watersheds. The TSS guideline introduced in Table 5 is indicated by the horizontal line at 30 mg/l. Figure 12 shows the seven urban storm sewer sites. The wide range of concentrations is apparent. Sites I and Q are watersheds in which construction was occurring. These watersheds can be expected to meet the recommended guidelines only 0.5 and 1.0 percent of the time during wet weather, which is the only time these storm sewers flow. Also of significant interest are the extremely high concentrations associated with commonly occurring frequencies; for example, the Iverson (I) median (50 percent) is 1325 mg/l and PDQ (Q) median is 296 mg/l. Sandburg (site Z) is an industrial site and again a large guideline exceedance is seen, with an expected guideline compliance of only two percent. Site T (Hwy.100) is a high-density residential area and site W (Wesley) is a medium-density residential area; both watersheds have similar values relative to TSS concentration. Sites X (Estates) and Y (Yates) are medium-density and multifamily residential watersheds in Brooklyn Park. They are the best in terms of guidelines exceedance, but can still only be expected to meet 30 mg/l TSS 16 percent of the time during wet weather. When data from all seven sites are combined, the 30 mg/l level is exceeded 91 percent of the time and concentrations over 1,000 mg/l occur about 10 percent of the time.

Figure 13 shows the TSS data for the four urban mainstem sites. Sites H (80th St.) and P (Purgatory Cr.) both occurred at the outflows of detention systems. Site H was at the end of an eight pond detention system in a high density residential area with construction and site P was on Purgatory Creek just below Staring Lake. The efficiency of these detention systems can be better appreciated by noting that site I (Figure 12) is a subwatershed of site H and site Q is a subwatershed of site P. The probabilities of exceeding 30 mg/l are

Figure 12 . Probability of Occurrence for Total Suspended Solids in Wet Weather Flows (Storm Sewers)

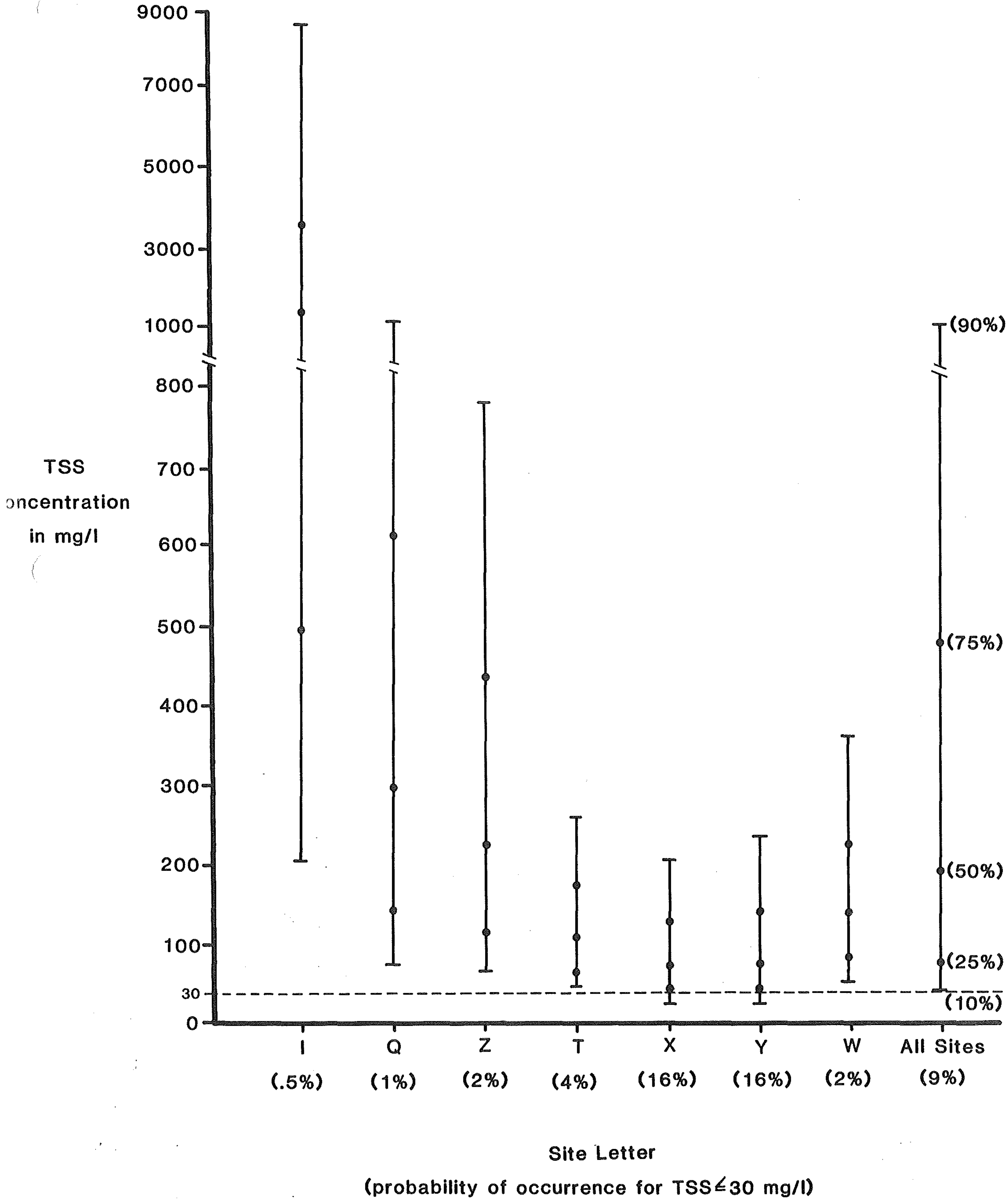
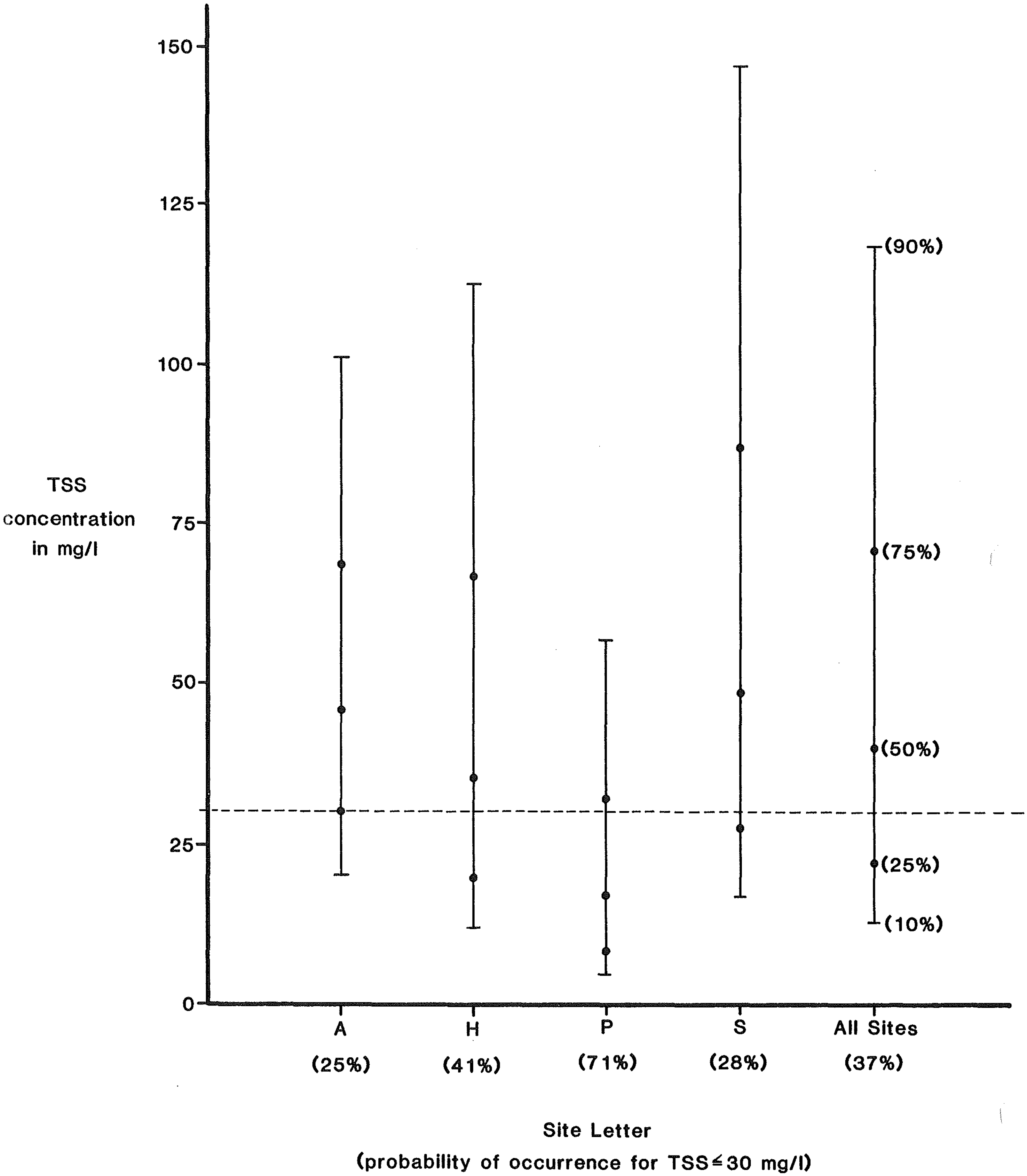


Figure 13. Probability of Occurrence for Total Suspended Solids in Wet Weather Flows (Urban Mainstems)



markedly higher for sites A (Bassett Cr.) and S (Shingle Cr.). These two sites drain similar watersheds in urban Hennepin County. Wetlands and detention facilities are fewer and impacts of highly polluted storm sewer runoff are common. Because these two streams drain urban areas, they do respond to most rainfall and snowmelt events. For reference (Figure 12), sites W, T and Z drain to site A, and sites X and Y are subwatersheds of site S.

The TSS probabilities from the six rural watersheds are presented in Figure 14. In evaluating this figure, it is important to remember the behavior characteristic of rural watersheds, that is, little to no response to rainfall events after vegetative cover establishment (see Figure 5). A "wet weather" flow usually occurs only in the spring, or after crop removal in the fall; the time in between is a period of extremely low flow. Sites V (Vermillion R.) and B (Bevens Cr.) can be expected to meet the TSS guidelines only 19 and 25 percent of the time, respectively. The other sites range from 42 to 85 percent below the guideline for wet weather periods. Comparison of Figures 13 and 14 could lead one to believe that urban and rural impacts are similar, but knowledge of the differences in hydrologic response between the two types of watersheds allows for proper interpretation.

The other probability data presented in this report are for lead (Pb). Figure 15 shows the Pb probabilities for the seven urban storm sewer sites. With the exception of site W, all of the sites and the summary data exceed the recommended guideline of 0.05 mg/l over 88 percent of the time during wet weather, which again is after most events. The highest probabilities--sites Z, T, X and Y--are for areas experiencing high traffic volumes. These data show clearly the significant impact of small storm sewer discharges on receiving waters in the vicinity of the discharge. This impact beomes less obvious as other discharges and in-stream treatment occur.

Figure 16 shows how the impact of Pb in highly polluted storm sewer discharges becomes lessened with increasing watershed size. The data seem to indicate that Pb will probably settle out of the water column somewhere downstream of the storm sewer inputs. This fact, however, also means that subsequent turbulent flows can resuspend or resolubilize the Pb and make it again available to the water column.

The data presented in this section on probability show that nonpoint sources of pollution, when they occur, routinely exceed recommended water quality guidelines. Similar exercises for other pollutants show similar high exceedance results.

CONCENTRATIONS SUMMARY

The most apparent conclusions on nonpoint source runoff concentrations can be made by comparing the concentrations in Tables 5 and 6, that is, observed value versus recommended guidelines. With the exception of the Elm Creek and Purgatory Creek sites, all flow-weighted mean TSS values exceed 30-day MPCA effluent standards; in most cases the standard is far exceeded. The TP situation is worse in that only one site's (Purgatory Creek) mean is less than or equal to the guideline; ammonia and BOD readings were not compared because the ammonia data is for ionized ammonia and BOD samples were minimized in favor of COD samples. The fecal coliform guideline of MPCA is greatly exceeded at all sites except Purgatory (immediately downstream from Staring Lake).

Figure 14. Probability of Occurrence for Total Suspended Solids in Wet Weather Flows (Rural Mainstems)

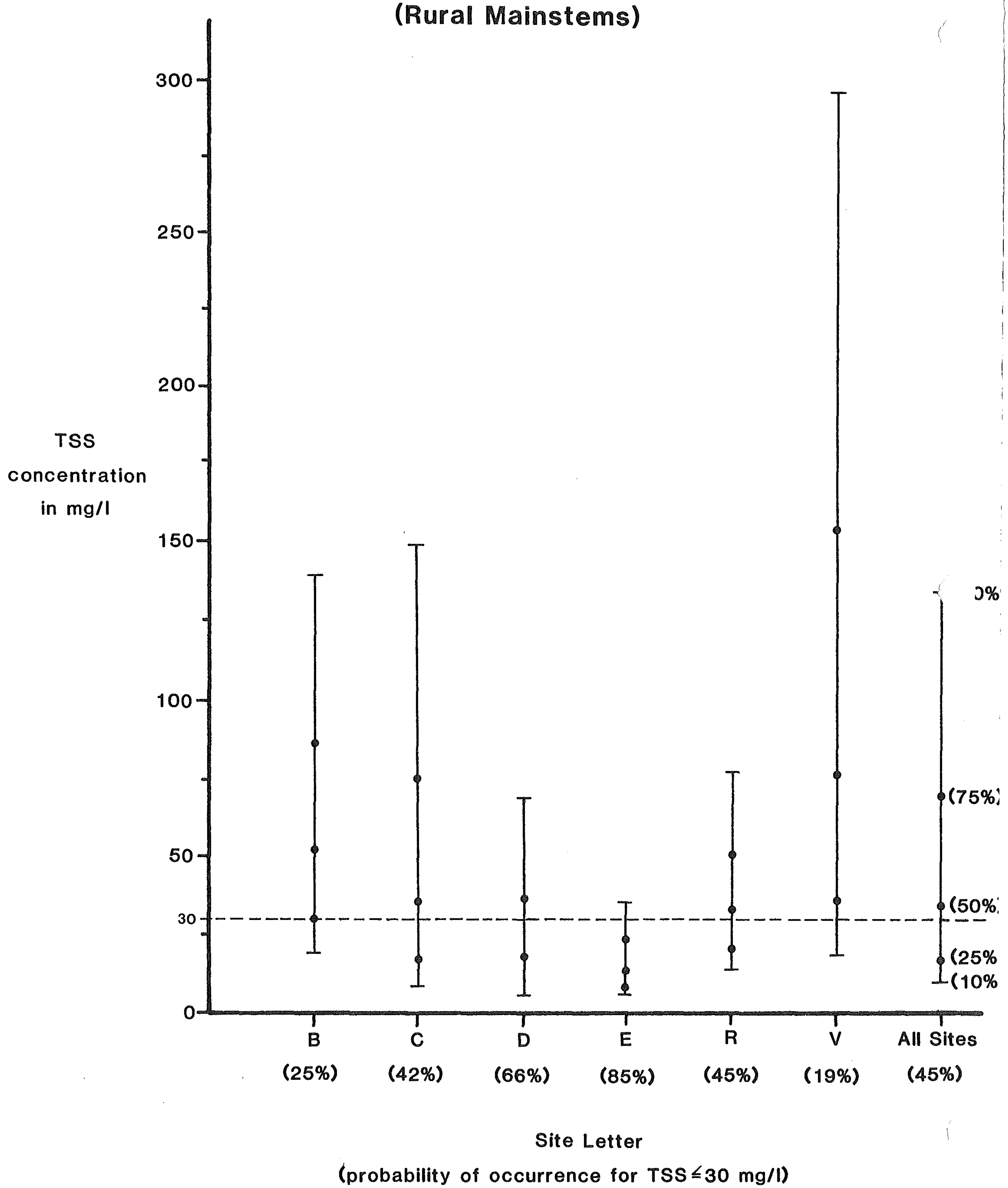


Figure 15. Probability of Occurrence for Lead in Wet Weather Flows (Storm Sewers)

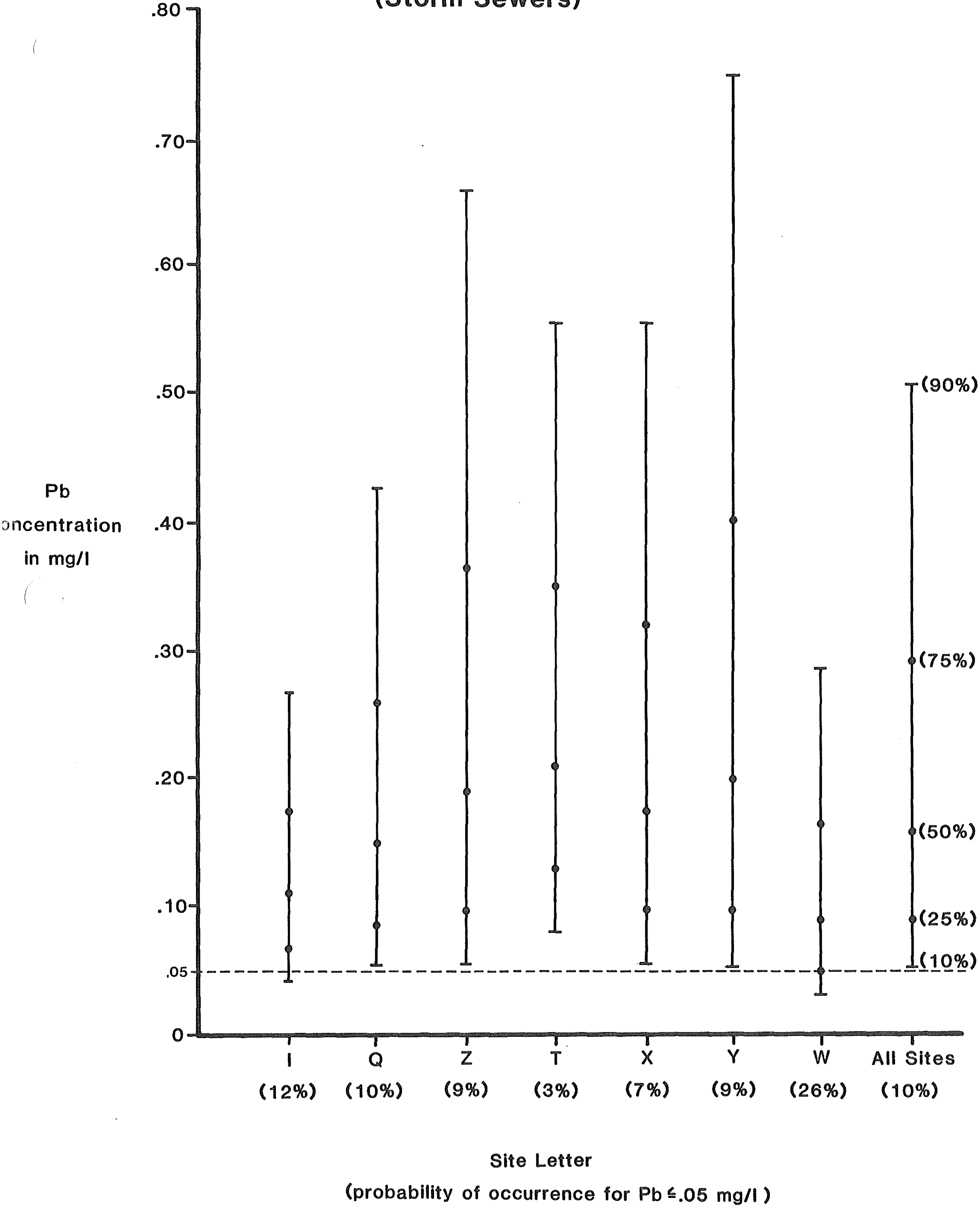
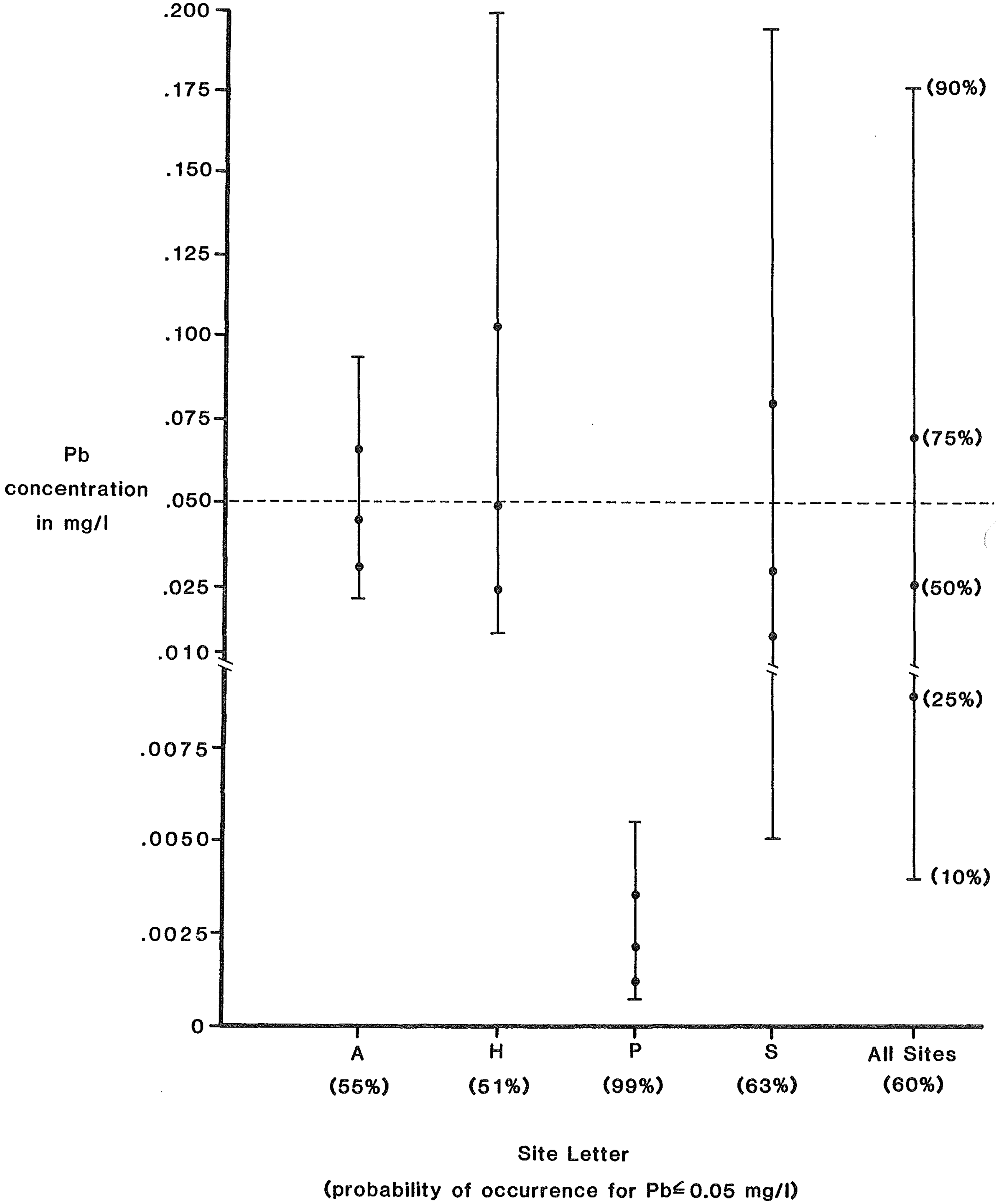


Figure 16. Probability of Occurrence for Lead in Wet Weather Flows (Urban Mainstems)



Other water quality guidelines were also greatly exceeded by 1980's average values. Chloride winter values in most of the urban storm sewers equalled or exceeded the criterion; peaks exceeded the 250 mg/l criterion up to 38 times (Yates). Mean nitrate guidelines were never exceeded and only one maximum value was in excess (Bevens). Metals concentrations equalled or exceeded some of EPA's recommended criteria in most instances. For cadmium (not presented in Table 6) in the agricultural areas, most means fell within or slightly above the aquatic and human health values while peaks exceeded the criterion up to five times. The mainstem sites have quite low readings, and the urban storm sewer sites have values similar to the agricultural sites. Chromium mean values for all sites exceed the 24-hour recommended aquatic life average of 0.29 ug/l Cr and many exceed even the limit recommended never to be exceeded by humans (50 ug/l). The peak value of 820,000 ug/l at Sandburg on March 20 is one that raises suspicion about sample contamination. An isolated single value this high likely indicates sample contamination or a reporting error.

Copper values (again not presented in Table 6) usually exceed the aquatic criterion, but only once (Sandburg) does a peak exceed the human health criterion. Lead for Purgatory and all of the agricultural sites, except Vermillion, falls well below EPA's criterion. The storm sewer sites, Vermillion and two of the mainstem sites, however, exceed to some degree the EPA criterion. The highest Pb mean occurred at Hwy. 100 because of the traffic. The highest peak occurred at 80th St., but again this station rarely flowed. Of greater concern would be the high values of Hwy. 100, Estate, Yates and Sandburg, all of which flow every time it rains.

Nickel values (again not in Table 6) remain quite low except for an occasional peak that exceeds the criterion. Finally, zinc values for most sites are quite high. Although a human health recommendation from EPA does not yet exist, most means and all but a few peaks get into and above the recommended aquatic levels.

As far as pesticides are concerned, reference to Table 5 shows that EPA criteria exist only for 2,4-D and dieldrin. Table 4 shows dieldrin was detected only once and at a level above the human health limit and in the aquatic range. Table 4 also shows that 2,4-D was detected twice, both at levels below EPA's criterion. Criteria for the other pesticides reported in Table 4 do not exist, but the presence of several pesticides in June runoff indicates that potentially toxic chemicals are being moved shortly after being applied to field surfaces.

LOAD SUMMARIES

ANNUAL LOADINGS

The total loads for 1980 at the 17 sites are listed in Table 7. In order to compare the loads from the various sites, a normalization procedure can be done to place all sites on a load-per-unit-area basis. Table 8 shows the normalized loads in pounds per acre (and kilograms per hectare) for the six rural sites and Table 9 shows similar values for the urban sites.

Examination of Table 8 shows that the South Branch Vermillion site far exceeds the other sites in normalized loading for most constituents; this is likely due to the intensive cash cropping practices (TSS); tile drainage (nitrogen); extensive fertilizer application (nutrients); and irrigation (runoff). Elm Creek is low in particulate runoff, but rather high in dissolved constituents

Table 7
LOAD SUMMARIES FOR 1980

Site (Letter)	Area (mi^2)	TSS	COD	TKN	N/N	TP	Cl	Pb	Q (inches)
		Load in Pounds							
Bevens (B)	82.90	997,725	1,678,202	76,964	65,315	17,426	855,863	--	1.86
Carver (C)	65.20	649,835	1,635,782	60,505	12,229	17,412	653,830	114.9	2.11
Raven (R)	32.40	500,025	845,209	43,478	41,156	7,955	179,840	48.2	2.30
Credit (D)	23.20	365,225	823,066	34,419	7,343	8,306	130,642	93.2	3.42
Elm (E)	14.30	85,387	542,689	17,327	2,269	2,882	277,731	47.6	4.02
Vermillion (V)	30.80	3,056,625	1,205,939	56,726	91,207	10,402	217,575	--	6.65
80th St. (H)	1.55	32,050	52,850	1,840	543	435	31,815	47.7	3.24
Bassett (A)	31.70	1,583,590	1,118,924	44,575	9,321	7,508	1,759,300	748.0	5.36
Shingle (S)	22.90	446,780	536,507	25,017	3,734	3,266	637,650	502.4	3.69
Purgatory (P)	24.00	218,460	603,796	16,687	529	1,095	467,300	39.3	3.14
Iverson (I)	0.15	174,700	9,571	327	26	163	19	6.8	2.43
PDQ (Q)	0.13	59,537	8,838	594	75	156	1,644	9.0	4.96
Wesley (W)	0.33	73,363	28,910	886	531	209	12,091	221.6	7.0[illegible]
Sandburg (Z)	0.12	103,490	20,317	872	125	68	17,200	29.2	10.42
Hwy. 100 (T)	0.47	34,704	50,650	761	188	126	28,233	165.0	6.41
Estates (X)	0.22	7,753	15,575	529	93	138	16,240	38.8	5.63
Yates (Y)	0.35	35,710	35,446	1,116	155	141	12,022	23.9	4.41

Table 8
1980 AGRICULTURAL WATERSHED LOADS AND PERCENTAGE WETLAND IN MONITORED WATERSHEDS

Site	Area sq. mi. (km^2)	Wetland Percent Water	Load lb/acre (kg/ha) TSS	COD	TKN	NN	TP	Annual Runoff in. (cm)
Bevens Creek	82.9 (215)	5.2 (0.8)	18.8 (21.1)	31.6 (35.5)	1.44 (1.61)	1.23 (1.38)	0.33 (0.37)	1.86 (4.72)
Carver Creek	65.2 (169)	9.6 (9.3)	15.6 (17.5)	39.2 (44.0)	1.45 (1.63)	0.29 (0.33)	0.42 (0.47)	2.11 (5.36)
Raven Stream	32.4 (83.9)	5.8 (0.2)	24.1 (27.1)	40.8 (45.7)	2.10 (2.35)	1.98 (2.23)	0.38 (0.43)	2.30 (5.84)
Credit River	23.2 (60.1)	11.0 (3.0)	24.6 (27.6)	55.4 (62.2)	2.32 (2.60)	0.50 (0.56)	0.56 (0.63)	3.42 (8.86)
Elm Creek	14.3 (37.0)	16.3 (0.2)	9.3 (10.5)	59.3 (66.5)	1,89 (2.12)	0.25 (0.28)	0.32 (0.35)	4.02 (10.21)
So. Branch Vermillion R.	30.8 (79.8)	4.0 (0.0)	155.1 (174.0)	61.2 (68.6)	2.88 (3.23)	4.63 (5.19)	0.53 (0.59)	6.65 (16.89)

because of the numerous wetlands that trap particulates while allowing solubilization of organic materials and nutrients. Bevens Creek had a high flow-weighted mean concentration for most constituents, but has a relatively low normalized load because of the large watershed size. The other watersheds fall generally in the same ranges for most constituents.

Table 9 shows the urban mainstem streams (first four) and the urban storm sewers (last seven). The most striking things to note here are the tremendous per-unit increases from the rural watersheds and the attenuation of normalized load from the storm sewers to the mainstems. Relative to the first point, only the South Branch Vermillion site falls in the TSS range of Table 9; for the other constituents, the rural watersheds are about the same as the urban mainstem, but markedly below the storm sewer sites.

Much load attenuation exists as the mainstems receive and assimilate stormwater runoff. Recall that Wesley, Sandburg and Hwy. 100 drain to Bassett Creek; Estates and Yates to Shingle Creek; PDQ to Purgatory Creek; and Iverson to 80th St. Reasons for this normalized load reduction are physical settling, biological uptake, aeration, oxidation and chemical transformation and runoff from non-urban areas.

Further details on the annual loading data will occur in the USGS technical completion report currently in preparation (Ayers et al., 1982). The USGS report will evaluate several of the mechanisms believed responsible for the load differences seen in Tables 8 and 9.

SEASONAL LOADINGS

The pollutant loading associated with snowmelt is particularly crucial to determine because it likely plays a significant role in the total annual load. This is important because the Council's orientation toward lakes, and to a lesser degree, tributary streams, requires the quantification of annual load. In most situations pollution washed into lakes during the winter and spring remains available to aquatic organisms during the growing season, that is, lakes do not pass pollution along as readily as rivers and streams.

Snowmelt loading was found to be a very significant part of total annual load for all sites, and particularly significant in the rural areas. A prior Metropolitan Council report (1981c) detailed the various components of the snowmelt load on an event basis. This analysis showed that the melt that occurred in mid- to late-March totally dominated the seasonal loading in the storm sewer, agricultural and mainstem sites. At the urban sites, snowmelts were recorded and data were collected for between two (Iverson) and eight (Estates) separate snowmelt events plus baseflow. The March melt accounted for approximately 61 to 94 percent of the seasonal flow and dominated the seasonal load, being responsible for 51 to 97 percent of this load (ignoring Cl which behaves differently). The Iverson construction site in Cottage Grove was also not used in the above comparisons because activity at the site was not yet fully under way during March. The ground was largely frozen and construction traffic was very light. The true indication of construction loadings will come in the analysis of precipitation event loading.

Table 9
1980 URBAN WATERSHED LOADS AND PERCENTAGE WETLAND FOR MONITORED SITES

Site	Area sq. mi. (km)^2	Wetland Percent (water)	Load lb/acre (kg/ha) TSS	COD	TKN	NN	TP	Pb	Annual Runoff in. (cm)
Bassett Creek	31.70 (82.10)	8.1 (6.4)	78.1 (87.6)	55.2 (61.9)	2.20 (2.46)	0.46 (0.52)	0.37 (0.42)	0.037 (0.041)	5.36 (13.61)
Shingle Creek	22.90 (59.30)	8.2 (4.6)	30.5 (34.2)	36.6 (41.1)	1.71 (1.91)	0.25 (0.29)	0.22 (0.25)	0.034 (0.038)	3.69 (9.37)
Purgatory Creek	24.00 (62.20)	14.5 (4.9)	14.2 (16.0)	39.3 (44.1)	1.09 (1.22)	0.03 (0.04)	0.07 (0.08)	0.003 (0.003)	3.14 (7.98)
80th Street	1.55 (4.01)	1.5 (0.0)	32.3 (36.2)	53.3 (59.8)	1.85 (2.08)	0.55 (0.61)	0.44 (0.49)	0.048 (0.054)	3.24 (8.23)
Iverson	0.15 (0.39)	0.0 (0.0)	1820.0 (2041.0)	99.7 (112.0)	3.41 (3.82)	0.27 (0.30)	1.70 (1.91)	0.071 (0.079)	2.43 (6.17)
PDQ	0.13 (0.38)	0.0 (0.0)	716.0 (803.0)	106.0 (119.0)	7.14 (8.01)	0.90 (1.01)	1.88 (2.10)	0.108 (0.121)	4.96 (12.60)
Wesley	0.33 (0.86)	4.0 (0.0)	347.0 (390.0)	137.0 (154.0)	4.20 (4.71)	2.51 (2.82)	0.99 (1.11)	1.049 (1.177)	7.03 (17.90)
Sandburg	0.12 (0.31)	0.0 (0.0)	1350.0 (1512.0)	265.0 (297.0)	11.40 (12.70)	1.63 (1.83)	(0.89) (0.99)	0.380 (0.426)	10.42 (26.50)
Hwy 100	0.47 (1.22)	0.3 (0.0)	115.0 (129.0)	168.0 (189.0)	2.53 (2.84)	0.62 (0.70)	0.42 (0.47)	0.549 (0.615)	6.41 (16.30)
Estates	0.22 (0.57)	0.0 (0.0)	55.1 (61.8)	111.0 (124.0)	3.76 (4.22)	0.66 (0.74)	0.98 (1.10)	0.276 (0.309)	5.63 (14.30)
Yates	0.35 (0.91)	0.0 (0.0)	159.0 (179.0)	158.0 (178.0)	4.98 (5.59)	0.69 (0.78)	0.63 (0.71)	0.107 (0.120)	4.41 (11.20)

At the agricultural and mainstem urban sites there was less response to melts, with the agricultural areas having only one response and the mainstems having from one to three melt responses. Again, the March event overwhelmed the baseflow and any other melt in terms of pollutant loading, contributing generally from 50 to 90 percent of the seasonal load.

The earlier report shows that the level of pollution loading associated with the baseflow is not commensurate with the level of flow. For example, baseflow runoff percentages for the storm sewer sites range from 4 to 16 percent of the seasonal total, but loadings for those same baseflows range from 0 to 8 percent of seasonal total, with pollutant totals ranging from 1 to 4 percent (ignoring Cl and the 76 percent N/N baseflow loading at Vermillion). The implication of these figures is that baseflow loading is not a significant contributor to snowmelt seasonal loadings, with the exception of Cl. The reason for Cl being an exception is that it is placed directly on road surfaces and any melt whatsoever will mobilize the highly soluble Cl and carry it into sewers or receiving streams. The result of this ready availability is that Cl loading occurs more uniformly over the melt season. Other pollutants that follow this phenomenon to a much lesser degree at various sites are TSS, COD, N/N and Pb. The Sandburg and Hwy. 100 sites have the most pronounced spread across the melting season because their densities of traffic and road salting/salt deposit from vehicles are higher than the other sites.

Many interesting facts can be obtained from the normalized snowmelt load figures occurring in Table 10. Starting with the TSS data, the most obvious individual piece of data is the Iverson construction loading; although activity was limited and runoff was very low, the runoff that did occur was extremely high when normalized (83,333 pounds per square mile per inch of runoff) because the ground had been exposed in anticipation of construction activity. Sandburg and Hwy. 100 had the next highest loadings. These two sites are, respectively, an industrial complex and a high-density residential area with a major highway bisecting it. The sediment loading at these sites is due to road sanding, vehicle carry-ins and erosion/degradation of uncurbed roadways (particularly the Sandburg site where truck traffic was heavy). The other urban sites reacted as would be expected for their land uses.

For the mainstem sites, Purgatory Creek, 80th St. and Bassett Creek values were all quite low because Purgatory Creek discharges from a lake, 80th St. discharges from a detention pond and Bassett has a fair amount of wetland and detention storage (both natural and artificial) in the watershed. Shingle Creek was higher because of residuals from winter dredging upstream of the monitoring station (data from the actual period of dredging are not included in the data analyses) and the lack of upstream detention storage. For the agricultural stations, Vermillion has the highest loadings and responded the fastest with the greatest concentrations to melt events. The reason for Vermillion loading is generally believed to be its lack of wetland storage (only 4 percent of the total watershed; Table 2) and its large percentage of plowed fields. The watersheds contributing the next two highest loads are similarly placed in order with respect to surface water and wetland surface areas; they are Raven Stream and Bevens Creek. The lowest agricultural loadings came from Elm Creek which has a large percentage of wetland area and responded the slowest of all of the agricultural sites, although it did contribute a moderate amount of total flow (1.77 inches; Table 10).

Table 10
NORMALIZED LOADINGS FOR JAN. 1 TO APRIL 15, 1980
Pounds/Square Mile
(Pounds/Square Mile/Inch Runoff)

Site	TSS	COD	TKN	N/N	TP	Cl	Pb	Runoff (inches)
Bevens	4,497	13,920	837	216	200	6,408	---	1.07
	4,203	13,009	782	202	187	5,989		
Carver	2,572	15,340	663	132	161	4,134	0.80	1.09
	2,360	14,073	608	121	148	3,793	0.73	
Credit	4,598	22,974	1,040	189	200	3,576	1.80	2.03
	2,265	11,314	512	93	99	1,762	0.89	
Raven	10,377	20,800	642	846	196	4,109	1.20	1.79
	5,797	11,620	359	473	109	2,296	0.67	
Elm	2,928	19,507	842	196	167	7,374	1.80	1.77
	1,654	11,201	476	111	94	4,166	1.00	
Vermillion	19,917	17,622	1,023	972	149	3,302	1.90	2.33
	8,548	7,563	439	417	64	1,417	0.82	
Bassett	5,601	10,685	427	116	62	26,128	5.80	1.48
	3,784	7,220	289	78	42	17,654	3.90	
Shingle	10,728	13,069	569	99	105	24,794	13.40	1.34
	8,006	9,752	425	74	78	18,503	10.00	
Purgatory	1,733	6,708	358	5.4	4.4	3,271	0.18	1.09
	1,590	6,154	328	5.0	4.1	3,000	0.17	
80th	3,955	13,299	617	135	155	7,608	7.60	1.10
	3,595	12,090	561	123	141	6,916	6.90	
Estates	13,810	21,660	908	182	200	46,900	43.00	1.62
	8,519	13,370	560	112	123	28,950	27.00	
Sandburg	45,480	45,470	817	237	153	126,200	91.00	2.15
	21,153	21,149	380	110	71	58,698	42.00	
Hwy. 100	21,100	31,170	1,040	73	145	46,170	60.00	1.31
	16,107	23,794	794	56	111	35,244	46.00	
PDQ	13,710	18,840	716	235	127	15,060	17.00	1.12
	12,241	16,821	639	210	113	13,446	15.00	
Yates	6,200	14,170	703	176	102	44,920	29.00	1.17
	5,299	12,111	601	150	87	38,393	25.00	
Iverson	5,000	980	28	15	9	320	1.00	0.06
	83,333	16,333	467	250	150	5,333	17.00	
Wesley	23,418	40,012	1,510	295	282	36,515	74.12	2.36
	9,881	16,918	639	125	119	15,440	31.34	

The COD figures in Table 10 also reveal a great deal about the sites, especially when compared by ratio to the TSS column. Again the highest normalized loadings are from the dense urban sites, but some of the agricultural sites are almost as high. The TSS:COD ratios of all of the sites are:

Bevens	0.32	80th	0.30
Carver	0.17	Estates	0.64
Credit	0.20	Sandburg	1.00
Raven	0.50	Hwy. 100	0.68
Elm	0.15	PDQ	0.73
Vermillion	1.13	Yates	0.44
Bassett	0.52	Iverson	5.10
Shingle	0.82	Wesley	0.59
Purgatory	0.26		

All of the agricultural sites (except Vermillion), Purgatory Creek and 80th St. have very low TSS:COD ratios. These low ratios indicate that the high COD values are not in heavy sediment form (large-grained inorganic soil particles), but rather are occurring in soluble form and as fine-grained, more organic particulate matter. This finding is quite significant; the likely process that is occurring is that vegetation exposed in the agricultural fields, wetlands, lawns and in the heavily vegetated detention pond at 80th St. is decomposing over the winter season. The ruptured cells and the physical disintegration of the plant material both contribute to the soluble and fine-grained particulate COD load. Additionally, the ground is frozen so infiltration is minimized. The settling that does occur in fields or in wetlands is limited to large-sized particles. The Vermillion watershed, on the other hand, has soils that are coarser and contain less clay; there are fewer wetlands to capture migrating large particles or to produce soluble COD; and watershed response is faster, with velocities able to carry heavier soil particles. These similar processes, only to a much larger degree, occur in the urban storm sewer watersheds, where the TSS:COD ratios range from lows of 0.44 and 0.64 in the residential areas to highs of 1.0 and 5.1 in the industrial and construction areas. The mainstem Bassett and Shingle sites occur in the mid-range (0.52 and 0.82).

The management implications following from the TSS and COD data are: that conservation tillage systems (like chisel plowing) that "rough up" a field while incorporating some of the residue are desirable to increase field detention pockets, minimize availability of decomposed vegetation to runoff and break up the hard surface that might inhibit infiltration; that vegetated buffer strips and grassed waterways are very useful to minimize erosion and trap sediments closer to the source; that dry detention storage areas (as in 80th St.) should contain a minimum of over-winter vegetation in anticipation of spring flushing; that construction sites should detain sediment on-site; and that maintenance of existing wetlands and detention storage in a watershed enhances overall water quality, particularly in high-density residential and industrial areas.

The seasonal nutrient loading data is similarly revealing when normalized, although distinctions are far less obvious. All of the monitored sites are generally in the same TKN range, and generally follow COD trends. The nitrate/nitrite (N/N) figures are similarly grouped in a close range with the exception of the Raven and Vermillion sites at 473 and 417 pounds per square mile per inch, respectively, and Purgatory Creek on the low end with a figure of 5.0 (Table 10). The two heavily agricultural watersheds are believed to have high soluble N/N loadings because of general absence of large wetland areas, presence of tile drainage, and probable high application of nitrogen fertilizers (information from interviews with county Soil Conservation Service personnel). The low Purgatory Creek loading is thought to be a result of nitrogen retention in Staring Lake. Total phosphorus (TP) again clusters within a fairly tight range, with no single site except Purgatory Creek particularly anomalous. The TP values are surprisingly high when compared to the nitrogen. This is most likely a result of the movement of phosphorus in association with fine-grained particles and in dissolved organic form (seen also in the COD data). Again, management techniques that minimize field runoff and vegetative exposure to runoff and that detain water and sediment are desired.

The remaining loading data on chloride (Cl) and lead (Pb) show similar behavior for similar land uses. Extremely high Cl and Pb loadings were observed at the Sandburg, Hwy. 100, Yates and Estates sites. Application of salts for deicing mobilizes massive amounts of chlorides with temperatures reaching only into the twenties Fahrenheit. The melt also carries with it the high Pb content of the slush and road debris deposited from vehicular traffic. Chloride and Pb in the agricultural runoff were low. In the mainstem sites, 80th was low because of the low salt usage in the Pinetree Pond Subdivison by the City of Cottage Grove and the detention storage; Purgatory, Shingle and Bassett Creeks were relatively low because of dilution of direct street runoff by discharges from areas of less intense urban uses. From a management standpoint, the controversy over application of salt to streets for safety versus limited application for environmental reasons is one that likely will result in safety dominating, as perhaps it should. The 208 program, however, should stress the fact that wise use of salt should be practiced not only because of the potential Cl problem, but also because of the associated pollutants like Pb that are readily carried from street surfaces every time a melt occurs; additional plowing and sanding with selective salting would likely reduce winter loading. Not encouraging melt by large applications of salt is an environmental practice that would additionally result in reduced costs for municipalities, counties and MnDOT. (See also Appendix G.)

The February 1981 report (1981c) contains normalized loading data on a seasonal basis for the three rainfall seasons. The precipitation that occurred during 1980 at the 17 sites, as well as the snowfall water equivalents, are shown in Table 11. The data here show that 1980 was a drier year than normal with a range of only 19.96 to 27.07 inches. The 1980 precipitation at the Minneapolis-St. Paul Airport was 21.77 inches, while the long-term normal is about 25.9 inches. The recurrence interval for 1980, based on the 1941-1980 Weather Bureau record, was 1.41 years, or 29 percent of the years can be expected to be less than or equal to 21.77 inches. The precipitation data for the 17 sites were obtained from the precipitation network outlined in Figure 1.

The February (1981c) report shows that the urban and agricultural sites behaved in a quite different manner. The major runoff loading for the urban sites occurred during the summer period, whereas the spring loading dominated at the agricultural sites; for both sets of sites, most rainfall occurred during the summer period. The urban surfaces did react to this rainfall, but the agricultural watersheds did not. The reason for this has to do with exposed soil; during the spring, the agricultural fields are exposed without vegetative cover. The fields are worked (planted, fertilized) and left quite vulnerable to rainfall. In 1980 rainfall occurred at a very bad time (June 5 and 7) when vegetative growth had not really begun. The loading figures for the spring, therefore, reflect the results of two large events during a particularly bad

Table 11
1980 RAINFALL AMOUNTS

Site(s)	Snow-fall*	M	J	J	A	S	O	N	Total
Bevens	4.06	1.39	2.46	1.34	6.20	3.99	1.02	0.03	20.49
Raven	4.56	2.13	1.89	0.24	5.91	4.73	0.89	0.17	20.52
Credit	5.11	2.36	3.53	1.26	6.83	4.18	0.89	0	24.16
Vermillion	5.48	2.38	3.97	0.66	6.00	4.21	0.86	0.23	23.79
Elm	4.49	2.10	5.25	3.22	6.55	3.15	0.68	0.05	25.50
Iverson and 80th St.	6.62	2.52	6.66	2.03	4.49	3.70	0.85	0.20	27.07
PDQ and Purgatory	4.68	1.36	4.29	1.79	4.06	2.93	0.71	0.13	19.96
Hwy. 100	4.62	1.40	5.58	2.91	5.13	3.09	0.64	0.20	23.57
Wesley	4.62	1.58	6.81	3.13	4.52	3.10	0.70	0.21	24.67
Estates	4.49	1.54	4.17	2.82	6.39	3.29	0.50	0.07	23.28
Carver	4.62	1.39	2.46	1.34	6.20	3.99	1.02	0.03	21.05
Bassett	4.62	1.72	6.49	3.06	4.95	3.35	0.68	0.22	25.10
Sandburg	4.62	2.19	7.09	3.13	5.20	3.86	0.70	0.26	27.05
Yates	4.49	1.51	3.84	2.80	6.60	3.39	0.60	0.07	23.31
Shingle	4.49	1.53	4.00	2.81	6.50	3.34	0.55	0.07	23.29

* Water equivalent.

time. Once vegetation is established and a canopy covers the soil, the agricultural runoff and subsequent loading diminish in a disproportionate manner relative to rainfall volumes. In urban areas, however, the runoff appears to occur in a manner proportional to rainfall; that is, almost every rainfall results in a substantial nonpoint source load.

Several additional things are of particular note from the earlier report. The extremely high TSS load of Iverson is, of course, reflective of peak construction activity during the summer season; the high TSS values for Bevens and Vermillion, on the other hand, occur in the spring and are indicative of the bare soil circumstances described previously.

The TSS:COD ratios are again informative when used as an indicator of sediment-associated versus soluble or fines-associated pollutant movement. Those sites where TSS is much greater than COD (Bevens, Credit, Vermillion, Bassett, PDQ, Iverson, Wesley, Sandburg, Hwy. 100 and Yates) all show that sediment is a dominant problem during rainfall runoff events. The sites, however, where COD (predominantly in the soluble form) is greater than TSS (Carver, Raven and Elm) show a dominance of soluble or fines-associated pollutants. Comparison of snowmelt versus rainfall loading figures shows some interesting behavioral changes. All of the agricultural sites were dominated by COD loading during the snowmelt, except Vermillion which was just about even. Again, soil cover character is seen influencing pollutant behavior. When the snow melts, it usually does so slowly so that larger-grained sediments are not as easily mobilized; soluble and fine-grained associated pollutants, however, are easily moved without much water energy, hence a higher COD load relative to TSS. The reverse happens when the fields are bare and it rains; the tremendous raindrop impact energy and runoff energy mobilize sediment of all sizes and move it quite readily, hence a higher TSS load relative to COD.

Also of interest is the behavior of the TSS:COD ratio after the vegetation becomes established (the summer period, 6/16-9/15). Generally, movement of TSS is no longer dominant since the soil is shielded from raindrop impact and protected from large degrees of runoff energy. The TSS:COD ratios even out or change to COD enrichment, caused by leaching of soluble pollutants or movement of fine-grained material with little energy. On the urban surfaces, however, TSS greatly exceeds COD.

The relationships between TKN and N/N are quite variable, and informative. The TKN value greatly exceeds N/N for all of the urban storm sewer and mainstem sites. The organic nitrogen portion of the TKN figure is thought to explain this dominance over the soluble N/N figures. In the agricultural areas, however, soluble N/N is totally dominant in the rainfall runoff at the Bevens, Raven and Vermillion sites. Bevens and Raven N/N values are believed to be the result of nitrogen loading from wetlands and fertilizer application, whereas Vermillion's high figure is likely from fertilizer and tile drains.

Total phosphorus, Cl and Pb figures are more easily discussed in the normalized sense. Trends for these loadings relative to flow do not deviate from those noted for urban and agricultural sites discussed previously.

Table 12, like Table 10, reveals the normalized character of the monitored watersheds. If one starts again with the normalized TSS figures, Iverson stands out as the very dominant high loading situation because of the construction activity occurring in the small watershed. The next highest figure was PDQ; because of the general residential nature of the watershed, the small

Table 12
NORMALIZED LOADINGS FOR APRIL 16 TO DEC. 31, 1980

Pounds/Square Mile
(Pounds/Square Mile/Inch Runoff)

Site	TSS	COD	TN	TKN	N/N	TP	Cl	Pb	Runoff (inches)
Bevens	17,866	8,786	575	314	502	96	5,988	0.72	0.79
	(22,615)	(11,122)	(728)	(378)	(636)	(122)	(7,580)	(0.92)	
Carver	6,127	9,663	499	354	145	110	7,255	0.72	1.02
	(6,007)	(9,474)	(489)	(347)	(142)	(108)	(7,113)	(0.72)	
Credit	22,910	14,358	522	411	111	109	3,419	1.43	1.39
	(16,482)	(10,329)	(376)	(296)	(80)	(78)	(2,460)	(1.03)	
Raven	2,908	3,685	445	144	301	22	2,271	0.24	0.51
	(5,702)	(7,225)	(873)	(282)	(590)	(43)	(4,453)	(0.47)	
Elm	5,643	24,420	636	578	49	94	13,713	1.06	2.25
	(2,50)	(10,853)	(283)	(257)	(22)	(42)	(6,095)	(0.47)	
Vermillion	84,188	32,825	2,726	651	2,075	178	5,819	---	4.32
	(19,488)	(7,598)	(631)	(151)	(480)	(41)	(1,347)		
Bassett	31,095	18,782	793	631	162	106	25,678	17.80	3.88
	(8,014)	(4,841)	(204)	(163)	(42)	(27)	(6,618)	(4.59)	
Shingle	12,314	15,310	143	32	111	43	14,149	11.10	2.35
	(5,240)	(6,515)	(61)	(14)	(47)	(18)	(6,021)	(4.72)	
Purgatory	13,100	17,512	581	526	55	37	16,200	1.93	2.05
	(6,390)	(8,542)	(283)	(257)	(27)	(18)	(7,902)	(0.94)	
80th	21,277	12,342	469	416	53	125	2,241	11.00	2.14
	(9,943)	(5,767)	(219)	(194)	(25)	(58)	(1,047)	(5.14)	
Iverson	2,033,900	104,787	3,587	3,400	187	1,694	922	67.00	2.37
	(858,186)	(44,214)	(1,515)	(1,435)	(79)	(715)	(389)	(28.00)	
PDQ	398,700	59,808	2,158	2,006	152	619	558	56.00	3.84
	(103,828)	(15,575)	(562)	(522)	(40)	(161)	(145)	(15.00)	
Wesley	150,715	33,691	1,446	1,034	412	444	---	43.50	4.67
	(32,273)	(7,214)	(310)	(221)	(88)	(95)		(9.30)	
Sandburg	444,742	155,008	3,298	2,847	452	765	34,450	186.00	8.27
	(53,778)	(18,743)	(399)	(344)	(55)	(93)	(4,166)	(22.00)	
Hwy. 100	115,747	52,072	1,584	1,307	277	273	---	145.00	5.10
	(22,695)	(10,210)	(311)	(256)	(54)	(54)		(28.00)	
Estates	43,777	33,195	1,193	961	232	191	1,058	80.00	4.01
	(10,917)	(8,278)	(298)	(240)	(58)	(48)	(264)	(20.00)	
Yates	72,003	38,843	1,711	1,421	290	267	4,517	107.00	3.24
	(22,223)	(11,988)	(528)	(439)	(90)	(82)	(1,394)	(33.00)	

amount of construction in the lower end (9 of 80 total acres) was not expected to alter the loads as significantly as it did. PDQ is essentially the same ind of land use as Wesley or Estates, yet the normalized loading is five to 10 times larger. This shows the severe impact that construction activity can have when runoff is not controlled.

The three high loads in the agricultural areas (Vermillion, Bevens and Credit) are reflective of the quick watershed response to rainfall (Vermillion and Credit) or of animal access to streams (Bevens). Another very important factor affecting TSS load in these three watersheds is the lack of wetlands. In Bevens and Credit, the wetlands that do occur are generally in the upper part of the watershed, and thus cannot serve to filter sediment as it proceeds downstream. In Vermillion, most wetlands that once existed have been drained, to the point now where only four percent of the watershed contains wetlands. The three other agricultural watersheds, however, have many wetlands that help filter sediment and lower TSS normalized loading rates by a factor of three to 10 over the preceding three watersheds (see Appendix A). The lowest loads occurred in Elm Creek (2,508 pounds/sq. mi./inch), which has the largest percentage of wetlands (16.3 percent). The final TSS note is the lower normalized loads for the urban mainstem sites and 80th St. site. As discussed in the concentrations section, per unit loadings decrease with increasing watershed size, but it should still be noted that these tributary or secondary streams are impacted by the urban stormwater feeding them.

The COD normalized loads are again high for Iverson and PDQ, for reasons stated in the TSS discussion. The Sandburg station becomes quite apparent as the second highest value, however. This is undoubtedly because of the high organic, chemical oxygen demand exerted by the runoff associated with vehicular traffic and the TSS load. Vermillion drops as a significant COD load because of the dominance of inorganic particulates loading as seen in the TSS value. Elm and Carver increase in importance because of the enrichment of soluble and fines-associated pollutants from the wetlands. The Estates and Yates residential areas contribute significant loads because of pollutants associated with residential activities (traffic, lawns, pets).

Soluble N/N loading dominates in the Bevens, Raven and Vermillion watersheds as discussed previously; all other soluble N/N loading values are quite small by comparison. The high TKN values again occurred at Iverson and PDQ, where a high volume of organic N is mobilized whenever soils rich in organic matter are eroded. The rest of the TKNs generally followed what was expected based on watershed character.

The TP figures follow the previous findings relative to highs at Iverson and PDQ. Surprisingly high values also occur at Bevens and Carver; the likely explanation at Bevens is movement with the large amount of soil lost, whereas at Carver it is likely soluble P moving from the lakes and wetlands or adsorbed to fine-grained particles. Also of note are the very low TP figures at the three urban mainstem sites, figures which are much lower than the runoff figures of their tributary urban storm-sewered watersheds.

The Cl results are quite surprising in that agricultural loads are high. The reader is cautioned that much extrapolation of data was used to arrive at the total rural Cl load, but, on the other hand, the samples that were collected showed high Cl values. Likely explanations for these high Cl figures exist in the occurrence of at least one major highway running through a portion of each agricultural watershed. Movement from these surfaces, and subsequent slow migration down the watershed could cause elevated Cl readings. Other explanations are animal excrement, calcium chloride spray for dust control, and some isolated point source discharges and on-land spreading.

Lead (Pb) loadings behave according to expectations, that is, agricultural loading is low while urban loading is high. Of particular note again is the decreased normalized load associated with the mainstem urban sites. It must be emphasized, however, that a decreased normalized load does not mean that a very significant load does not occur; a quick reference to the loads in Table 12 for the mainstem sites shows the extent to which major Pb loads occur.

To summarize the entire discussion on seasonal loading, a series of seven bar graphs was made to represent the various behavioral patterns of the sampled watersheds. Figures 17 through 23 show the seasonal loading percentages for seven pollutants and the seasonal runoff volumes (Q). Figures 17, 18 and 19 show seasonal behavior for three rural area watersheds. Of particular note for all three is the loading dominance of the first two seasons. The snowmelt contribution is in the 50 percent range for most pollutants. The spring contribution is almost entirely the result of the June 5-7 event that shows up so clearly in Figure 5 of a previous section. For Vermillion (Figure 17) the COD, TSS, TKN and TP loads all occur in a similar manner, with about 90 percent of the load occurring early in the year. Nitrite-nitrate and runoff behave similarly, likely because the soils and drainage tiles allow for shallow subsurface movement of water and mobilization of soluble N/N. The seasonal character of Elm Creek (Figure 18) does not vary from pollutant to pollutant or to the runoff (Q); the runoff decreases seasonally as precipitation totals decrease and vegetative cover becomes established. Bevens Creek (Figure 19 and Figure 5) again shows the snowmelt and spring loading dominance and the flow reduction in the later two seasons as vegetation establishes. In summary, the rural area management attention should focus on decreasing early season loading by maximizing infiltration and on-site detention of stormwater. Conservation tillage and associated management practices should be successful in achieving this objective. Also, the pesticides discussed previously and shown in Table 4 are applied during this period of maximum runoff and loading; attention to pesticide and fertilizer application is certainly warranted.

Figure 20 is Bassett Creek, which acts similar to the other urban mainstem sites. Five of the pollutants and runoff behave in a similar seasonal manner, but TSS and Pb reach peaks during the spring most likely because of rainfall washing street surfaces clean of accumulated winter debris. Contrast Bassett Creek with Sandburg (Figure 21), a subwatershed within Bassett. Sandburg's pollutant seasonal behavior is not uniform between constituents; loading dominance is variable by season. The only uniform characteristic about the loads is the minimum load occurring for each constituent in the fall when precipitation decreases. The Cl and Pb peaks in the snowmelt are due to the tremendous vehicular traffic at this industrial park; the Cl allows for quick and frequent melting and of course the Pb from fuel is deposited directly on the streets where the road salt is applied. Finally, none of the pollutants behave in a consistent manner with runoff, a factor that illustrates well the erratic nature of urban stormwater runoff.

Figure 17. VER LLION SEASONAL RUNOFF LOADS, 1980

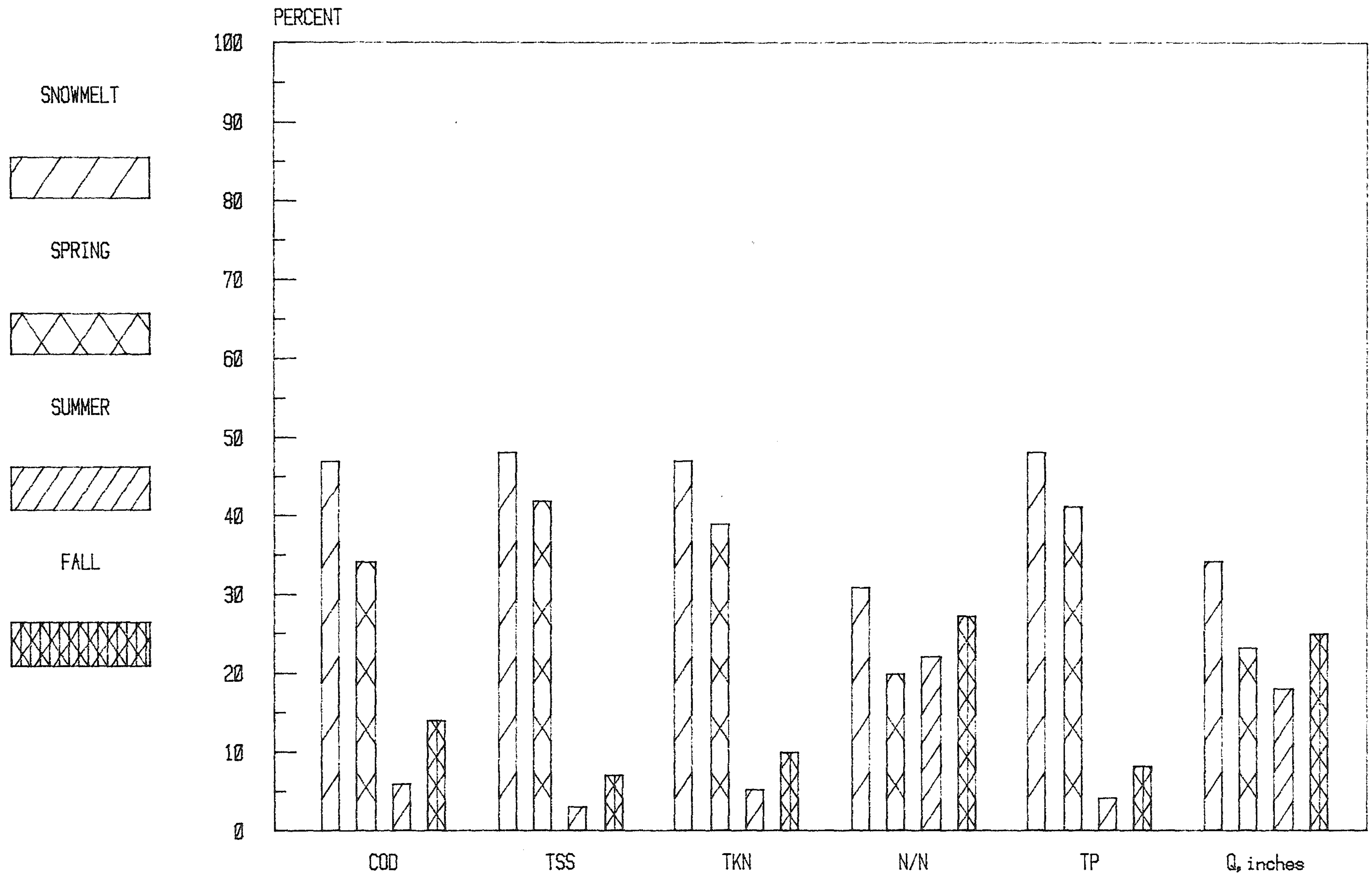


Figure 18. ELM CREEK SEASONAL RUNOFF LOADS, 1980

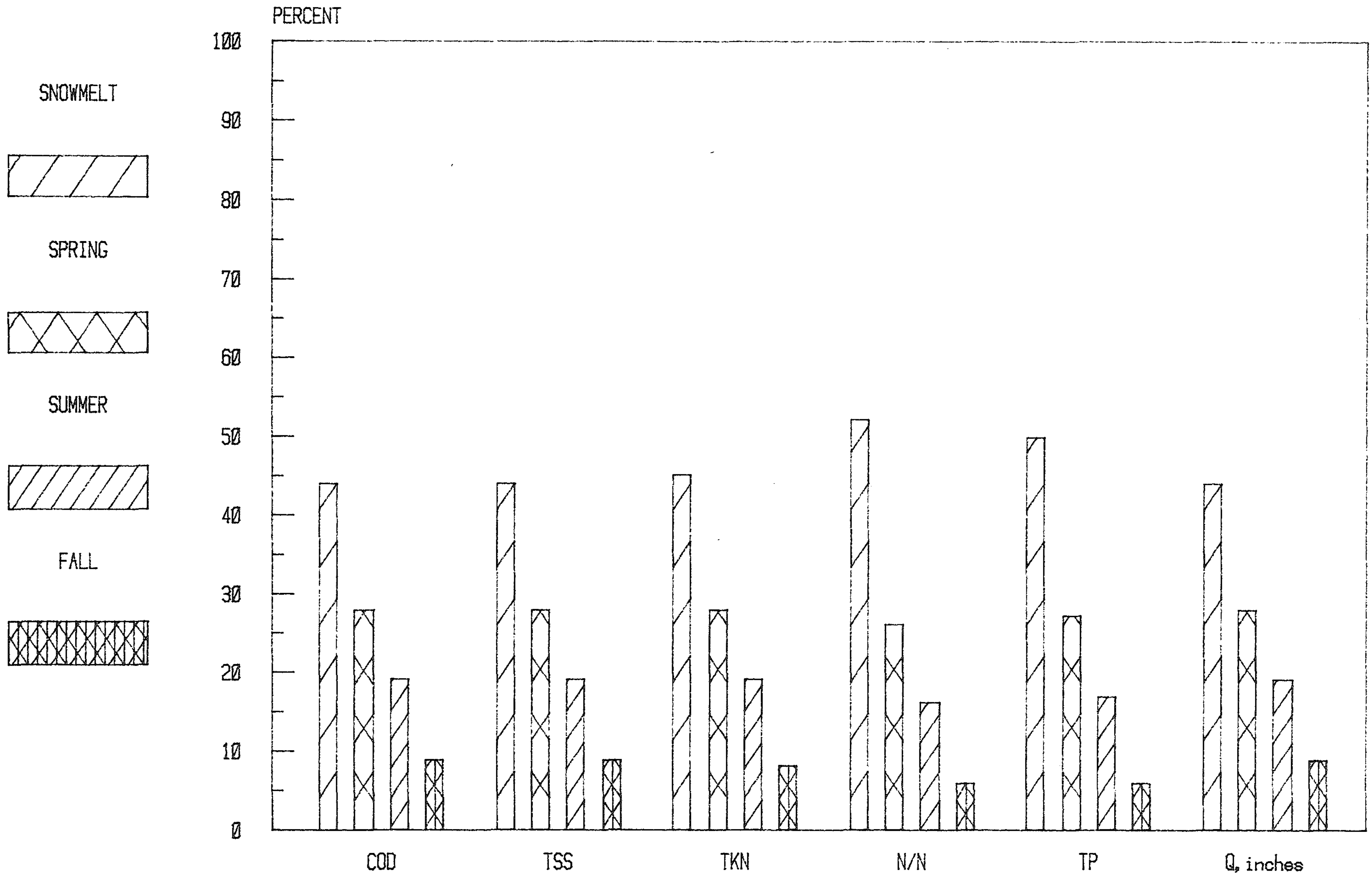


Figure 19. BEVENS SEASONAL RUNOFF LOADS, 1980

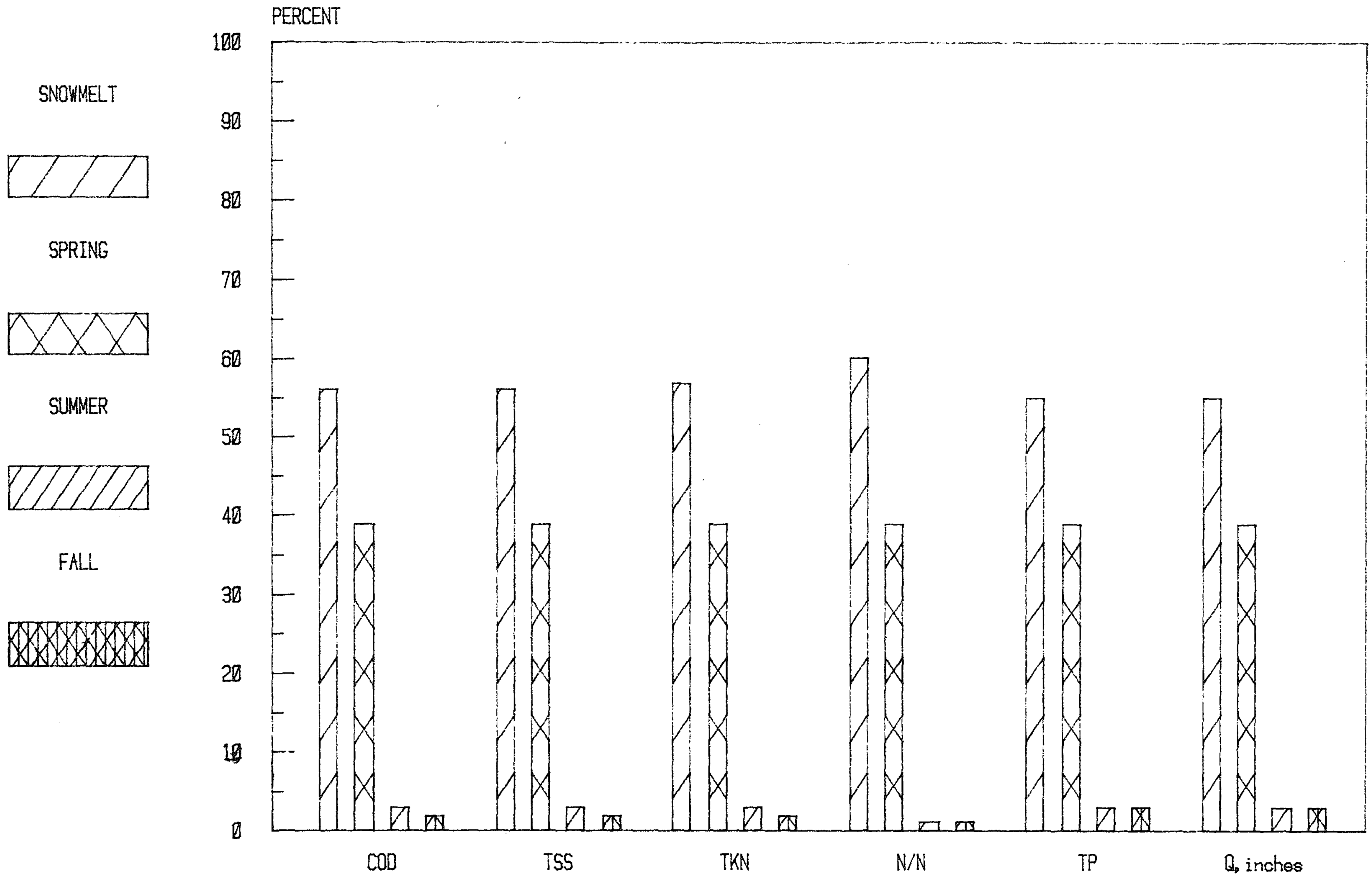


Figure 20. BASSETT SEASONAL RUNOFF LOADS, 1980

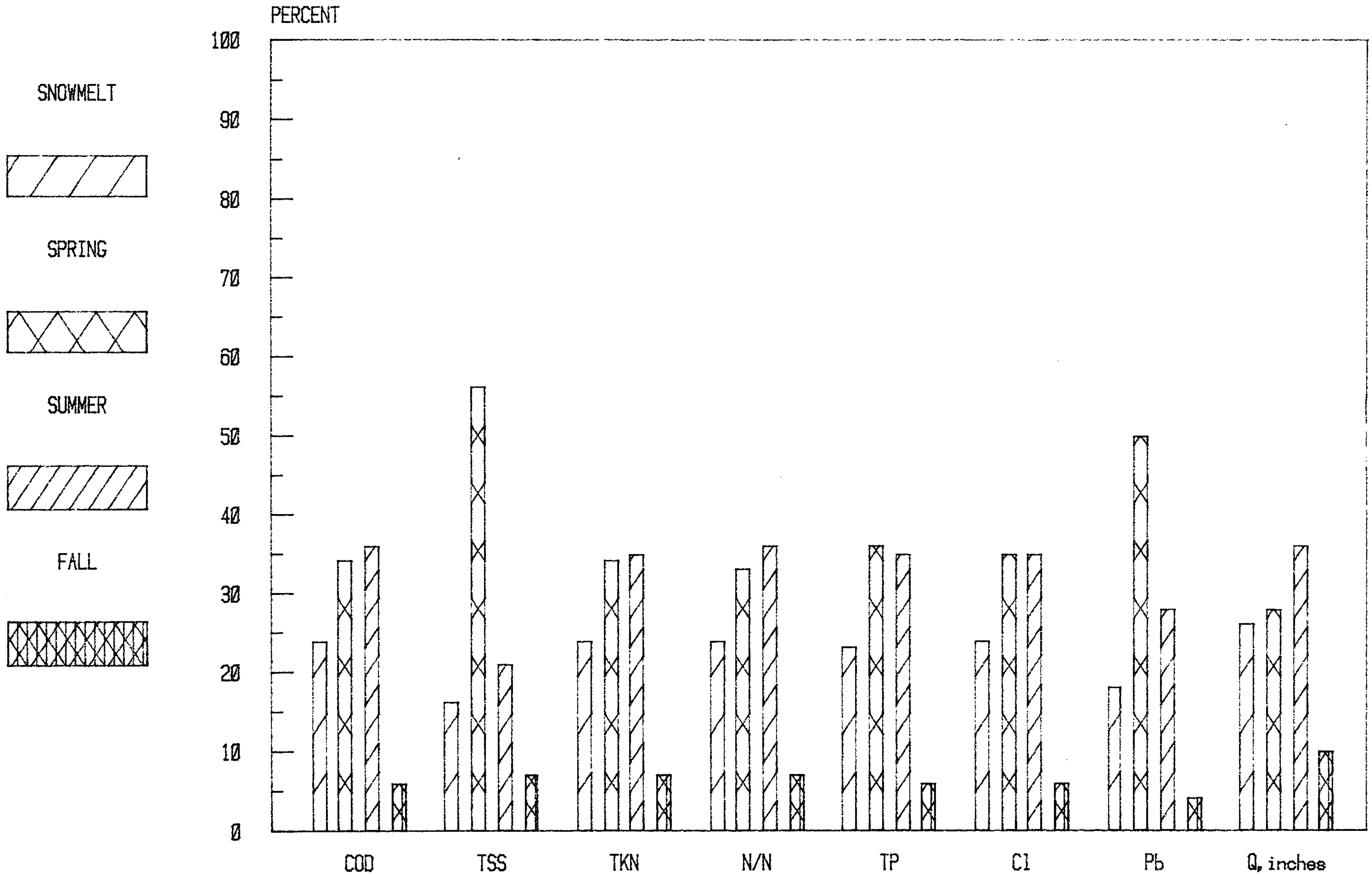


Figure 21. SANDBURG SEASONAL RUNOFF LOADS, 1980

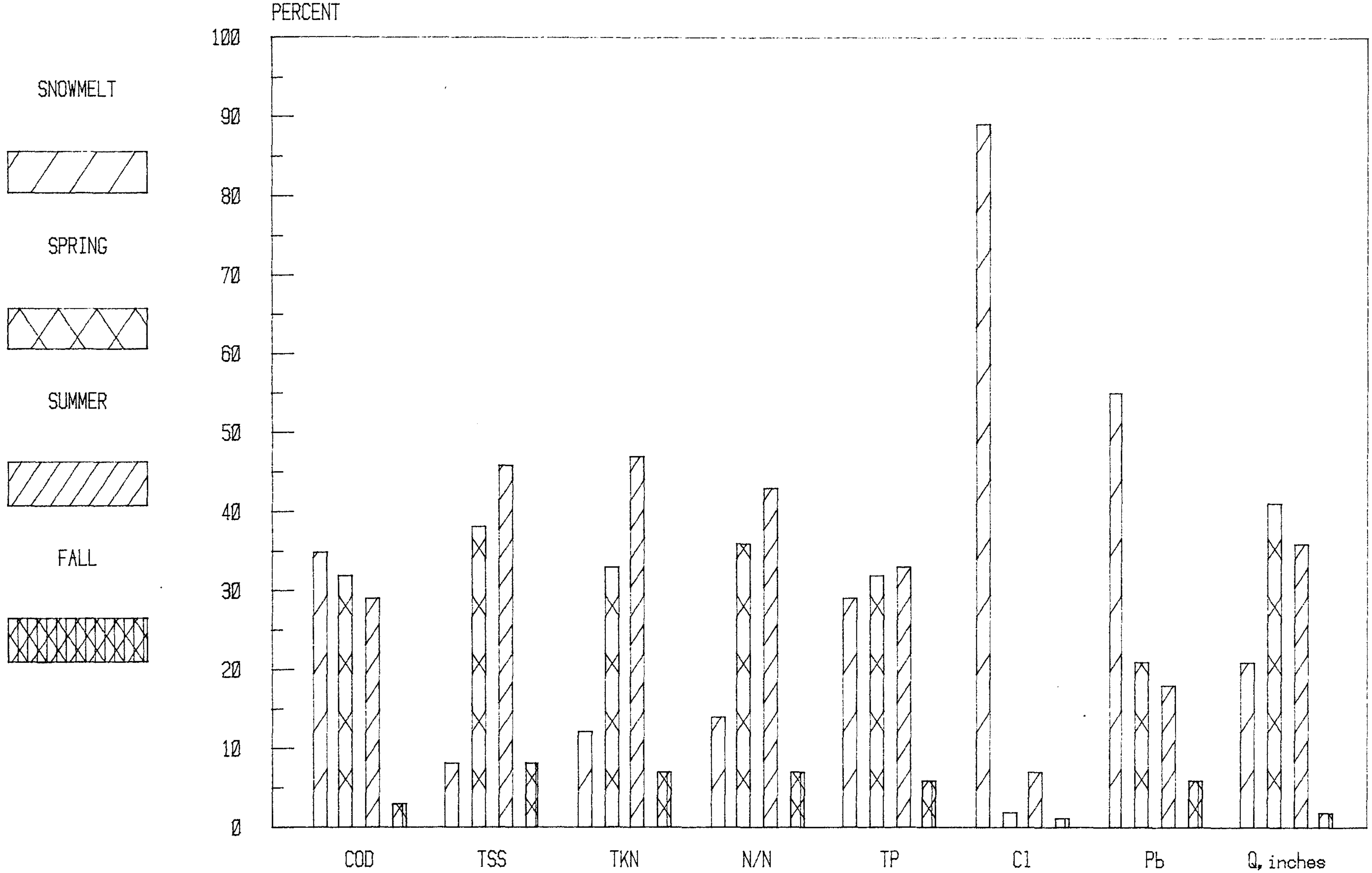


Figure 22 shows the residential Estates site runoff patterns. The seasonal patterns are quite similar to runoff with the exception of Cl. The Cl peak results from the application of 2:1 sand to road salt ratio for ice control. Brooklyn Park does a commendable job of salt storage and application control, but the 2:1 ratio is the highest in the Region and the results are seen in this figure. Figure 23 shows the Iverson construction watershed. The runoff and loading pattern clearly show evidence of loading during the construction season when the soil is exposed and activity is at its peak.

In summary, urban surfaces are more responsive to precipitation because of the presence of impervious surfaces. Pollutant behavior is quite variable, but it is safe to say that loading occurs throughout the year as the urban areas respond to essentially every snowmelt and precipitation event with a load contribution; management approaches should focus on control of frequent, small events rather than the larger, infrequent storms.

ATMOSPHERIC LOADINGS (WETFALL AND DRYFALL)

Six automatic wetfall/dryfall atmospheric samplers were purchased by the USGS Urban Hydrology Program and placed in the Region to standardize our area with the other areas in the program. The samplers consist of two buckets and a rotating lid that covers the dryfall bucket during precipitation and the wetfall bucket during dry periods.

The six samplers were placed around the Region (Figure 1) in an attempt to represent regional variability (as best as can be with only six samplers). Four of the six samplers (Bevens, Eden Prairie, Shingle and Cottage Grove) were placed at or very near flow monitoring sites; the other two samplers (Maplewood and Minneapolis) were placed in areas where it was felt atmospheric data was needed. The samplers were emptied and cleaned on a periodic basis that lasted from two weeks to two months, depending on the precipitation activity. All of the chemical analyses performed on the samples were done at the USGS laboratory in Atlanta.

The purpose of collecting atmospheric samples is to identify and quantify to a limited degree the pollutants that enter the land surface washoff system by means of atmospheric deposition. Of particular concern are those pollutants resulting from industrial processes, automobile exhaust and wind erosion of exposed land. The findings of this study will better enable us to determine nonpoint pollution sources and prepare management strategies for those sources. Atmospheric loading management also happens to be the most difficult source of pollution to control because locations of the source inputs are so extremely diverse and diffuse, varying from western Minnesota agricultural fields, to industries and power plants located in the Metropolitan Area, to any number of seemingly insignificant contributors.

Appendix B contains tables on the atmospheric collection statistics (Table B-1) and on the atmospheric loading totals (Table B-2) for seven constituents. Composite or bulk samples were taken for Cottage Grove and Shingle for several collection events because of equipment malfunction.

It is very important to note that the atmospheric data collected cannot be considered adequate nor statistically valid for the Region. The data were collected to determine the nature of atmospheric inputs, not to quantify in an absolute manner the loading totals. The figures presented here and in Appendix B will be used to make some generalizations and should not be used as a definitive statement of wetfall/dryfall loading.

Figure 22. ESTATES SEASONAL RUNOFF LOADS, 1980

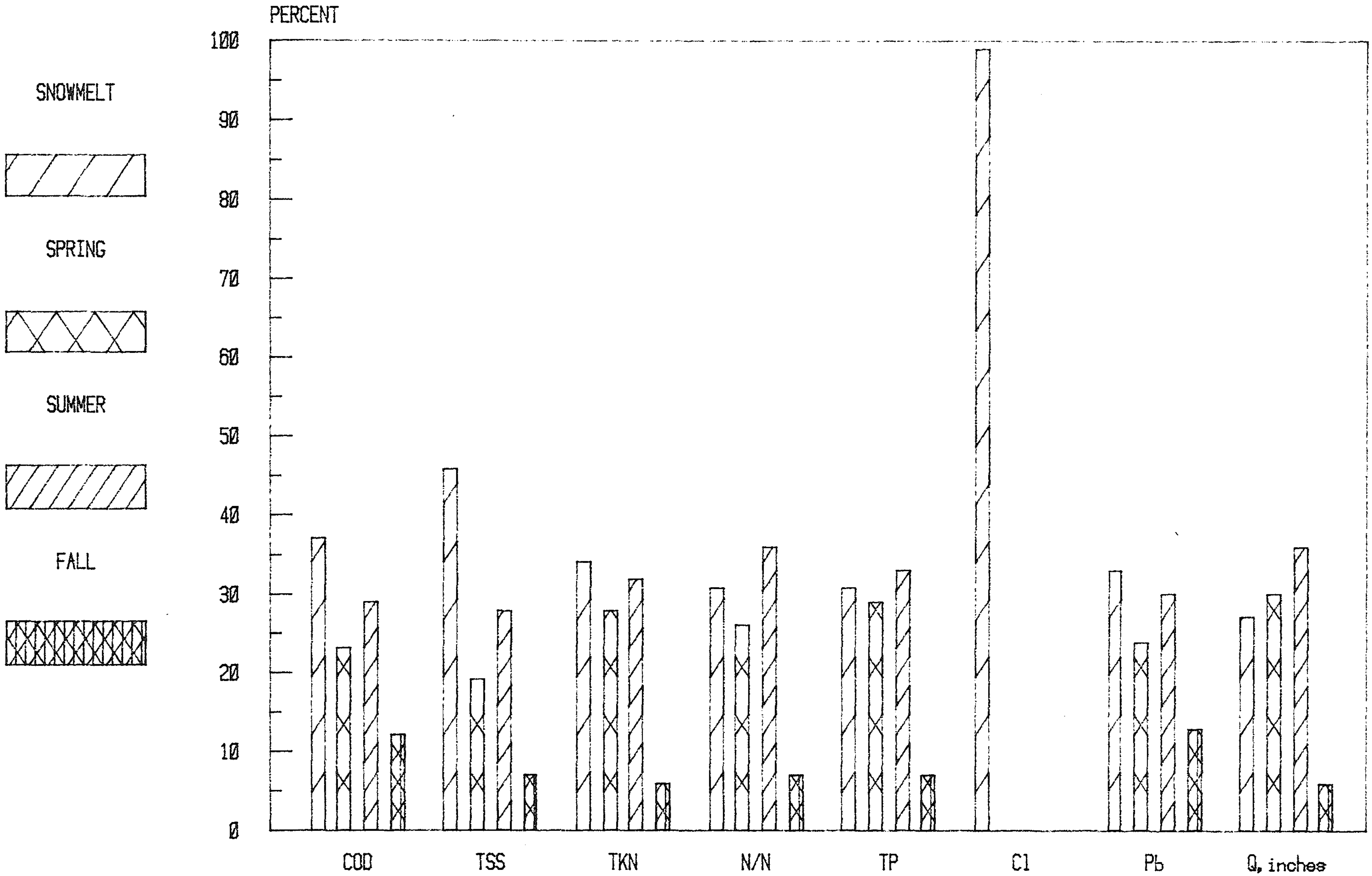
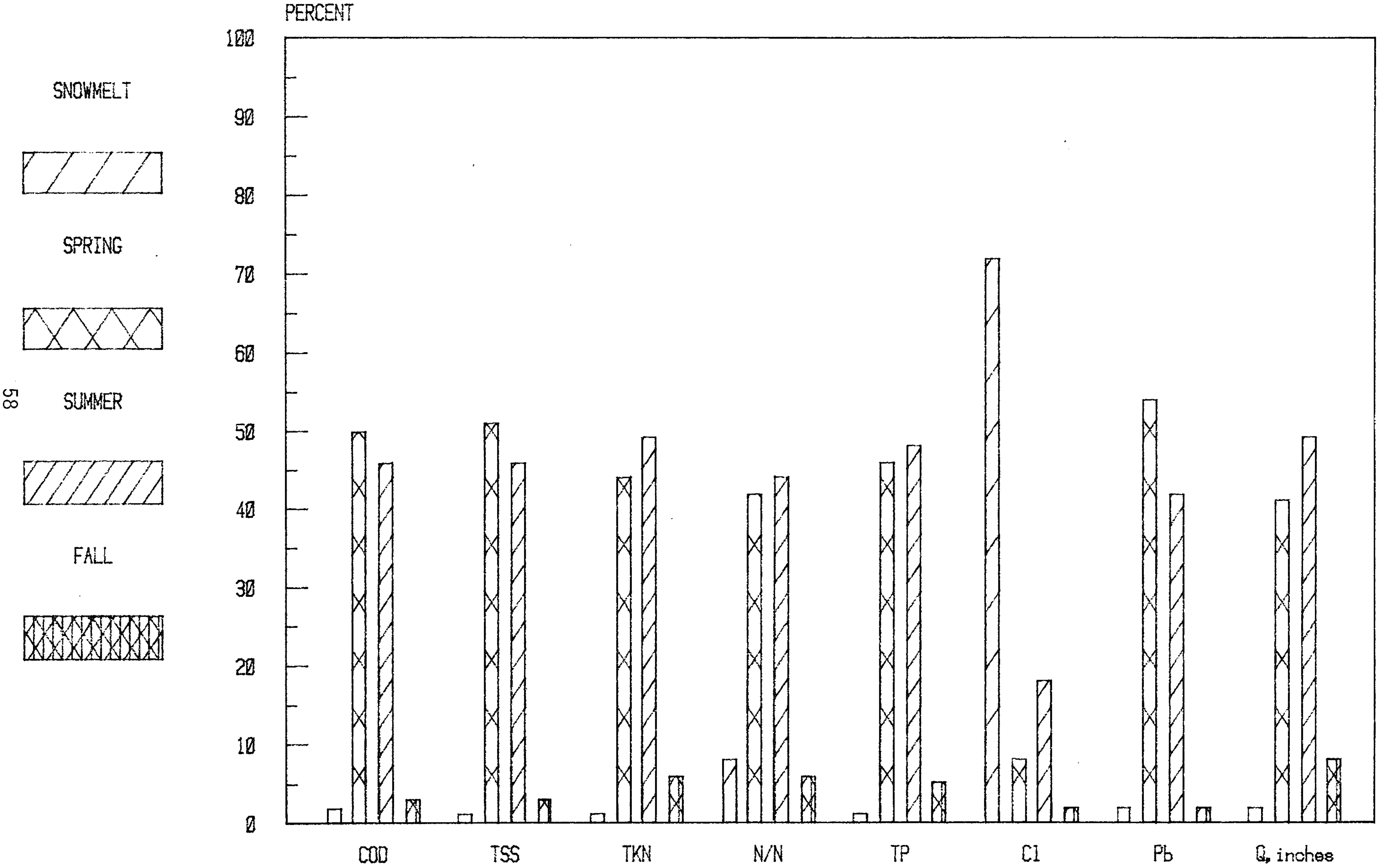


Figure 23. IVERSON SEASONAL RUNOFF LOADS, 1980



Analysis of the various collection period data in Appendix B for each of the six stations yields some interesting results. For essentially all of the stations, the dryfall peak normalized values (in mg/sq ft/day) occurred during the spring. The peak values for the two rural area collectors (Bevens and Eden Prairie) in 13 out of 14 cases occurred during the two-week period from June 3 to June 16 when the bare fields were exposed to wind erosion. The low-value dryfall periods usually occurred after mid-August when field cover was very high. Conclusions on wetfall data are not as obvious because of the volumetric factor incorporated with the rainfall. The loading data are perhaps more informative.

To determine the atmospheric loads to our 17 watersheds, the closest atmospheric station was chosen and the wetfall/dryfall data were applied. It should be noted again that the analyses were done to obtain an idea of magnitude and are not intended to be quantitively precise. Obviously projecting atmospheric loads from a bucket to a watershed is statistically tenuous, but some ideas of relative contribution can be gained. Table B-2 summarizes the atmospheric loads that were determined for the monitored watersheds. The values given are for total pounds deposited over the entire watershed.

Analysis of the various collection event loadings that went into the preparation of Table B-2 yields information on the nature of atmospheric loading. In the six agricultural watersheds, dryfall loading was greatest from early June through early July when fields are bare while the crops grow. The soils at the surface generally dry out and winds are gusty. Loadings again picked up in the period from mid-September through all of October when the fields were harvested and the autumn winds began. The urban sites are less influenced by agricultural practices than by urban industrial processes and vehicular emissions. The highest atmospheric loadings in the urban area watersheds were experienced during the collection period from mid-April through mid-May, a period when little rain fell, residual winter debris on the streets was available to be windswept, and agricultural activity picked up. Again, industrial and vehicular activity during this period is impossible to assess. The lowest agricultural dryfall loading generally occurred in early September when field cover was at its peak. Urban loads during this period and in April were both generally rather low.

Watershed wetfall loads were determined by multiplying the normalized wetfall rate (mg/sq ft/inch of precipitation) by the amount of precipitation during the collection period. Agricultural area maximum loads were variable, but generally occurred from mid-July to early September, a period of about six to nine inches of rain. Urban atmospheric peaks were also variable, with highs occurring commonly in late May to early June (about two inches of rain in a short period) and in the same July-to-September period as the agricultural watersheds. Lowest loading values for both urban and agricultural watersheds of course occurred during periods of little precipitation. The mid-April-to-late-May period in 1980 saw generally less than one-third of an inch of rain; subsequently, very low loads were generated. A similar low loading period existing from mid-June to mid-July.

Table 13 was put together to try to get a better feel for the contribution of atmospheric pollution to total pollution for the 17 monitored watersheds. Again, the data are quite difficult to interpret, with atmospheric loading commonly appearing to contribute well over 100 percent of the total watershed load. The assumption that went into the construction of Table 13 is that the atmospheric load falling on a water surface or an effective impervious surface is direct loading and will be transported to the sampling station. Atmospheric contributions to pervious surfaces are not directly seen because of the interactions with the vegetative and inorganic materials located on those surfaces. Obviously interactions on the impervious and water surfaces do occur, and some of the atmospheric load to pervious surfaces is seen at the sampling site, but the numbers in Table 13 reflect only the prior assumption for evaluation purposes.

Table 13
ATMOSPHERIC CONTRIBUTION TO WATERSHED LOADING

		Percent Total Load				
Site	Contributing Coefficient*	TKN	N/N	TP	Cl	Pb
Bevens	0.020	23	39	6	--	--
Carver	0.106	71	127	25	--	--
Raven	0.012	5	2	3	--	--
Credit	0.045	15	36	4	--	--
Vermillion	0.010	3	1	1	--	--
Elm	0.023	9	36	3	--	--
Shingle	0.168	106	377	60	1	70
Bassett	0.148	35	79	22	1	296
Purgatory	0.099	59	930	61	1	350
80th St.	0.112	27	51	6	1	13
Iverson	0.040	5	33	1	34	3
Hwy. 100	0.263	55	113	36	1	6
Wesley	0.153	19	16	9	1	2
Sandburg	0.537	25	88	92	1	19
Estates	0.165	47	142	13	1	8
Yates	0.133	29	109	17	1	18
PDQ	0.080	7	51	2	1	11

* Effective impervious area plus area of standing water (Table 2).

Firm conclusions on atmospheric loading as a part of total loading unfortunately cannot be made because of the data variability in Table 13. Some general statements, however, can be made. It appears that a fair amount of atmospheric nitrogen can contribute to total watershed loading, especially in the urban area. It also appears that a portion of the nitrogen definitely remains in the watershed, as indicated by several contributions over 100 percent; that is, a large amount of atmospheric nitrogen appears to fall, but a substantially lesser amount actually runs off.

Phosphorus loading appears to contribute far less of the total watershed load, never exceeding the 100 percent figure common for nitrogen. Phosphorus loading from the atmosphere, however, can be a major contributor to lake "loading" (Metropolitan Council, 1981a). Chloride obviously comes predominately from road salt application and only once exceeds one percent--at the construction site where a lot of road dust was stirred up and little salt was applied. Lead, like phosphorus, is quite variable, seeming to occur at either extreme end of a loading range. The larger mainstem streams appear to have a more significant atmospheric lead loading, whereas the small storm sewer sites appear to have only a small percentage of atmospheric lead loading. This fact would seemingly be explained by the larger percentage of impervious surface in the small watersheds contributing a greater percentage of lead from direct deposition of vehicular emissions.

In summary, little definitive can be said about atmospheric loading other than it appears to contribute a fair amount of nitrogen to total watershed loads, and a variable amount of phosphorus and lead. Atmospheric chloride appears to be minimal when compared to that applied on road surfaces.

RUNOFF SUMMARY

The data collected during 1980 show quite conclusively the nonpoint source runoff impact to receiving waters. The degree of impact is variable, with rural areas apparently less degraded than small urban storm-sewered watersheds. Guidelines recommended by government agencies and water quality researchers are frequently surpassed, with peak concentration values often an order of magnitude above the guidelines. Rural area management should focus on detention of snowmelt and rainfall runoff on agricultural fields through institution of conservation-oriented practices, and urban area management should also focus on holding back stormwater for frequently occurring events, on keeping urban surfaces clean, and on minimizing the impacts of construction.

IV. MODELING OF RUNOFF IMPACT

The purpose of the 1980 water quality sampling program was to gather data that could be applied region-wide to evaluate nonpoint source runoff impact. In order to accomplish this, a mathematical model had to be chosen for projection of the monitoring results. This section of the report discusses the model selection, application specifics and results of the projection.

MODEL SELECTION

A staff report on model selection was prepared in August 1980 (Metropolitan Council, 1980). This report evaluated numerous water quality models for their ability to achieve seven objectives. Those objectives are: modeling at a planning level; compatibility with, and use of, collected water quality data; ability to portray runoff processes and pollutant relationships; ability to be used for projection of data to ungaged, unsampled watersheds; capability of use in conjunction with management practice scenarios; accuracy; and ease of application.

Six models were chosen for an in-depth evaluation because they appear to come close to meeting most of these objectives. The models were EPA's Stormwater Management Model (SWMM), Agricultural Runoff Management Model (ARM) and Non-point Source Model (NPS); the Army Corps of Engineers' Storage, Treatment Overflow and Runoff Model (STORM); standard multiple regression, statistical models; and the U.S. Department of Agriculture, Science and Education Administration, Agricultural Research (USDA, SEA-AR) sediment yield model. Although no model achieved all of the objectives, the statistical approach was chosen because it best met program modeling needs. The analysis that led to this approach follows.

SWMM, ARM and NPS were removed from consideration shortly into the process because of the extensive data needs and time requirements for model operation. All model documents reviewed and all reports dealing with model evaluation warned of these constraints when dealing with these three models (see previously mentioned report). The ARM and NPS additionally were removed because they were to be replaced by the Hydrological Simulation Program-Fortran (HSPF) model which was being field-tested by the U.S. Environmental Protection Agency and, therefore, was not yet available in verified, usable form.

The STORM and statistical modeling options were seriously considered for urban and agricultural areas, and USDA - sediment yield was considered for the agricultural area only. STORM has been applied to many 208 areas throughout the country with a fair degree of success. The major problems that arise when STORM is analyzed relate to its water quality and pollutant transport assumptions. The points of concern are the association of all pollutants with the washoff of dust and dirt and the fact that pollutant accumulation is assumed to be a linear function. There are problems with these assumptions because many pollutants, especially the soluble portion, move independently of the dust and dirt from urban and agricultural surfaces. Pollutants moving, for example, from urban lawns or through subsurface agricultural pipes are not accounted for since they are usually in a soluble form. Additionally, pollutant accumulation has been found in most studies to be an exponential function, leveling off to a near constant level after accumulation for a period of several days. The STORM program will accumulate pollutants at a constant, linear rate in between storms, even if a long time period occurs. Thus, if only one storm occurs per month, for example, 30 times the daily accumulation rate accounted for in the model will result rather than a more accurate, exponentially derived amount of pollutants. This linear assumption incorporates an error factor that can be avoided by working with a more realistic accumulation rate.

The question of STORM being limited to only five pollutants (suspended and settleable solids, BOD, total nitrogen, and orthophosphate) was not as serious as it initially appears. Through statistical relationships, other pollutants can be related to these five and parallel assumptions on behavior can likely be made. There is, of course, the possibility that good relationships will not be apparent. The five-constituent limit was a factor in evaluating STORM, but did not influence the decision on the model as much as the two limitations on pollutant transport.

Other limits on the use of STORM include ignoring antecedent moisture condition in runoff calculations; not accounting for changes in water quality during storage periods; use of the Universal Soil Loss Equation (USLE) as the basis for its agricultural pollution component; and limited acceptance of rainfall data from other than one major, regional station. STORM has many benefits that have been responsible for its wide use, but the limitations discussed caused enough concern that STORM was not recommended for use in this 208 program.

Statistical analysis was the second type of modeling that was evaluated in a fair amount of detail. Multiple regression models in linear and log-transform form appear to answer several of the needs that occur when considering nonpoint source modeling. Statistical modeling defines quite well the spatial and temporal variations in water quality as a function of climate, watershed character and land use. The basic forms of the multiple regressions are as follows:

For linear analysis,

$$Y = a + b_1X_1 + b_2X_2 \ldots + b_nX_n$$

where Y = dependent water quality variable

a = regression constant

b = regression coefficient

X = independent variables

Non-linear or exponential relationships often occur in stormwater runoff situations. When runoff behavior does not appear to be linear, a log-transform multiple regression is performed, as below:

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 \ldots + b_n \log X_n$$

An equivalent form of this equation is:

$$Y = aX_1^{b1} \; X_2^{b2} \; . \; . \; . \; X_n^{bn}$$

Experience has shown that most water quality relationships can be explained by the linear or log-transform multiple regression approach. All of the references in the bibliography that used statistical methods achieved a fair amount of success with statistical analysis.

The primary benefit of a statistical model is that it allows for consideration of all possible factors that might affect water quality rather than just those factors included in a model that was developed in another geographical area and verified with data collected under different circumstances. The SAS and USGS data management systems available to the Council for use provide the opportunity to evaluate for significance any parameter felt to be important. Factors such as percentage of wetlands, antecedent moisture, land use type, basin slope and configuration, and rainfall behavior were analyzed as independent variables in the equations previously discussed. Historic continuous rainfall records were used to extend the data base once rainfall-runoff-water quality relationships were established; seasonal evaluation was also accomplished.

Once empirical relationships were established using field data and basin/climatic characteristics, projection of results became possible. Three or fewer independent variables usually were used to define each dependent variable. The independent variables then formed the basis for projection because these same variables were used for the ungaged, unsampled watersheds to simulate the dependent water quality variable. Management evaluation was made by changing the independent variables on the basis of statistics to reflect different management scenarios. Examples of this were increasing detention storage in the watersheds, decreasing runoff factors, and altering loadings from specific land uses that might be affected by management techniques. Evaluation of future water quality conditions as the region develops can be made by altering the variables found in the equations.

Statistical analysis allowed for evaluation not only of what is occurring on the average, but also what is likely to happen a certain percent of the time. This is particularly helpful in assessing standards violations and benefits of different management strategies. Also a particular load for a certain frequency precipitation event or a certain runoff volume assists in extending the period of record through use of U.S. Weather Bureau records. Results of the statistical analysis can be used for projection either through use of a desktop programmable calculator or by programming a computer to do the necessary calculations. Either method is relatively easy.

The final model considered in detail was the USDA sediment yield model prepared by SEA-AR (Otterby and Onstad, 1978). To summarize, this model is based on the USLE and focuses on sediment yield and sediment transport. The three products of the model are large-scale basin sediment yield, field erosion on a county basis, and smaller-scale sediment yield (sedimentation) on a county basis. The model evaluated management practices, tillage practices and rotations to vary management approaches for evaluation.

This model was developed for the MPCA 208 Nonpoint Source Program. The model itself addresses only sediment and does not incorporate other pollutants into the analysis; this is a limiting factor for application to this region because we are very interested in a number of different pollutants. The USLE also is a good overland erosion predictor, but ignores gully and streambank erosion, each of which contributes a high load of sediment that moves down the watershed. The USLE also gives results for annual average erosion while the 208 study also needs input on event and monthly/seasonal basis.

Otterby and Onstad referred in their report to a study by Dendy and Bolton (1976) in which a statistical model was used to evaluate sediment yield and movement. Dendy and Bolton showed that statistical methods can do a good job of predicting relationships if a good data base exists. They used only drainage area and flow to arrive at a general statistical model for sedimentation in several reservoirs across the country.

Again, the statistical modeling approach appeared preferable for the agricultural area because of the flexibility allowed within the methodology. A very good data base was available upon which to analyze the variables that most directly affect water quality from agricultural areas. The Otterby and Onstad model is a very good approach for strictly erosion analysis, but that is not the objective of model use for this 208 study.

MODEL APPLICATION

Details of model application and many of the actual statistical models described in this section are contained in the USGS technical completion report (Ayers et al., 1982). The purpose here is to summarize the modeling process so that the reader is aware of the procedure and, therefore, better able to evaluate the modeling results. The data management and modeling procedure is outlined in Figure 24, and the following discussion is a step-by-step summary.

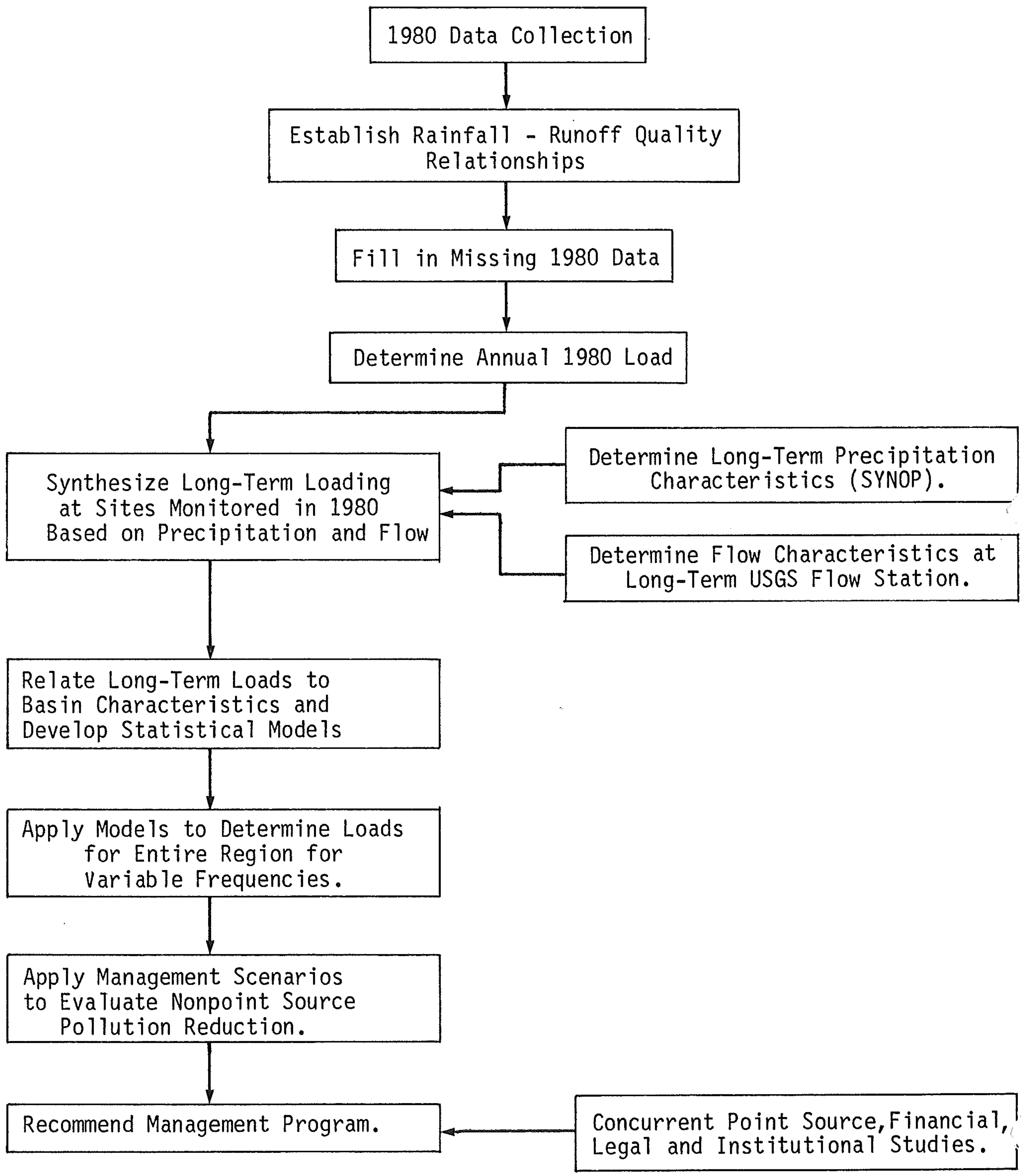
The data collection work done during 1980 is decribed in a previous section. The continuous flow recording and abundant water quality analyses (approximately 16,000) allowed for seasonal correlations to be made for most constituents at every site. The seasonal flow-concentration graphs that were prepared allowed for the filling in of missing concentration data, and eventually the determination of a load figure for every flow event. On those rare occurrences when flow data were not available because of equipment failure, hydrograph comparison with a similar watershed enabled a load figure to be determined. The loads were then tabulated on a daily, monthly, seasonal, and annual basis for each of the 17 sites.

The precipitation data collected at or near the 17 sites were also put into the data management system to compare with generated load. Regression models were then prepared to predict flow and load as a function of rainfall, flow, and observed quality behavior in the sampled watersheds; snowmelt load of course has to be a function of flow because of the delayed precipitation response.

At the four urban mainstem and six rural sites, loads were generated using flow as the predominant independent variable in a regression model. The flow usually had to be used in a square root or logarithmic form to attain a normalized distribution that more closely fit the constraints of linear regression. At the seven urban storm sewer sites, rainfall was used as the prediction tool because of the fast rainfall-runoff response time; flow at long-term sites was used to predict flow at the storm sewer sites. Using these two modeling techniques, a "dayload" was generated for every site for every day of 1980. The 1980 total loads are shown in Table 7.

The next series of steps was included to determine the long-term loading characteristics at the 17 sites. Precipitation data from the National Oceanographic and Atmospheric Administration (NOAA) are available from 1948 for the Minneapolis-St. Paul Airport. Long-term flow data is available for different small stream USGS flow gaging stations since 1963. The SYNOP program, as

Figure 24. DATA MANAGEMENT AND MODELING PROCESS



described in Appendix C, was used to reduce the long-term precipitation data to usable statistics. In order to merge the precipitation and flow data, only the precipitation data from 1963 to 1980 were used. Linear regression models were then developed to predict the flow at the USGS Vermillion River and Purgatory Creek stations from preciptation at the airport; then the six rural monitoring sites and the Purgatory mainstem site were correlated to the Vermillion or Purgatory long-term station for near-winter flow. All sites' winter flow was determined by the same manner. To get good correlations, the flow data often had to be transformed to a natural log or square root function.

The long-term precipitation record at the Rosemount NOAA station was similarly used to predict flow at the other three urban mainstem sites (80th St., Bassett and Shingle). In this regression set, antecedent rainfall and Julian dates also were used as independent variables and mathematic transformations were necessary.

Non-winter flow at the seven urban storm sewer sites was determined directly by using the long-term precipitation data at the airport rather than using flow at the USGS station. Because urban runoff is more complicated than larger mixed watersheds, SYNOP was particularly useful. Models for flow for various sites used some of the following: daily precipitation, maximum hourly precipitation, storm duration, antecedent moisture and amount of precipitation in preceding one, three and seven days. Additionally, several had to be mathematically transformed. Winter flow was obtained by using flow at the long-term USGS sites.

To emphasize, all of the aforementioned models are detailed in the USGS technical completion report (Ayers et al., 1982). The long-term flow data that were determined for each of the 17 sites were then put into the dayload models to replace the 1980 flow; i.e., the assumption is made that the daily flow versus daily load correlations determined previously are nearly uniform in most years. The availability of long-term loading then for these sites means that frequency analyses can be done. These analyses were done for the 1.1-, 2.0- and 10-year frequency annual and seasonal loads, respectively, the 10-, 50- and 90-percent duration loads. A 10-percent duration load means that only 10 percent of annual loads on a long-term basis are lower than this figure.

Once frequency of load information was available, stepwise regressions could be run with load as a dependent variable and basin characteristics as independent variables. Table 14 (A, B, and C) lists the watershed basin characteristics that were determined for the 17 sites. The actual basin characteristics are listed in Appendix D.

Stepwise regression models were run through the Statistical Analysis System (SAS) to determine the "most significant" characteristics that predicted load. The SAS procedure was used to develop models for the 10, 50 and 90 percent duration years. The actual models that resulted are shown in Tables 15A, B and C. "Hybrid" variables obtained from Table 14 and used in these models include the following:

LUWTWR = LUWET + LUWTR.
USWET = USLER/LUWET.
LUWETPG = LUWET + LUPASG.
LUURBCO = LUURB - (LUCI + LUOS).
LUWETAGI = LUWET + LUAGI.
LUURBC = LUURB - LUCI.
LUOSAG = LUOS + LUAGI.
LUURBO = LUURB - LUOS.
LUWETME = LUWET + LUMEAD.
LUWETSF = LUWET/LURSF.
LUWETOAT = LUWET/LUOAT.
LURSFURB = LURSF/LUURB.
LUWETURB = LUWET/LUURB.
LUWETTC = LUWET/TCAREA.

Table 14
WATERSHED BASIN CHARACTERISTICS AS INDEPENDENT VARIABLES

A. Characteristics of Urban and Agricultural Watersheds

Variable Name	Variable Description
1. TAREA	Total watershed area in square miles.
2. TCAREA	Total contributing watershed area in square miles.
3. IAREA	Impervious area in percentage of total drainage area.
4. EAREA	Effective impervious area in percentage of total drainage area.
5. RELEF	Watershed relief as the difference between high and low elevation in feet.
6. CSLOPE	Main conveyance slope, in feet per mile, measured at points 10 and 85 percent of the distance from station to divide.
7. DRDNS	Drainage density in feet of conveyance channel per acre of watershed.
8. AOFLOW	Average overland flow to a conveyance channel in feet.
9. MDITCH	Miles of artificial ditches in watershed.
10. PDRSO	Poorly drained soils as a percentage of watershed area.
11. PAHOR	Weighted permeability of the A soil horizon in inches per hour.
12. AWCA	Weighted available water capacity of the A horizon in inches of water per inches of soil.
13. HYSGR	Weighted hydrologic soil group, where A=1, B=2, C=3 and D=4.
14. MANRT	Long-term, mean annual precipitation in inches.
15. ATMTP	1980 atmospheric load for TP in pounds.
16. ATMTN	1980 atmospheric load for TN in pounds.
17. LUWET	Percentage of watershed in wetlands.
18. LUWTR	Percentage of watershed in open water (lakes, streams, ponds).

Table 14 (Contd.)
WATERSHED BASIN CHARACTERISTICS AS INDEPENDENT VARIABLES

B. Agricultural Watershed (Only) Characteristics

Variable Name	Variable Description
1. LUCRN	Percentage of watershed in corn.
2. PCRNAT	Percentage of corn acreage needing additional treatment.
3. LUBN	Percentage of watershed in soybeans.
4. PBNAT	Percentage of soybean acreage needing additional treatment.
5. LUOAT	Percentage of watershed in oats.
6. LUWHT	Percentage of watershed in wheat.
7. LUMEAD	Percentage of watershed in meadow.
8. PCRPAT	Percentage of cropland needing additional treatment.
9. LUPASG	Percentage of watershed in pastureland and grassland.
10. LUWOD	Percentage of watershed in woodland.
11. LUURB	Percentage of watershed in residential, commercial/industrial and miscellaneous.
12. ROTFAC	Unitless rotation factor.
13. USLER	Universal soil loss equation annual erosion rate in tons per acre.
14. NUMAU	Number of animal units in watershed feedlots.
15. FLCOD	Design load for feedlot COD load in pounds.
16. FLTP	Design load for feedlot TP load in pounds.
17. LUCROP	LUSMGR + LUROW.
18. LUROW	LUCRN + LUBN.
19. LUSMGR	LUOAT + LUWHT.
20. NONCRP	LUMEAD + LUPASG + LUWOD
21. LUAGI	LUCROP + NONCRP.

Table 14 (Contd.)
WATERSHED BASIN CHARACTERISTICS AS INDEPENDENT VARIABLES

C. Urban Watershed (Only) Characteristics

Variable Name	Variable Description
1. LURLD	Percentage of low density (less than two units per acre) single-family residential in watershed.
2. LURMD	Percentage of medium density (three to eight units per acre) single-family residential in watershed.
3. LURHD	Percentage of high density (nine or more units per acre) single-family residential in watershed.
4. LUCI	Percentage of commercial/industrial in watershed.
5. ACCON	Acreage under construction in watershed.
6. LUOS	Percentage of open space, recreation and parks in watershed.
7. LUAGI	Percent of agricultural and idle land in watershed.
8. LURMF	Percentage of multifamily residential in watershed.
9. LURSF	Percentage of total single-family residential in watershed.
10. POPDN	Population density in persons per acre.

Many more models were produced in addition to those in Table 15, but Table 15 is a list of the "best" models. The additional models were used in the management work to follow because they did give general indications of pollutant behavior as a function of watershed character.

Once the models in Table 15 became available, the process of predicting region-wide pollution loading at different frequencies could be accomplished. The Region was divided into tertiary subwatersheds which were subsequently grouped into larger subwatersheds according to land use and/or basin character. Figure 25 shows the various subwatersheds and Appendix E lists the watersheds and their land uses.

All of the final models were chosen based upon their ability to be calibrated with the 1980 field data and to predict realistic values for the numerous regional subwatersheds. In this sense, the models were merely the tool used to expedite the evaluation; this tool was used along with the knowledge gained from the field data to conduct the nonpoint study. There were, of course, several drawbacks involved with using the simplistic multiple regression modeling approach. These were: possible variable intercorrelation; variable balancing which introduced unexpected positive/negative correlations; the low number of sites meant that the models were limited to only a few variables; and "chance" correlations occasionally surfaced. Overall, however, the positive aspects of the approach taken far outweighed these negatives, and careful thought made the suspect results obvious.

The results of the modeling exercise for the 10, 50 and 90 percent durations are given in Appendix E after the subwatershed descriptions. Table 16 summarizes the load values for the Region, and Figure 26 shows those values graphically. The most important thing to note about these figures is the wider range of rural area loadings, particularly in the change from the 50 to 90 percent duration. This is indicative of the loading process noted earlier in this report, that is, the urban area contributes a load in relative proportion to the precipitation, whereas the rural area does not readily respond to small precipitation events. The rural area, however, appears to reach a saturation point between the 50 and 90 percent duration after which extensive loading occurs, as evidenced by the June 5-7 1980 event discussed previously (see also Figures 3-5). The rural area loading figures are also substantially larger than the urban area, but keep in mind that the total rural area is about 1980 square miles and the urban area is only about 975 square miles.

After the loading figures in Appendix E were determined, they were combined with the runoff figures to determine flow-weighted mean concentrations for each of the frequencies thus far discussed. The tabulation of these means follows the loading data in Appendix E. Figures 27-31 graphically show how these means compare to the recommended guidelines discussed earlier (Table 6) by showing the percent reduction needed to reach the recommended guideline. Frequency bar graphs again appear in Appendix E.

The largest number of watersheds need reductions in total phosphorus (see Figure 27). These extensive violations become more important in light of the fact that the Region has about 950 lakes over 10 acres in size. The TP input to these lakes is largely responsible for their generally degraded nature, as discussed in a subsequent part of this section. Only three subwatersheds do not need TP reductions, leaving 107 that do. For agricultural areas, the average reduction needed is 75 percent; for urban areas, 73 percent.

Table 15A
FINAL SELECTED MULTIPLE REGRESSION MODELS
FOR LONG-TERM 10 PERCENT DURATION LOAD (lbs/mi^2)

Urban Models:	R^2	C.V.$^{(1)}$	Signif (%)
IN$^{(2)}$= 7.05-0.08*LUCI-4.32*LUWETTC	.99	1.3	97
TN = 1277+1.7*RELEF-4315*LUWETURB	.99	.48	99
COD = 12080+145*RELEF-1424*LUWTR	.99	.42	99
TSS = 25183+1832*LUWTR-111319*LUWETURB	.99	.46	99
TKN = 1245+28.6*LUWTWR-5011*LUWETURB	.99	1.5	97
NN = TN-TKN			
TP = 231+10*LUWTR-1011*LUWETURB	.99	1.0	96
Cl = -985130+961176*LUWETSF+13960*LUURBO	.99	.10	99
Pb = 50-8.35*LUWTR	.94	41	97
Agricultural Models:			
IN$^{(3)}$= -.005+.002*LUCROP+.008*LUWET+ .15*LUWETTC-.1*LUWETURB	.99	.29	99
TN = 10464-33*LUWTWR-44*LUPASG- 70*LUWETAGI-96*LUWETME	.99	.10	99
COD = 21028+817*LUWTWR-259*LUPASG+ 425*NONCRP-926*LUWETME	.99	.15	99
TSS = 38684-646*CSLOPE-13442*LUWETURB- 75*TAREA-205*LUWETPG	.99	.34	99
TKN = 121+6.5*LUWTR+14*LUPASG+ 3.1*LUMEAD+16*NONCRP	.99	.11	73
NN = TN-TKN			
TP = -1280+14*LUCROP+31*LUWTR+ 22.6*NONCRP-1.1*TAREA	.99	.76	99

(1) Coefficient of variation=100*(standard deviation/mean).
(2) Inches total.
(3) Inches per square mile.

Table 15B
FINAL SELECTED MULTIPLE REGRESSION MODELS
FOR LONG-TERM 50 PERCENT DURATION LOAD DETERMINATION (lbs/mi^2)

Urban Models:	R^2	C.V.[1]	Signif (%)
[2] IN = 1.32+0.012*RELEF+0.025*LUURBCO	.99	.16	99
TN = 9296-86*LUWETAGI-54.8*LUURBCO	.99	1.0	99
COD = 7175-772*LURSF+1297*LUURBC	.99	.46	99
TSS = 126,055-1389*LUWETAGI-585*LUURBCO	.99	.29	99
TKN = 2957-21.8*LUWTWR-23.6*LUWETAGI	.99	1.5	98
NN = TN-TKN	--	--	--
TP = 2139-20.3*LUWETAGI-15*LUURBO	.99	6.6	95
Cl = -41600-84800*LURSFURB+2556*LUURBO	.99	1	99
Pb = 69.6-4.7*LUWTWR-0.8*LURSF+1.3*LUURBCO	.99	1	99
Agricultural Models:			
IN[3] = 0.188-0.002*TAREA+0.01*CSLOPE+ 0.008*DRDNS-0.009*LUPASG	.99	.51	99
TN = 1137-90*LUAGI+346*LUURB+113*LUCROP	.98	9.5	97
COD = 169,000-1924*LUAGI+460*LUCROP-238*LUMEAD	.99	1.1	99
TSS = 136,000-1676*LUAGI-7025*USLER+83300*USWET	.99	8.6	99
TKN = 1565+73*LUWTR+10*LUWET-46*LUMEAD	.98	3.5	97
NN = TN-TKN	--	--	--
TP = 254+25.7*LUWTR-4.2*LUMEAD	.99	4.7	99

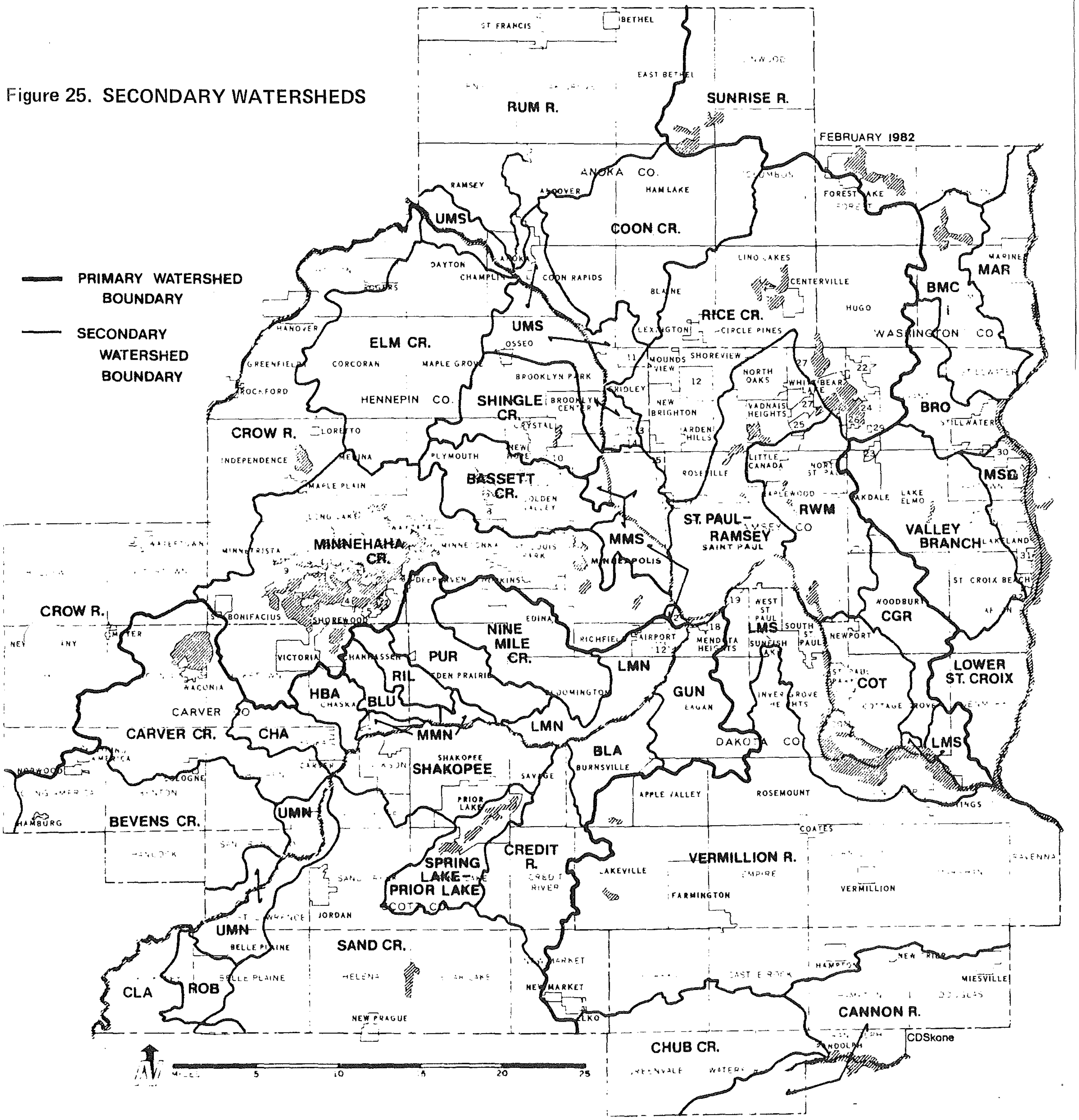
[1] Coefficient of variation (C.V.)=100*(standard deviation/mean).
[2] Inches total.
[3] Inches per square mile.

Table 15C
FINAL SELECTED MULTIPLE REGRESSION MODELS
FOR LONG-TERM 90 PERCENT DURATION LOAD (lbs/mi^2)

Urban Models:	R^2	C.V.[1]	Signif (%)
[2] IN = 2.87-0.37*LURSF+0.45*LUURBCO	.99	.36	99
TN = 5220-9.7*LURLD-53*LUWETAGI	.99	8.5	89
COD = -27281+32984*LUWETTC+1105*LUURBO	.99	.33	99
TSS = 115857-11716*LUWETTC-1264*LUWETAGI	.99	8.8	89
TKN = 3961-73*LUWTR-33*LUWETAGI	.99	.03	99
NN = TN-TKN	--	--	--
TP = 240+7.3*LURMD-317*LUWETSF	.99	.41	99
Cl = 80573-127339*LUWETSF+34182*LURSFURB	.99	.10	99
Pb = -35.9+9.2*LUOS	.95	39	97
Agricultural Models:			
IN[3] = -.02+.06*CSLOPE-.017*LUPASG-.022*LUWETURB	.99	.10	99
TN = 16858-113*LUWTWR-114*LUPASG-224*LUMEAD-5700*LUWETURB	.99	.44	99
COD = 174841-29*NONCRP+51783*LUWETTC-103760*LUWETURB+4206*LUWETOAT	.99	.10	99
TSS = 2,689,392-4900*LUWTWR-16840*LUPASG-20043*LUWETAGI-28233*LUWETME	.99	.59	99
TKN = 7215+3023*LUWETTC+5193*LUWETURB+.5*PCRPAT-4.7*LUWETPG	.99	.22	99
NN = TN-TKN	--	--	--
TP = 213+13*LUWETTC-360*LUWETURB+10.4*RELEF-235*LUWETOAT	.99	.14	99

(1) Coefficient of variation=100*(standard deviation/mean).
(2) Inches total.
(3) Inches per square mile.

Figure 25. SECONDARY WATERSHEDS



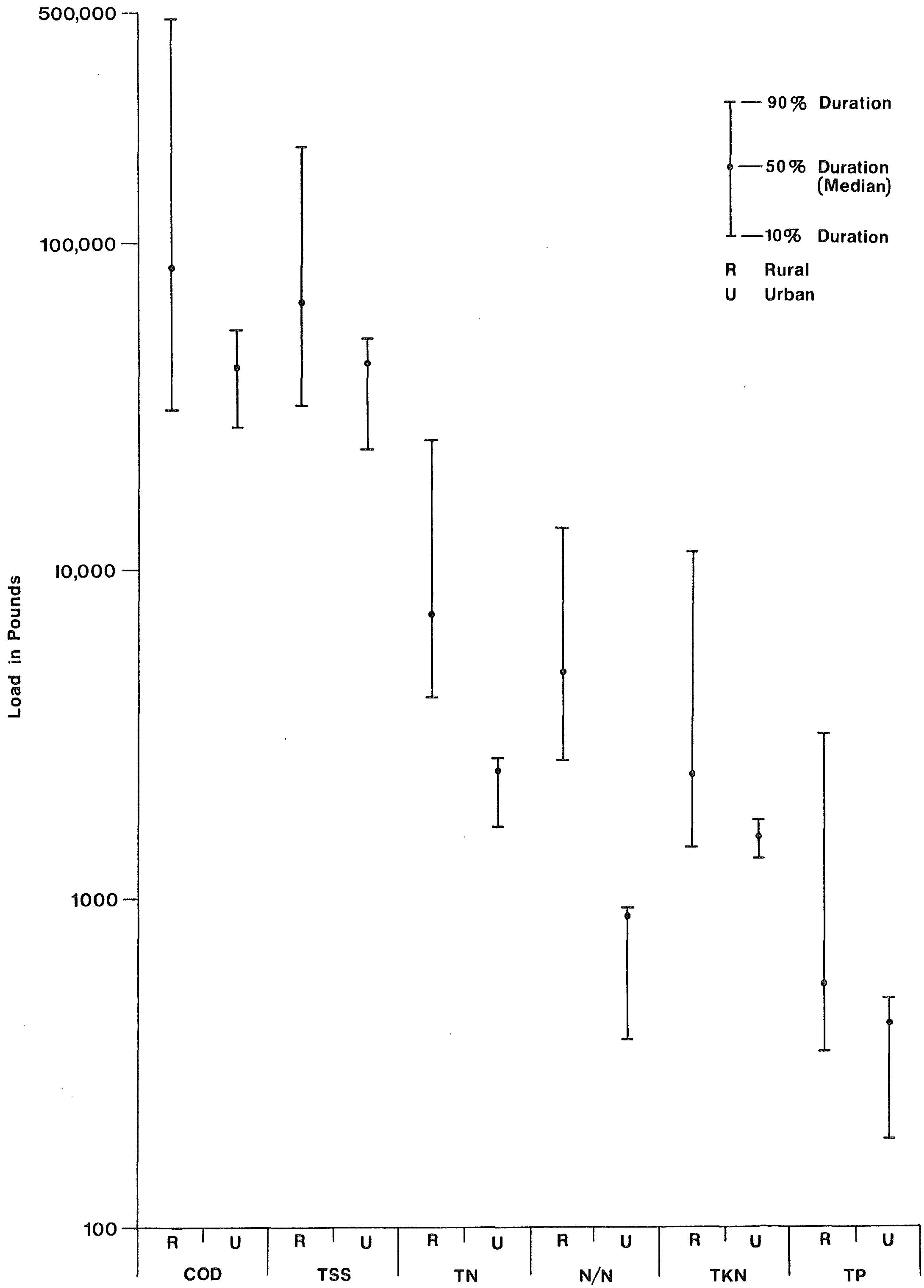
BLA	BLACK DOG LAKE			MSC	MIDDLE ST. CROIX RIVER
BLU	BLUFF CREEK	GUN	GUN CLUB LAKE	PUR	PURGATORY CREEK
BMC	BIG MARINE-CARNELIAN	HBA	HAZELTINE-BAVARIA	RIL	RILEY CREEK
BRO	BROWNS CREEK	LMN	LOWER MINNESOTA RIVER	ROB	ROBERTS CREEK
CGR	COTTAGE GROVE-RAVINE	LMS	LOWER MISSISSIPPI RIVER	RWM	RAMSEY-WASHINGTON METRO.
CHA	CHASKA	MAR	MARINE-ON-ST. CROIX	UMN	UPPER MINNESOTA RIVER
CLA	CLARKS LAKE	MMN	MIDDLE MINNESOTA RIVER	UMS	UPPER MISSISSIPPI RIVER
COT	COTTAGE GROVE	MMS	MIDDLE MISSISSIPPI RIVER		

Table 16.
NONPOINT SOURCE LOADS FOR THE METROPOLITAN AREA FOR 10, 50 AND 90 PERCENT DURATIONS

(Load in Pounds Times 1,000)

Percent Duration (Frequency)	COD	TSS	TN	NN	TKN	TP	Cl	Pb
Rural								
10 (1.1 yr.)	31,300	31,912	4,101	2,674	1,427	344.3	--	--
50 (2.0 yr.)	82,662	65,419	7,272	4,876	2,396	556.4	--	--
90 (10 yr.)	494,553	198,457	25,010	13,444	11,566	3,216	--	--
Urban								
10 (1.1 yr.)	27,591	23,154	1,681	371.4	1,310	186.3	43,169	15.8
50 (2.0 yr.)	41,264	42,950	2,456	914.0	1,542	416.6	60,675	33.8
90 (10 yr.)	54,279	50,538	2,687	951.6	1,735	499.9	81,596	83.7

Figure 26. NONPOINT SOURCE LOADS FOR 10, 50 AND 90 PERCENT DURATION



TOTAL PHOSPHORUS

TP

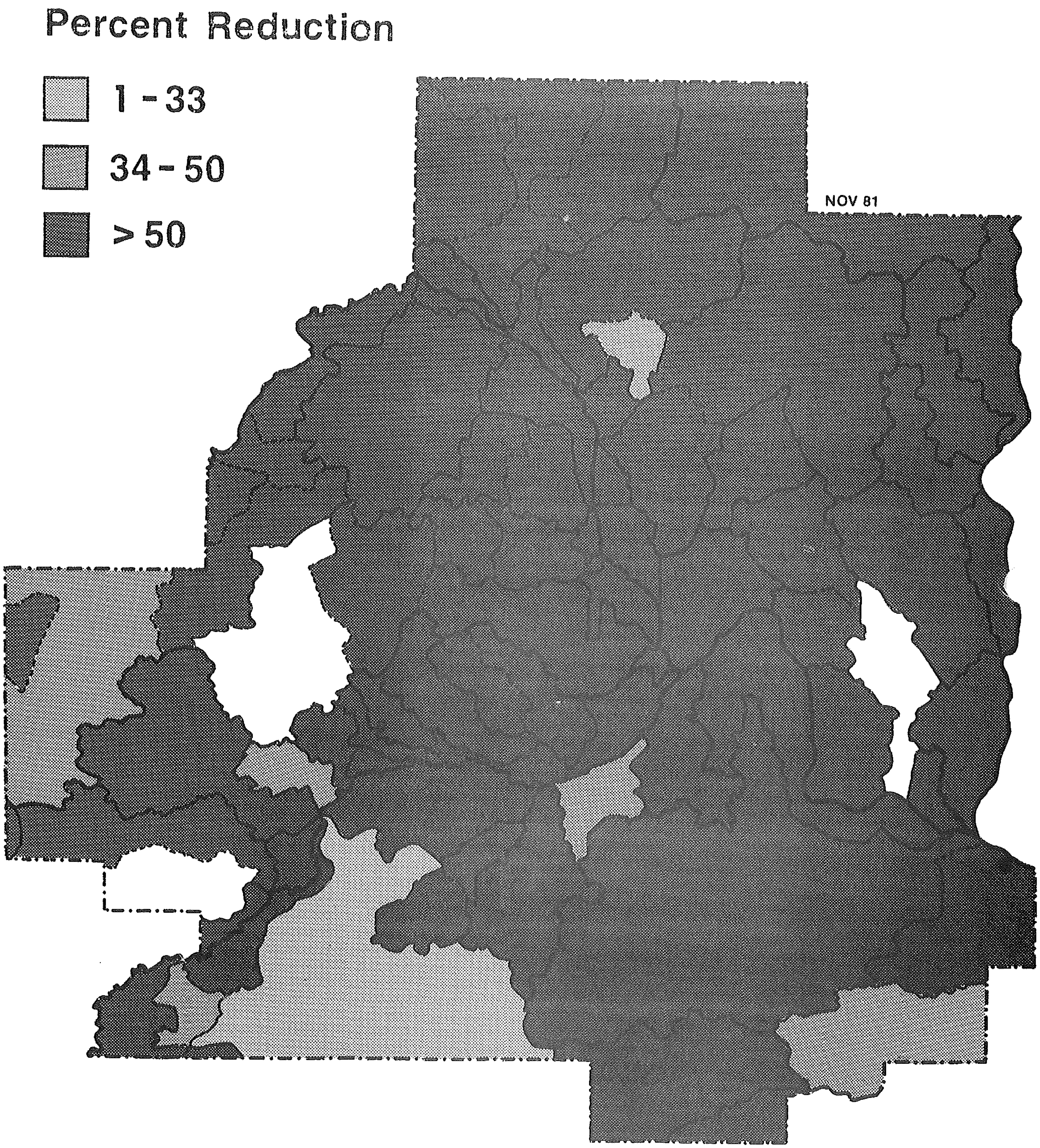


Figure 27. SUBWATERSHEDS NEEDING LOAD REDUCTION TO MEET RECOMMENDED TP GUIDELINE

Figure 28 shows the subwatershed reduction needs for total nitrogen (TN). Only 17 of the subwatersheds are not in need of TN reduction. Figure 28 indicates that the subwatersheds not needing reduction are generally rural in character. However, the average reduction need for rural areas in need of reduction is 56 percent, as opposed to only 36 percent for urban areas.

The reduction needs for total suspended solids (TSS) are shown in Figure 29. Although the problem does not appear as widespread as that for TP and TN, the TSS pollution problem is serious. Only 20 subwatersheds appear to need no further TSS reduction. The average rural watershed needing reduction will need to reduce TSS by 43 percent; the comparable urban figure is 34 percent.

Figure 30 focuses on the chemical oxygen demand (COD) reduction needs and shows the widespread nature of this nonpoint problem. A total of 31 subwatersheds need no reduction in their COD levels. The average reduction need for those rural subwatersheds needing reduction is 38 percent, whereas that for similar urban subwatersheds is only 18 percent.

Figure 31 shows the subwatersheds exceeding the lead (Pb) guideline. These watersheds are of course urban and typified by high traffic volumes. Of the 10 watersheds needing reduction, the average need is 15 percent.

The conclusion to be drawn from this analysis is that nonpoint sources of pollution are definitely impacting the small tributary receiving streams, causing most of these streams to exceed recommended water quality guidelines for one or more pollutants. Specifics on the extent of these violations in each watershed follow in a subsequent section dealing with the application of management practices. In this later section, the 110 subwatersheds are combined into 44 secondary watersheds for management purposes; each of these 44 is then examined for problem identification and management strategy.

MODELING SUMMARY

The data and projections presented in this section seem to strongly indicate that secondary or tributary streams are severely impacted by nonpoint source pollution. Guidelines violations are commonplace and extreme violations are not unusual. The error analysis done in Ayers et al. (1982) shows that these modeling results are subject to an error of about 30 percent, which still means that even with a maximum error in interpretation, these streams are routinely violating guidelines.

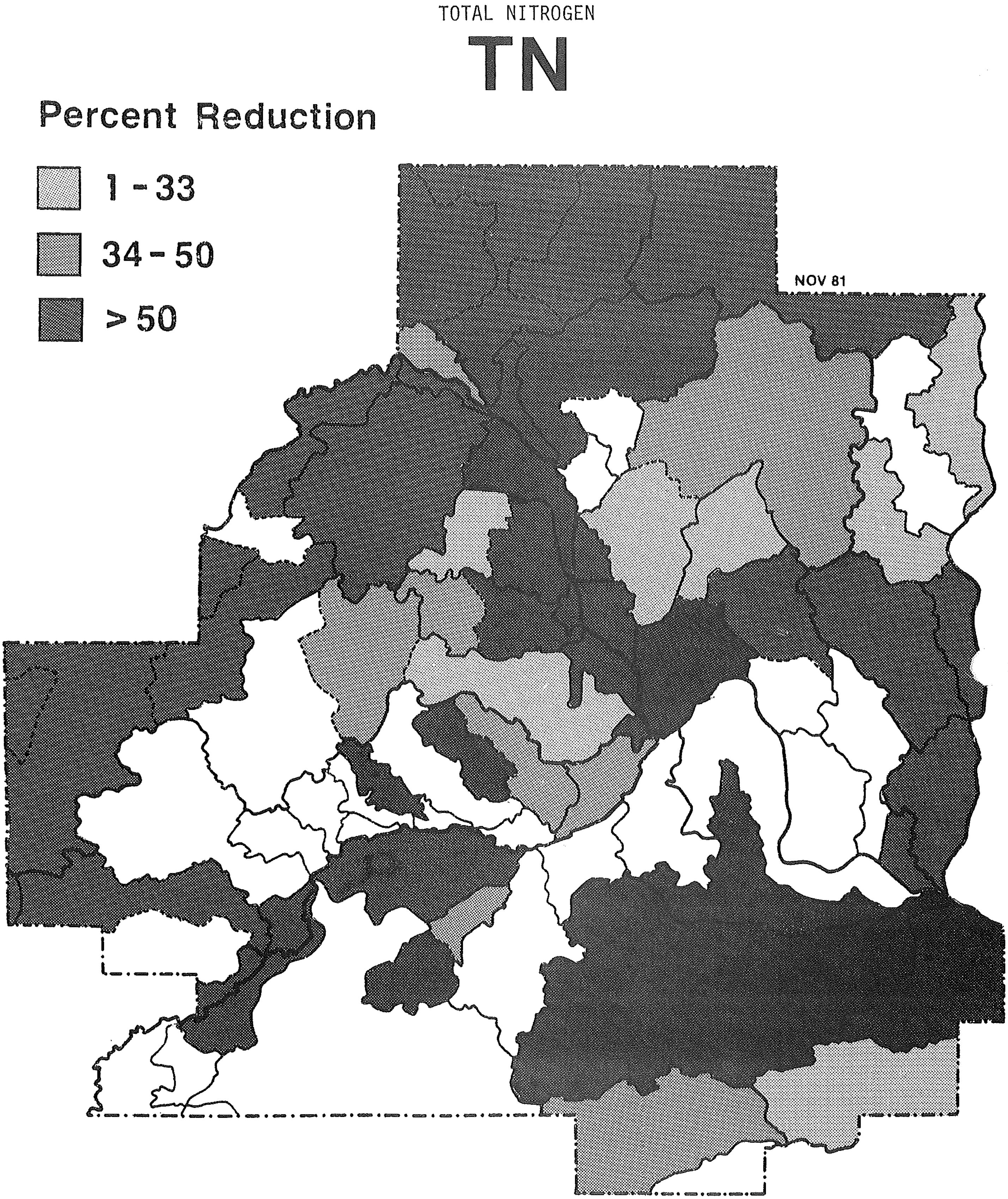


Figure 28. SUBWATERSHEDS NEEDING LOAD REDUCTION TO MEET RECOMMENDED TN GUIDELINE

TOTAL SUSPENDED SOLIDS

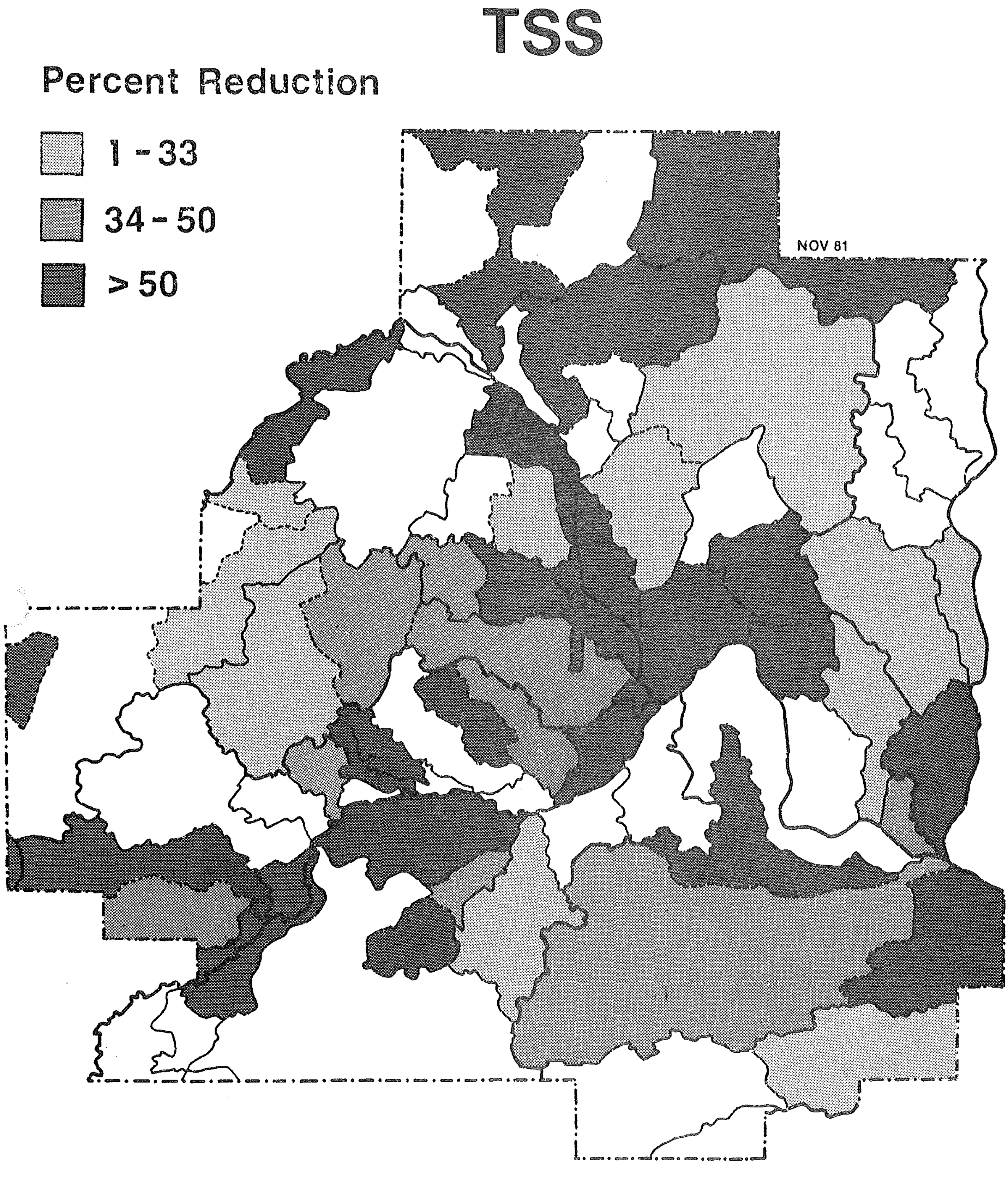


Figure 29. SUBWATERSHEDS NEEDING LOAD REDUCTION TO MEET RECOMMENDED TSS GUIDELINE

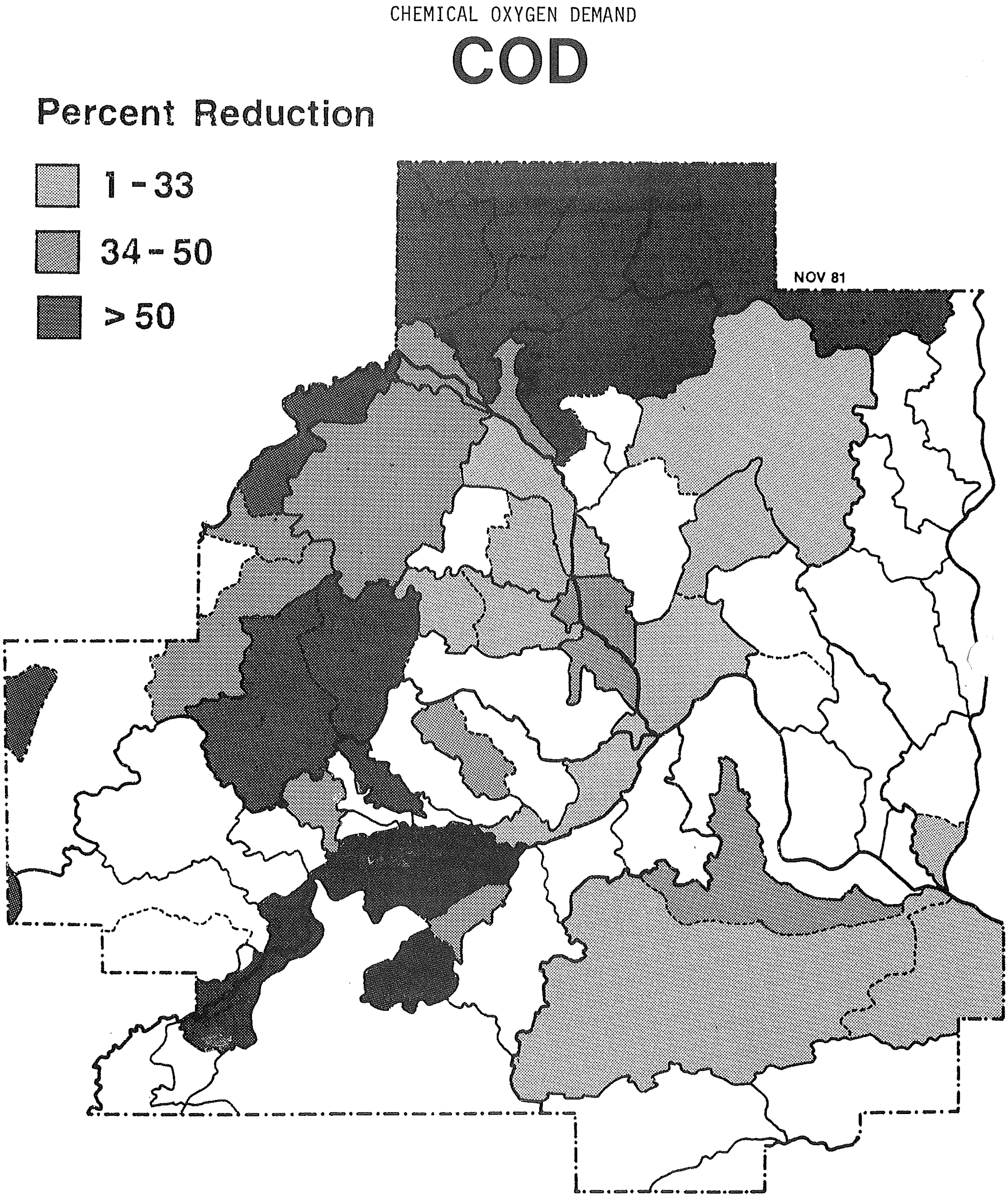


Figure 30. SUBWATERSHEDS NEEDING LOAD REDUCTION TO MEET RECOMMENDED COD GUIDELINE

LEAD

Pb

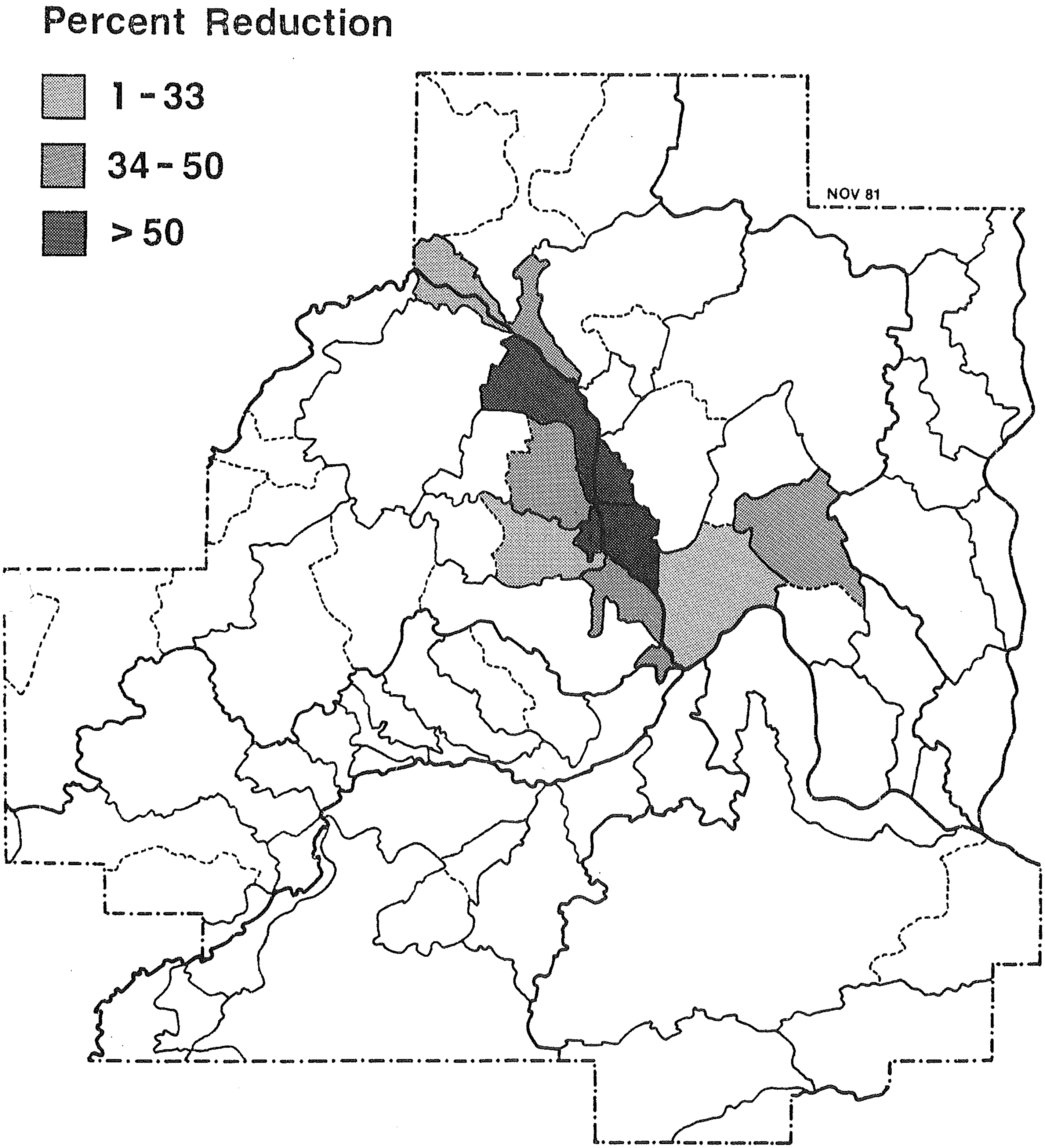


Figure 31. SUBWATERSHEDS NEEDING LOAD REDUCTION TO MEET RECOMMENDED Pb GUIDELINE

V. LAKES

Lakes are primary receivers of pollution because they are quiescent bodies of water in which pollutants may accumulate, settle, dissolve or recycle periodically. Phosphorus is a principal cause of lake problems because it promotes eutrophication; that is, the process whereby a water body becomes rich in plant nutrients, leading to a proliferation of plant life and depletion of oxygen in the lake's bottom waters. Nonpoint source pollution has accelerated eutrophication to such an extent that nearly all of the lakes in the Metropolitan Area are now eutrophic. Although eutrophy is not necessarily bad, the degree of eutrophy in most of our lakes is such that recreational opportunities have been diminished.

This section of the technical report is a summary of previous work by Osgood (Metropolitan Council, 1981a) and an analysis of the loading information that was done in conjunction with the previous section.

SUMMARY OF 1980 FINDINGS

The lake data collected in 1980 are evaluated in a previously referenced Council lakes technical report by Osgood. This report concludes that the primary reason for the degradation of the Region's lakes is nonpoint source pollution. The years of pollution loading have led to a condition whereby pollutants (specifically nutrients) have accumulated in lake-bottom sediments and are commonly recycled within the lakes. Conditions have apparently worsened to the point that total elimination of external nutrient loading would not yield immediate results because in-lake recycling will continue to provide nutrients during the summer. The solution to lake pollution problems will be a long process, lasting many years. It is extremely important, however, to take the first step in that process; that is, reduction of the external load. In order for the lakes to begin cleansing themselves, they must be relieved of the external loading that initiates the recycling process.

The data used to arrive at these conclusions were derived from sampling 60 of the 950 regional lakes (Figure 2 in Section II). These 60 lakes were chosen to represent the physical (see Figure 32) and other conditions present in the Region; none of the lakes receive point source pollution. Figure 33 illustrates the trophic state, or condition, of the 60 lakes. (Since the sample lakes are generally large, the remaining lakes in the area are probably in worse condition than Figure 33 indicates.) Oligotrophic lakes are extremely clear, nutrient-deficient lakes. Square and Christmas Lakes are the only lakes in the Metropolitan Area that approach this condition. Mesotrophic lakes are more nutrient enriched, less clear, and likely to be more abundant in aquatic life forms. Eutrophic lakes are generally nutrient enriched, turbid, and abundant with life, provided the eutrophication process has not led to accelerated aging or hypereutrophy. The eutrophication process is a normal aging process that leads to conditions favorable to some fish and aquatic life. The problem with many lakes is that some activities--such as fertilization, construction, and transportation--have accelerated the eutrophication in such a way that hypereutrophy has begun and severe degradation has prematurely resulted. This degradation leads to poor water quality conditions, less desirable aquatic life and decreased recreational opportunities.

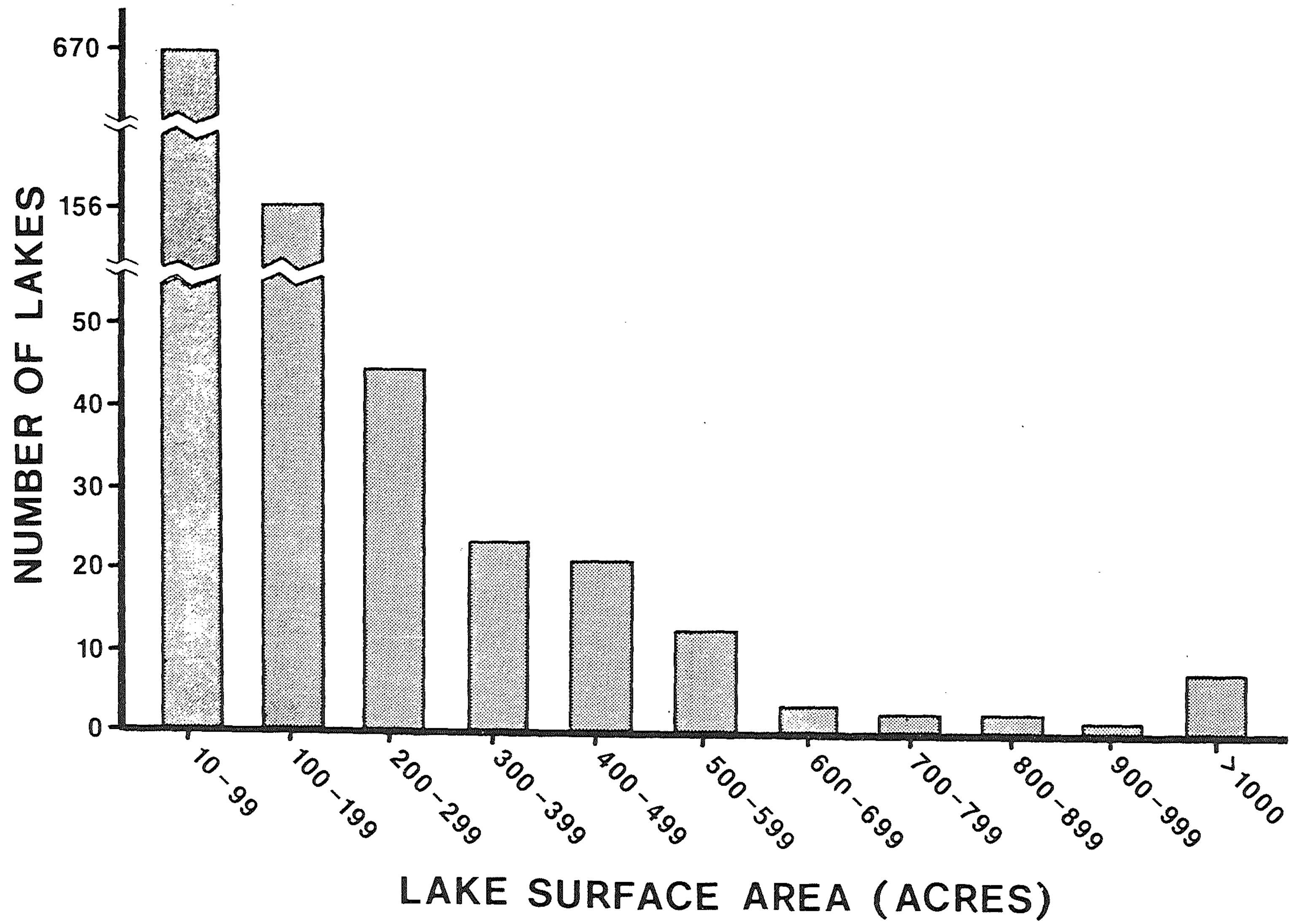


Figure 32. SURFACE AREA DISTRIBUTION OF LAKES IN THE METROPOLITAN AREA (FROM MC BRIDE 1976)

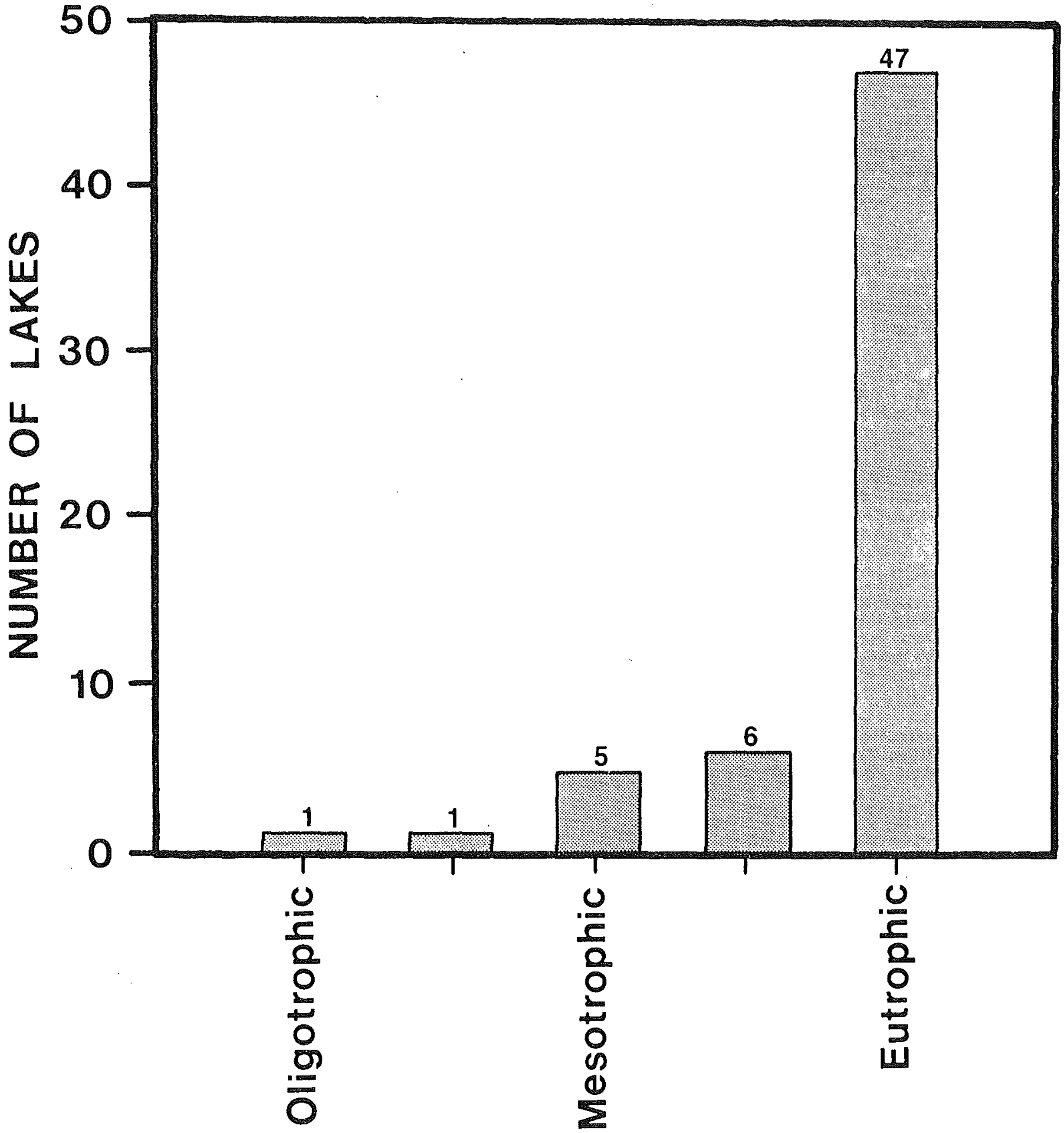


Figure 33. TROPHIC STATUS OF 60 STUDY LAKES—1980

The poor condition of degraded lakes can be tested by chemical and biological means, but the most obvious indicator of condition is usually physical appearance. Figure 34 is a graphic display of Secchi depth, an indication of water clarity obtained by lowering a painted disk (Secchi disk) in the water until it disappears. A depth of less than two meters (about six feet) is generally indicative of a eutrophic condition. Figure 34 shows that about 75 percent of the values are less than two meters, while over half are less than 1.5 meters.

Eutrophy is often defined as nutrient enrichment. Phosphorus in particular indicates trophic status of a lake. Figure 35 shows the total phosphorus (TP) measured in the sampled lakes in 1980. The dotted line between 20 and 30 mg/l is approximately indicative of the break between mesotrophic and eutrophic conditions. The figure shows that 85 percent of the values were 30 ug/l, or greater, with a mean concentration of 84 ug/l. Data on total versus dissolved phosphorus reported by Osgood suggest that about half of the phosphorus in the surface waters of the sampled lakes was in particulate form (greater than 0.45 um) and half was dissolved (less than 0.45 um). The phosphorus data show that Metropolitan Area lakes are enriched in phosphorus, and since nonpoint sources are the only pollution impacts to these lakes, the enrichment undoubtedly comes from these sources.

Figure 36 is the distribution of total Kjeldahl nitrogen (TKN), used to represent nitrogen because it was found to be the only nitrogen species that usually exceeded the detection limit. Eighty-six percent of the values in Figure 36 are between 0.5 mg/l and 2.49 mg/l; this is relatively constant and leads to the conclusion that nitrogen is the limiting nutrient to algal growth only when phosphorus concentrations are extremely high.

Figure 37 shows how biological data can also assist in assessing trophic status. Chlorophyll a, a plant pigment, is an indicator of the presence of algae. The chlorophyll a values over 10 ug/l are generally indicative of eutrophic conditions; only four of the 60 lakes averaged less than 10 ug/l. Most of the values falling in the 0-19 ug/l range are actually between 10 and 19. Again, the chlorophyll content of the sampled lakes is quite high and is directly related to nutrient enrichment. Chlorophyll a is further evaluated in Figure 38 according to the Carlson Trophic State Index (TSI) (Carlson, 1977), where a value of zero is least eutrophic and 100 is most eutrophic. Under Carlson's scheme for chlorophyll a the transition from mesotrophic to eutrophic occurs around 50; Figure 38 shows that most of the sample lakes are eutrophic to hypereutrophic according to the chlorophyll a data. The Osgood report shows that from an algal standpoint, the blue-green (or less desirable) algae are those that are predominantly fluorishing in the Area's nutrient-enriched lakes.

Another problem associated with lakes degraded from nonpoint source pollution is that conditions in the bottom of the lake can promote dissolution of toxic materials that might have accumulated there. A one-time sample from the 60 monitored lakes was taken in 1980 in cooperation with the Minnesota Department of Transportation to determine heavy metal content of the water at the surface and at the bottom. Nonpoint pollution from urban areas is usually high in metal content as it discharges to receiving waters. These metals generally attach to particulate material and sink, and are thereby available to be dissolved later. Figure 39 is typical of the disturbing behavior pattern seen in the sampling. The cadmium distribution is shown to commonly exceed the 0.05 mg/l EPA guideline for protection of aquatic life. Similar patterns that exceed recommended water quality levels were also seen commonly for chromium,

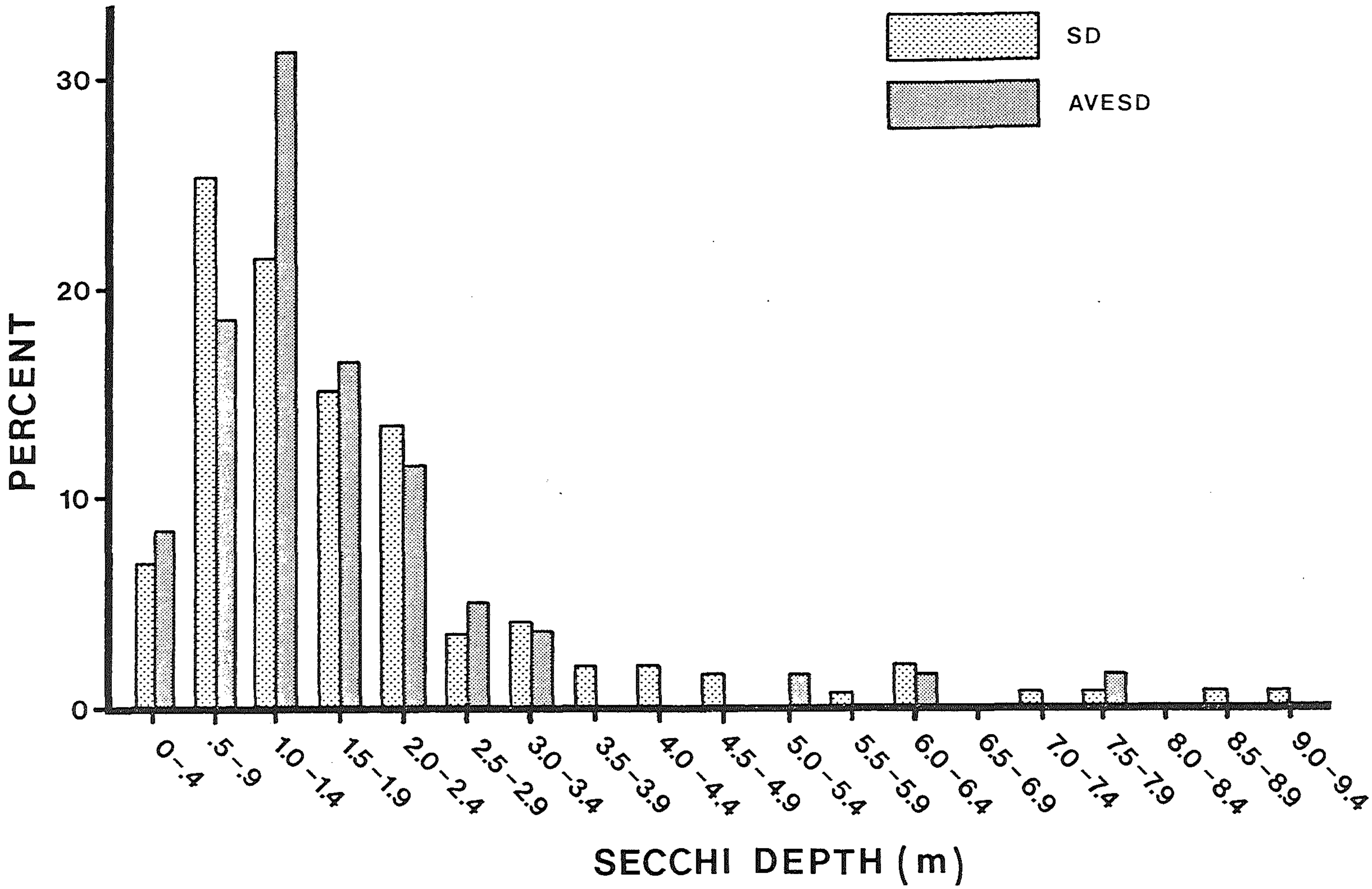


Figure 34. SECCHI DISK TRANSPARENCIES IN 60 STUDY LAKES—1980

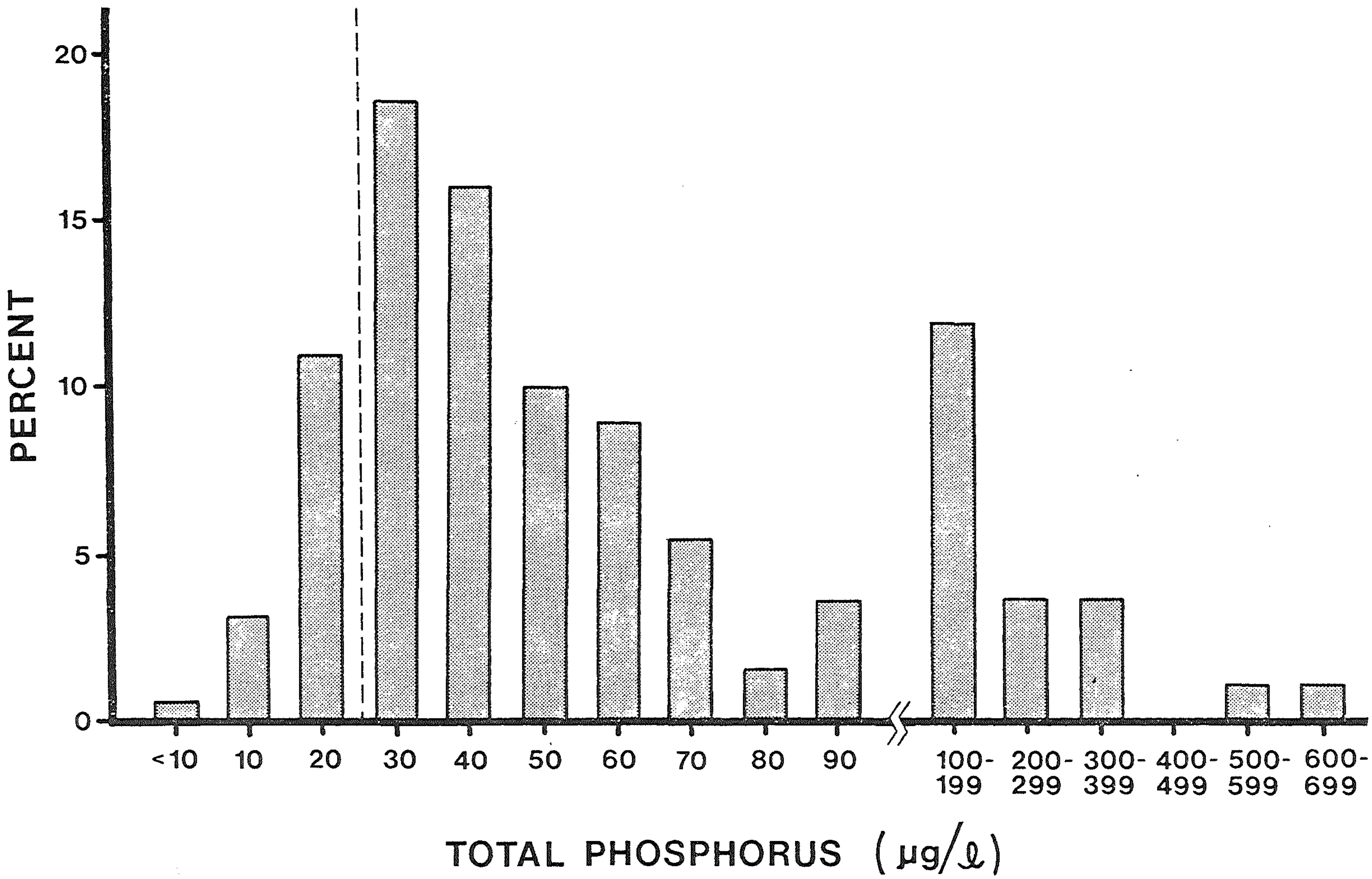


Figure 35. OCCURRENCE OF TOTAL PHOSPHORUS IN 60 STUDY LAKES—1980

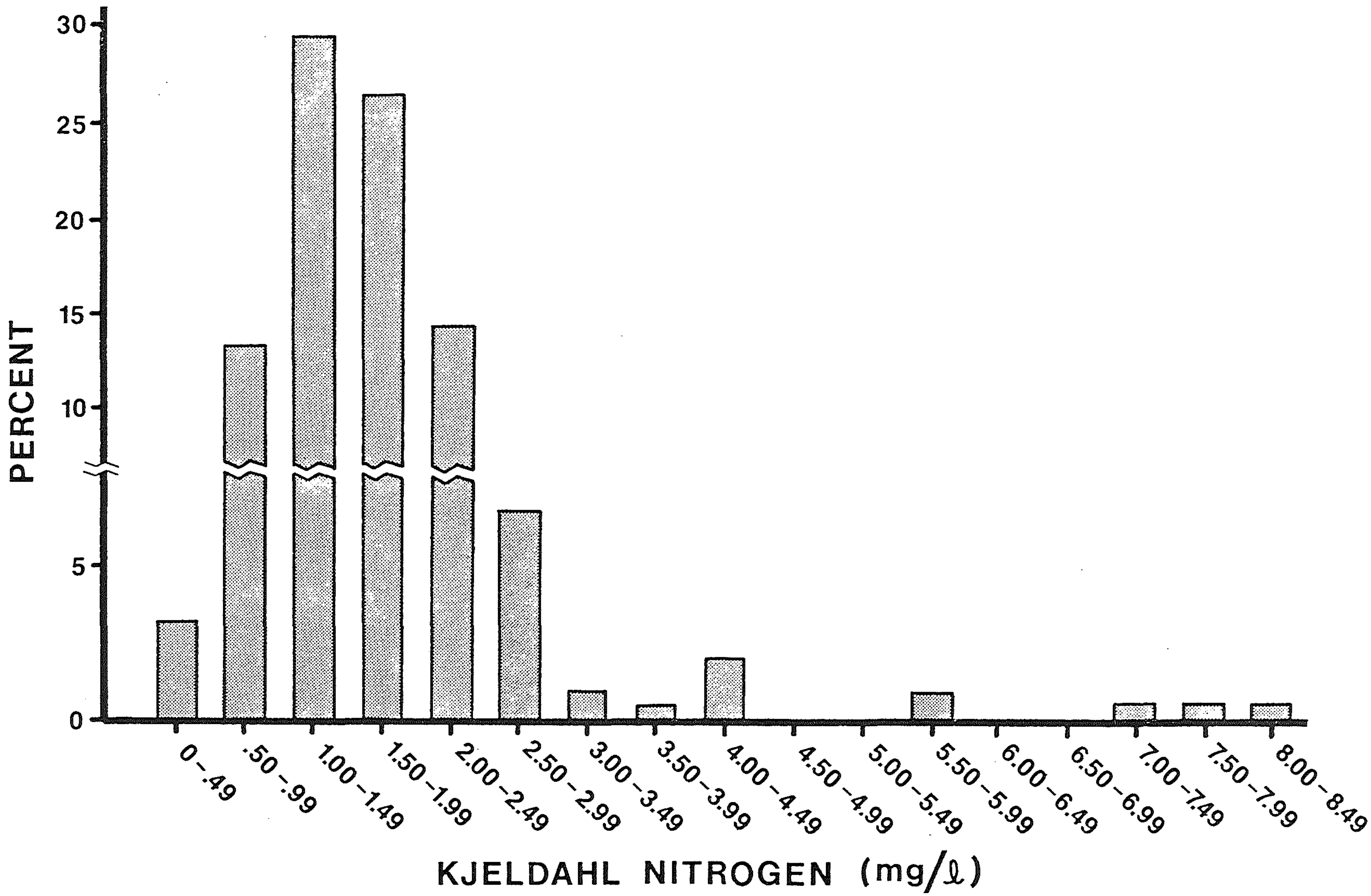


Figure 36. OCCURRENCE OF KJELDAHL NITROGEN IN 60 STUDY LAKES—1980

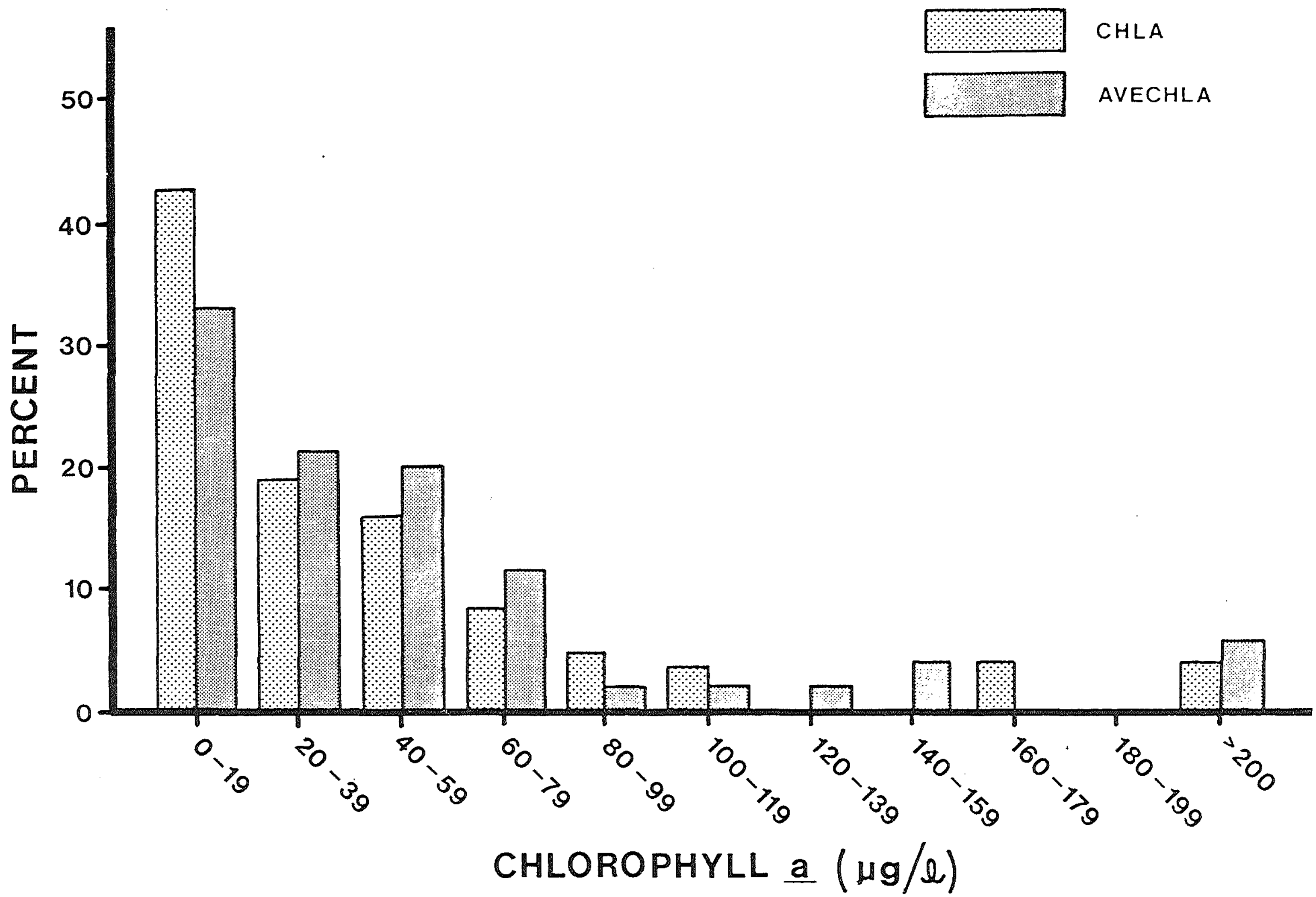


Figure 37. OCCURRENCE OF CHLOROPHYLL a IN 60 STUDY LAKES—1980

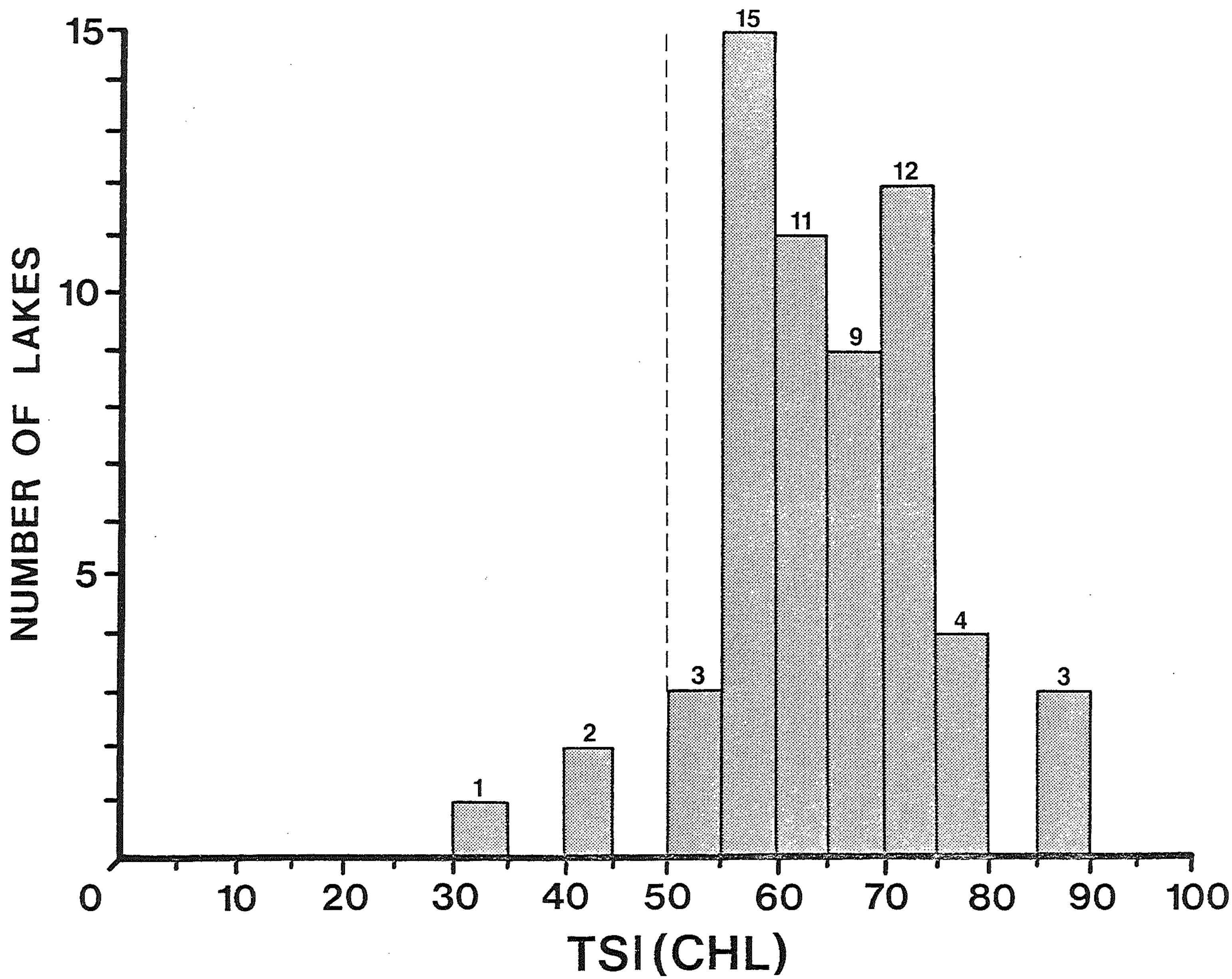


Figure 38. TSI (CHL) OF STUDY LAKES—1980

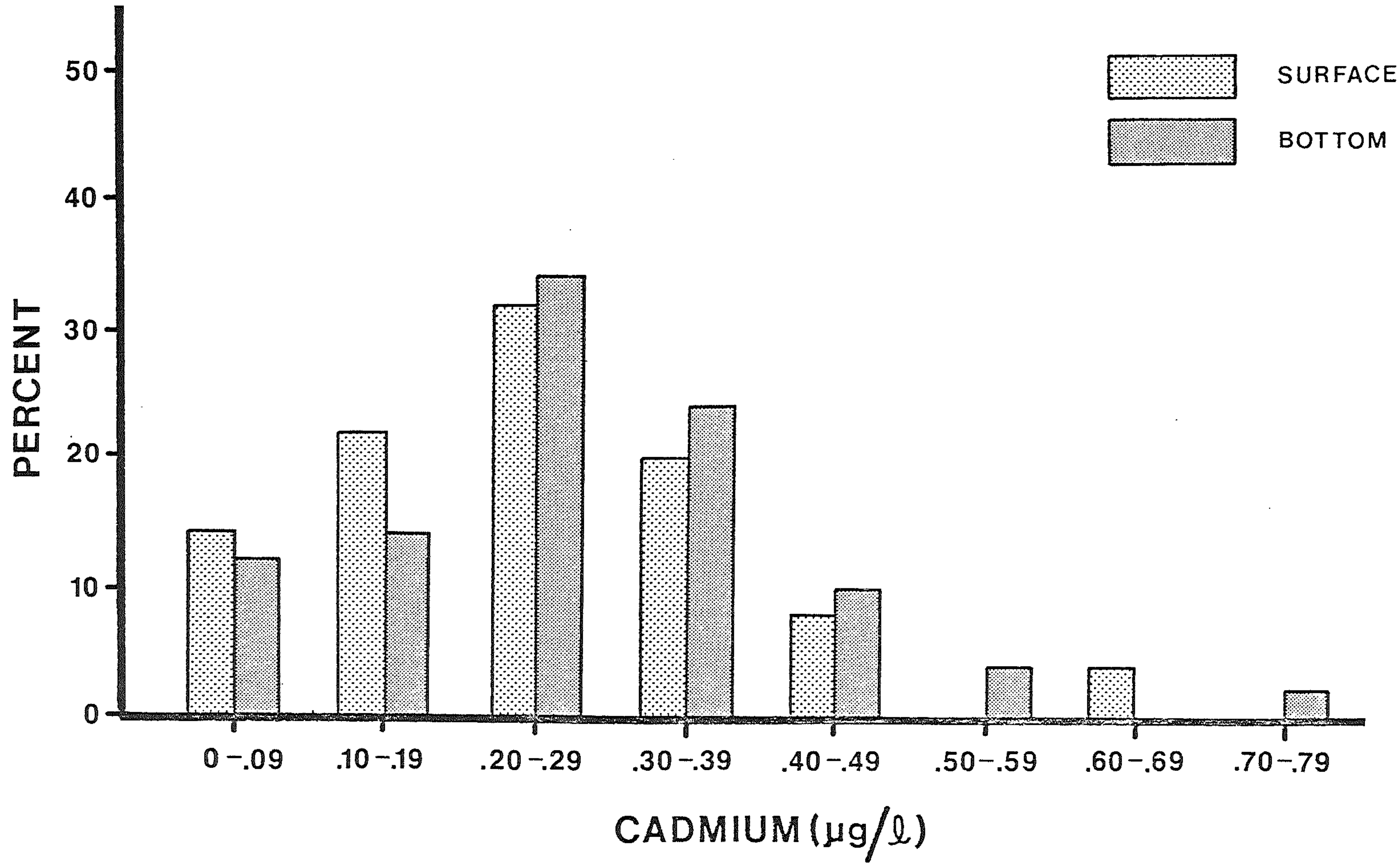


Figure 39. OCCURRENCE OF CADMIUM IN 50 STUDY LAKES—AUGUST 1980

copper, lead, mercury and arsenic. The results regarding heavy metals are far from conclusive because of the limited scope of the study. However, they raise concerns that metals are accumulating and apparently are becoming concentrated in many of our lakes. Similar analyses for 12 other heavy metals can be found in the Osgood report.

In summary, the 1980 representative sampling program on lakes of the Region indicates that they all are being degraded by nonpoint source pollution. This is particularly critical since these lakes are located throughout the Metropolitan Area, with almost every drainage way of any type eventually discharging to a lake, or to a stream that later reaches a lake. The Region's greatest natural resource, its lakes, is severely impacted by nonpoint source pollution.

LOADING TO PRIORITY LAKES

The priority lakes discussed in a previous section are listed in Table 17, along with some descriptive information. The multiple regression modeling discussed in Section IV was also used to generate loading data for each of the 97 priority lakes for purposes of management discussion. The flow-weighted means for TP are listed in Table 18 by lake number from 1 to 97, and Figure 40 is a frequency graph of the same data. The data in Table 18 are very rough estimates that were used by Osgood (Metropolitan Council, 1981a) to determine quality of inflow to the 1980 sample lakes. The concentration data were combined with hydraulic data to determine overall loading character to the lakes. Extremely high values in Table 18 should be considered an indication of highly concentrated runoff; these values should not be used directly because of uncertainties about their accuracy.

The data presented in Figure 40 illustrate quite clearly the primary reason for the degraded condition of Metropolitan Area lakes. Table 5 shows that the recommended guideline for TP inflow to lakes (0.1 mg/l) is exceeded in 87 of the 97 priority lakes. Management alternatives in priority lake watersheds must focus on phosphorus reduction as a necessary first step to lake improvement. Recommendations to achieve this result are contained in the following section.

LAKES SUMMARY

The data contained in the Osgood report on in-lake conditions and the modeling results reported in this document indicate that very high levels of phosphorus are entering area lakes in runoff and these inputs are affecting the lakes' trophic condition. Again, emphasis must be placed on minimization of nutrient input as a first step to lake improvement.

Table 17. INVENTORY OF PRIORITY LAKES

LAKE	DNR NUMBER	PRIORITY CATEGORY [1]	SECONDARY WATERSHED	REGIONAL PARK(S)	COMMUNITIES [2]
ANOKA COUNTY					
1 CENTERVILLE	20006	A	RICE CREEK *	RICE CREEK-CHAIN OF LAKES P.R.	CENTERVILLE, LINO LAKES
2 COLUMBUS	20018	A	RICE CREEK *		COLUMBUS TWSP.
3 COON	20042	C	SUNRISE RIVER		COLUMBUS TWSP., EAST BETHEL, HAM LAKE
4 CROOKED	20084	C	COON CREEK *		ANDOVER, COON RAPIDS
5 EAST TWIN	20133	B	RUM RIVER *		BURNS TWSP.
6 GEORCE	20091	B	RUM RIVER *	LAKE GEORCE R.P.	OAK GROVE TWSP.
7 HAM	20053	C	COON CREEK *		HAM LAKE
8 HOWARD	20016	A	RICE CREEK *		COLUMBUS TWSP.
9 ISLAND	20022	C	SUNRISE RIVER	MARTIN-ISLAND-LINWOOD R.P.	LINWOOD TWSP.
10 LINWOOD	20026	C	SUNRISE RIVER	MARTIN-ISLAND-LINWOOD R.P.	LINWOOD TWSP.
11 MARTIN	20034	C	SUNRISE RIVER	MARTIN-ISLAND-LINWOOD R.P.	LINWOOD TWSP.
12 NETTA	20052	C	COON CREEK *		HAM LAKE
13 OTTER	20003	A	RICE CREEK *	BALD EAGLE-OTTER LAKE R.P.	LINO LAKES, WHITE BEAR TWSP. ***
14 PELTIER	20004	A	RICE CREEK *	RICE CREEK-CHAIN OF LAKES P.R.	CENTERVILLE, COLUMBUS TWSP, FOREST LAKE TWSP., HUGO, LINO LAKES ***
15 RANDEAU	20015	A	RICE CREEK *		COLUMBUS TWSP., LINO LAKES
CARVER COUNTY					
16 ANN	100012	C	RILEY CREEK		CHANHASSEN
17 AUBURN	100044	C	MINNEHAHA CREEK *	CARVER P.R.	LAKETOWN TWSP., VICTORIA
18 BAVARIA	100019	C	HAZEL.-BAVARIA		CHASKA, LAKETOWN TWSP.
19 BURANDT	100084	C	CARVER CREEK		WACONIA, WACONIA TWSP.
20 HYDES	100088	C	CARVER CREEK		WACONIA TWSP.
21 LOTUS	100006	C	PURGATORY CREEK		CHANHASSEN, EDEN PRAIRIE ***
22 LUCY	100007	C	RILEY CREEK		CHANHASSEN
23 MILLER	100029	C	CARVER CREEK		BENTON TWSP., COLOGNE, DAHLGREN TWSP., LAKETOWN TWSP., WACONIA, WACONIA TWSP.
24 MINNEWASHTA	100009	C	MINNEHAHA CREEK *	LAKE MINNEWASHTA R.P.	CHANHASSEN, CHASKA, SHOREWOOD, VICTORIA ***
25 PARLEY	100042	C	MINNEHAHA CREEK *	CARVER P.R.	LAKETOWN TWSP., MINNETRISTA ***
26 PIERSON	100053	B	MINNEHAHA CREEK *		LAKETOWN TWSP.
27 REITZ	100052	C	CARVER CREEK		LAKETOWN TWSP, WACONIA, WACONIA TWSP.
28 RILEY	100002	C	RILEY CREEK		CHANHASSEN, EDEN PRAIRIE ***
29 SCHUTZ	100018	C	MINNEHAHA CREEK *	CARVER P.R.	CHASKA, LAKETOWN TWSP., VICTORIA
30 STIEGER	100045	C	MINNEHAHA CREEK *	CARVER P.R.	VICTORIA
31 WACONIA	100059	C	CARVER CREEK	LAKE WACONIA R.P. **	LAKETOWN TWSP., MINNETRISTA, WACONIA, WACONIA TWSP, WATERTOWN TWSP.***
32 WASSERMAN	100048	C	MINNEHAHA CREEK *		LAKETOWN TWSP., VICTORIA
33 ZUMBRA	100041	C	MINNEHAHA CREEK *	CARVER P.R.	LAKETOWN TWSP., MINNETRISTA, VICTORIA ***
DAKOTA COUNTY					
34 CRYSTAL	190027	C	VERMILLION R.*		APPLE VALLEY, BURNSVILLE, LAKEVILLE
35 MARION	190026	C	VERMILLION R.*		CREDIT RIVER TWSP., LAKEVILLE ***
36 ORCHARD	190031	C	CREDIT RIVER		CREDIT RIVER TWSP., LAKEVILLE ***

Table 17 INVENTORY OF PRIORITY LAKES, CONTINUED

LAKE	DNR NUMBER	PRIORITY CATEGORY [1]	SECONDARY WATERSHED	REGIONAL PARK(S)	COMMUNITIES [2]
HENNEPIN COUNTY					
37 BASS	270098	C	SHINGLE CREEK *		PLYMOUTH
38 BRYANT	270067	C	NINE MILE CREEK	BRYANT LAKE R.P.	EDEN PRAIRIE, MINNETONKA
39 BUSH	270047	C	NINE MILE CREEK	HYLAND-BUSH-ANDERSON LAKES P.R.	BLOOMINGTON
40 CALHOUN	270031	C	MINNEHAHA CREEK *	MINNEAPOLIS CHAIN OF LAKES R.P.	EDINA, MINNEAPOLIS, ST. LOUIS PARK
41 CEDAR	270039	C	MINNEHAHA CREEK *	MINNEAPOLIS CHAIN OF LAKES R.P.	MINNEAPOLIS, ST. LOUIS PARK
42 CHRISTMAS	270137	B	MINNEHAHA CREEK *		CHANHASSEN, EXCELSIOR, SHOREWOOD ***
43 DUTCH	270181	C	MINNEHAHA CREEK *		MINNETRISTA, MOUND
44 EAGLE	270111	C	SHINGLE CREEK *	EAGLE LAKE R.P.	MAPLE GROVE, PLYMOUTH
45 FISH	270118	C	ELM CREEK *	FISH LAKE R.P.	MAPLE GROVE
46 GLEN	270093	C	NINE MILE CREEK		MINNETONKA
47 HARRIET	270016	C	MINNEHAHA CREEK *	MINNEAPOLIS CHAIN OF LAKES R.P.	MINNEAPOLIS
48 INDEPENDENCE	270176	C	CROW RIVER	BAKER P.R.	INDEPENDENCE, MEDINA
49 L. OF THE ISLES	270040	C	MINNEHAHA CREEK *	MINNEAPOLIS CHAIN OF LAKES R.P.	MINNEAPOLIS
50 LANGDON	270182	C	MINNEHAHA CREEK *		MINNETRISTA, MOUND
51 LITTLE LONG	270179	B	MINNEHAHA CREEK *		MINNETRISTA
52 LONG	270160	C	MINNEHAHA CREEK *		LONG LAKE, MEDINA, ORONO
53 MEDICINE	270104	C	BASSETT CREEK *	MEDICINE LAKE R.P.	GOLDEN VALLEY, MINNETONKA, NEW HOPE, PLYMOUTH
54 MINNETONKA	270133	C	MINNEHAHA CREEK *	LAKE MINNETONKA ACCESS **, NOERENBERG GARDENS SPECIAL USE SITE	DEEPHAVEN, EXCELSIOR, GREENWOOD, INDEPENDENCE, LAKETOWN TWSP., MEDINA, MINNETONKA, MINNETONKA BEACH, MINNETRISTA, MOUND, ORONO, ST. BONIFACIUS, SHOREWOOD, SPRING PARK, TONKA BAY, VICTORIA, WAYZATA, WOODLAND ***
55 MITCHELL	270070	C	PURGATORY CREEK		EDEN PRAIRIE
56 NOKOMIS	270019	C	MINNEHAHA CREEK *	NOKOMIS-HIAWATHA R.P.	MINNEAPOLIS
57 REBECCA	270192	C	CROW RIVER	LAKE REBECCA P.R.	GREENFIELD, INDEPENDENCE
58 SARAH	270191	C	CROW RIVER	LAKE SARAH R.P.	CORCORAN, GREENFIELD, INDEPENDENCE, LORETTO, MEDINA
59 STARING	270078	C	PURGATORY CREEK		EDEN PRAIRIE, MINNETONKA, SHOREWOOD
60 TWIN	270042	C	SHINGLE CREEK *		BROOKLYN CENTER, BROOKLYN PARK, CRYSTAL, NEW HOPE, ROBBINSDALE
61 WEAVER	270117	C	ELM CREEK *		MAPLE GROVE
62 WHALETAIL	270184	C	CROW RIVER	WHALETAIL R.P.	MINNETRISTA
RAMSEY COUNTY					
63 BALD EAGLE	620002	A	RICE CREEK *	BALD EAGLE-OTTER LAKE R.P.	DELLWOOD, GRANT TWSP., HUGO, LINO LAKES, WHITE BEAR LAKE, WHITE BEAR TWSP.
64 CHARLEY	620062	A	ST. PAUL-RAMSEY *		NORTH OAKS, SHOREVIEW, WHITE BEAR TWSP.
65 DEEP	620018	A	ST. PAUL-RAMSEY *		NORTH OAKS, WHITE BEAR TWSP.
66 GERVAIS	620007	C	RAM.-WASH. METRO *	PHALEN-KELLER R.P.	LITTLE CANADA, MAPLEWOOD
67 JOHANNA	620078	C	RICE CREEK *		ARDEN HILLS, NEW BRIGHTON, ROSEVILLE
68 JOSEPHINE	620057	C	RICE CREEK *		ARDEN HILLS, ROSEVILLE, SHOREVIEW
69 LONG	620067	C	RICE CREEK *	LONG LAKE-RUSH LAKE R.P.	NEW BRIGHTON
70 OWASSO	620056	C	ST. PAUL-RAMSEY *		ROSEVILLE, SHOREVIEW
71 PHALEN	620013	C	RAM.-WASH. METRO *	PHALEN-KELLER R.P.	ST. PAUL, MAPLEWOOD
72 PLEASANT	620046	A	ST. PAUL-RAMSEY *		NORTH OAKS
73 SNAIL	620073	C	ST. PAUL-RAMSEY *	GRASS-VADNAIS LAKE R.P.	SHOREVIEW
74 SUCKER	620028	A	ST. PAUL-RAMSEY *	GRASS-VADNAIS LAKE R.P.	NORTH OAKS, SHOREVIEW, VADNAIS HEIGHTS
75 TURTLE	620061	C	RICE CREEK *		SHOREVIEW
76 VADNAIS	620038	A	ST. PAUL-RAMSEY *	GRASS-VADNAIS LAKE R.P.	GEM LAKE, SHOREVIEW, VADNAIS HEIGHTS, WHITE BEAR LAKE, WHITE BEAR TWSP.

Table 17 INVENTORY OF PRIORITY LAKES, CONTINUED

LAKE	DNR NUMBER	PRIORITY CATEGORY [1]	SECONDARY WATERSHED	REGIONAL PARK(S)	COMMUNITIES [2]
RAMSEY COUNTY, CONTINUED					
77 WABASSO	620082	B	ST. PAUL-RAMSEY *		SHOREVIEW
SCOTT COUNTY					
78 CEDAR	700091	C	SAND CREEK	CEDAR LAKE R.P. **	CEDAR LAKE TWSP., HELENA TWSP.
79 FISH	700069	C	PRIOR-SPRING L. *		SPRING LAKE TWSP.
80 McMAHON	700050	C	SAND CREEK		CEDAR LAKE TWSP., SPRING LAKE TWSP.
81 O'DOWD	700095	C	SHAKOPEE *		JACKSON TWSP., LOUISVILLE TWSP, SHAKOPEE
82 PRIOR (LOWER)	700026	C	PRIOR-SPRING L. *		PRIOR LAKE, SAVAGE
83 PRIOR (UPPER)	700072	C	PRIOR-SPRING L. *	SPRING LAKE R.P.	PRIOR LAKE, SPRING LAKE TWSP.
84 SPRING	700054	C	PRIOR-SPRING L. *	SPRING LAKE R.P.	SAND CREEK TWSP., SPRING LAKE TWSP.
85 THOLE	700120	C	SHAKOPEE *		JACKSON TWSP., LOUISVILLE TWSP.
WASHINGTON COUNTY					
86 BIG CARNELIAN	820049	C	BIG MARINE-CARN.		MAY TWSP., STILLWATER TWSP.
87 BIG MARINE	820052	C	BIG MARINE-CARN.	BIG MARINE LAKE P.R. **	MAY TWSP., NEW SCANDIA TWSP.
88 BONE	820054	C	SUNRISE RIVER		NEW SCANDIA TWSP., CHISAGO LAKE TWSP. ***
89 CLEAR	820163	A	RICE CREEK *		FOREST LAKE, FOREST LAKE TWSP.
90 DeMONTREVILLE	820101	C	VALLEY BRANCH		LAKE ELMO, OAKDALE
91 ELMO	820106	C	VALLEY BRANCH	LAKE ELMO P.R.	LAKE ELMO
92 FOREST	820159	C	SUNRISE RIVER		FOREST LAKE, FOREST LAKE TWSP., NEW SCANDIA TWSP., WYOMING TWSP. ***
93 JANE	820104	C	VALLEY BRANCH		LAKE ELMO
94 PINE TREE	820122	C	RICE CREEK *		DELLWOOD, GRANT TWSP.
95 SQUARE	820046	B	MARINE-ON-ST. CROIX	SQUARE LAKE R.P.	MAY TWSP.
96 SUNSET	820153	C	RICE CREEK *		HUGO
97 WHITE BEAR	820167	C	RICE CREEK *		BIRCHWOOD, DELLWOOD, MAHTOMEDI, WHITE BEAR LAKE, WHITE BEAR TWSP, WILLERNIE

1 A) HEALTH-RELATED
B) MULTI-RECREATIONAL, EXCEPTIONAL WATER QUALITY
C) MULTI-RECREATIONAL, PUBLIC ACCESS PRIORITY
D) SINGLE PURPOSE RECREATIONAL

2 COMMUNITIES LYING WHOLLY OR PARTIALLY WITHIN THE LAKE'S WATERSHED.

* DENOTES CRITICAL WATERSHED
** DENOTES PROPOSED ADDITION TO THE REGIONAL PARK SYSTEM BY THE YEAR 2000.
*** INDICATES LAKE WATERSHED CROSSES COUNTY BOUNDARY

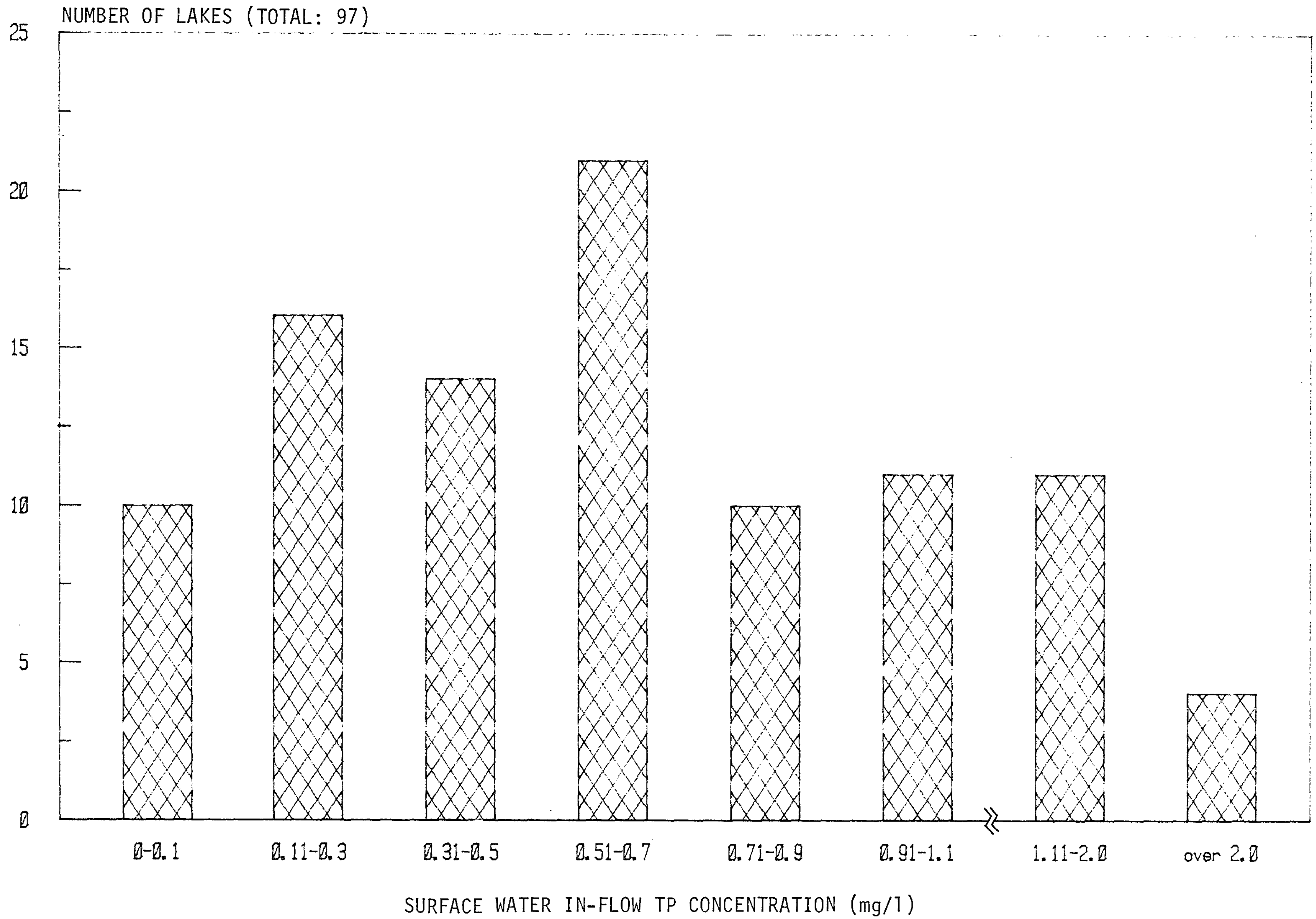
R.P. REGIONAL PARK
P.R. PARK RESERVE

Table 18
TOTAL PHOSPHORUS FLOW-WEIGHTED MEAN CONCENTRATION OF INFLOW TO PRIORITY LAKES*

Lake Number	TP mg/l	Lake Number	TP mg/l
1	0.28	50	0.06
2	0.29	51	0.06
3	1.00	52	0.79
4	0.68	53	0.29
5	0.87	54	0.79
6	1.13	55	0.24
7	0.67	56	0.57
8	0.28	57	0.79
9	1.02	58	0.69
10	1.02	59	0.24
11	1.02	60	0.17
12	0.67	61	0.41
13	1.64	62	0.60
14	0.28	63	1.64
15	0.28	64	0.38
16	1.00	65	0.35
17	0.06	66	1.17
18	0.56	67	0.63
19	1.52	68	0.63
20	0.55	69	0.63
21	0.24	70	0.38
22	1.00	71	1.17
23	0.56	72	0.38
24	0.79	73	0.38
25	0.06	74	0.38
26	0.06	75	0.63
27	1.52	76	0.38
28	2.30	77	0.38
29	0.06	78	0.12
30	0.06	79	3.90
31	1.52	80	0.12
32	0.06	81	0.80
33	0.06	82	0.94
34	1.20	83	0.94
35	1.19	84	3.90
36	0.46	85	0.81
37	0.36	86	0.36
38	0.70	87	0.35
39	2.08	88	1.00
40	0.57	89	0.28
41	0.57	90	0.81
42	0.79	91	0.81
43	0.06	92	1.00
44	0.36	93	0.81
45	1.08	94	0.28
46	0.70	95	0.27
47	0.57	96	0.28
48	0.60	97	1.64
49	0.57		

* See Table 17 for lake names.

Figure 40. PRIORITY LAK_ IN-FLOW TP CONCENTRATION



VI. MANAGEMENT OF NONPOINT SOURCES

This section of the report deals with the technical basis for application of nonpoint source management practices (MPs). The extensive discussion of the philosophy of MPs application occurs in Water Quality Management Report No. 5 (Metropolitan Council, 1981b) and in the draft Water Resources Management Development Guide (Metropolitan Council, 1982b). The research conducted for the 208 study and information gathered in contact with agencies and communities all points to the fact that water quality control cannot be separated from water quantity control. Stressed again and again, therefore, is the comprehensive stormwater management approach that treats the problems of runoff in total rather than as isolated parts.

Application of MPs to identified runoff problems can take numerous courses, from minimal application through large-scale, capital-intensive construction projects. The purpose of this report is to take the identified nonpoint source water quality problem and the possible options for management approaches and recommend a framework within which they can be brought together. Later work on individual watersheds will address the actual implementation of management programs and their costs.

It has become increasingly obvious, in these days of financial limitations, that a successful nonpoint pollution control program will require emphasis on low-cost, easily implementable solutions. This approach should be followed whenever such MPs can be applied without compromising appropriate water quality improvements. Such solutions, however, may not be applicable in areas so developed that options requiring land consumption or preservation of natural resources are impossible or extremely costly. Such conditions will be discussed later in the report.

In order to meet the objective of low-cost, easily implementable MPs, a number of recurring themes will appear throughout the following discussion and in subsequent discussions concerning application of MPs. First, minimum or nonstructural MPs will be emphasized and proposed for every situation except where such options are impossible. In all cases where choices have to be made between structural and nonstructural solutions and where the effectiveness of the nonstructural techniques is comparable, the nonstructural approach should be followed.

Second, reliance upon the natural drainage system will be emphasized. Use of wetlands and floodplains as primary water storage, conveyance and treatment systems will continually be stressed. Preservation of existing systems is greatly encouraged because once a natural system is altered, it is extremely costly to restore. Restoration of such resources as wetlands and natural filtration areas, however, might prove to be the best MP approach to take in certain situations and will not be eliminated from future considerations. Infiltration of excess runoff waters will be a dominant recommendation in cases where no threat to the quality of groundwater exists. The environmental and economic benefits of using in-place, naturally occurring stormwater handling systems lend support to these systems rather than structural systems. Appendix H and Brown and Oberts (1982) are descriptions of a small study that was conducted during the 208 process to assess the impact of wetlands on water quality. Although the results are limited in scope, it certainly appears as though wetlands and natural drainage systems are quite beneficial to stormwater control.

Finally, conjunctive or multiuse systems will be encouraged because of the benefits that can be realized for quantity/quality improvement and for cost allocation. Any MP that can be shown to address more than a single water-related problem or that can be used for a purpose (recreation, aesthetics, recharge, water supply) not directly related to a water-related problem will find favor from an economic, as well as a common sense, viewpoint. Many of the practices suggested for control of nonpoint source pollution are similarly applicable for control of the rate and total volume of runoff water. The goal of both control methodologies is to slow water down, naturally or artifically, so that the natural system is not overwhelmed to the extent that it cannot handle the water being supplied. In most places, this approach would merely involve adding a quality dimension to the ongoing stormwater management programs of communities. Since most of the quantity control techniques are essentially the same, the manager has only to be cognizant of the quality aspects and perhaps slightly alter a particular practice. Simple methods such as detention, infiltration, wetland storage and erosion control retard the rapid movement of water, while helping to control inputs of pollution into the water. Other uses such as recreation, aesthetics, water supply and wildlife enhancement can also tie in conjunctively with quantity and quality control through such practices as natural area preservation, groundwater recharge basins, temporary storage of stormwater in recreation areas and use of stored stormwater for emergency fire control supply.

The MPs that are reviewed and discussed in this report will, for the most part, be oriented in such a manner that communities (urban, urbanizing) and individuals (rural) can easily implement them. The urban and urbanizing community and the rural individual are the common denominators that occur in the application of essentially every management approach. It appears that most approaches focus on the local units of government and/or the agricultural landowner. The evaluation that follows in this report shows the tremendous strides that can be made by using the previously mentioned low-cost MPs at the municipal and individual farm level. There will undoubtedly be cases, however, wherein a low-cost, nonstructural approach simply will not be adequate. In these situations, expected to occur in densely developed areas and areas with severe water quality problems, an approach will be adopted that minimizes structural control while providing for adequate abatement of the problem.

All of the 208 planning work done by the Council is done on a watershed (or drainage basin) basis. Although watershed boundaries and political subdivisions practically never coincide, it makes absolutely no sense to plan for water resources using any other subdivision than that within which the impact will be seen. The political subdivision rather than watershed approach has led to numerous water-related problems in the past, particularly between communities with different planning philosophies occurring upstream/downstream from each other. To the extent possible, management recommendations will be made on a watershed basis and institutional consideration will be made with watersheds in mind.

This report is a first effort at defining a nonpoint source management program. In most cases, detailed management scenarios complete with site-by-site design details will not occur in the watershed analyses later in this section. Rather, the goal of this phase of the 208 Program is to identify in a regional manner the nonpoint problems and how they can be managed. Recommendations will be general and on a secondary watershed basis. Specific design details will be left to a program implementation phase wherein actual engineering design, basic plans and site-specific projects are formulated by implementing agencies. The application of appropriate MPs should be based on a set of objectives that move toward cleaning targeted water bodies. The two primary pieces of work that will be used in defining MP application are the problem definition aspects of this report (Metropolitan Council, 1981c) and the preliminary priority system for water bodies developed by the 208 Advisory Committee (Metropolitan Council, 1982b).

The conclusions of the problem definition pointed to the fact that runoff from urban and agricultural surfaces did indeed impact receiving waters, particularly lakes. Lakes are primary receivers of pollution impact because they are usually quiescent bodies of water in which pollutants are given a chance to accumulate, settle, solubilize and recycle repeatedly. Phosphorus was identified as the principal cause of in-lake problems because it promotes the process of eutrophication; culturally induced nonpoint source pollution has accelerated eutrophication to such an extent that most of our lakes are now eutrophic. Although eutrophy is not necessarily always bad, the degree of eutrophy in most of our lakes is such that recreational opportunities have somewhat diminished. To address the impact of nonpoint sources on our lakes, it is proposed that top priority be given to MPs that maximize phosphorus removal from runoff. These practices will also, it is hoped, control nitrogen input to the lakes; if they appear not to, then secondary attention should be placed on MPs which focus on nitrogen removal. Attention should also be paid to those MPs effective at removal of sediments, metals, oxygen-demanding substances and chlorides, which have also been identified as in-lake quality problems.

The problem identification section also concluded that movement of soluble and fines-associated particulate matter is as much a threat of pollution as is movement of larger sediment and organic debris, particularly because they travel long distances and tend to concentrate in lakes and river bottoms. Appendix I contains 1980 data and a discussion of pollutant settleability that indicates the nature of this problem. Historically, nonpoint source programs have paid most attention to erosion control and elimination of off-site sediment movement. It is now time to supplement this type of program with MPs that address soluble pollution and fine-particulates, both of which easily slip through traditional sediment control practices such as detention ponds, hay-bales and grade stabilization structures. It is emphasized that the MPs used to control on-site erosion (vegetative establishment, phased construction, mulching, and so on) and those historically used for larger-scale sediment entrapment should not be discontinued; the point is that these systems appear to be missing a significant portion of the total nonpoint source pollution load and need supplemental MPs. The MPs that hold the best promise for soluble and fines-associated control will be discussed later in this report.

Also identified as problem areas were the tributary streams draining into the larger river system. These tributary streams typically do not receive point source discharges, but are rather controlled relative to quality by nonpoint source runoff and groundwater seepage. Section III showed that the ten tributary streams monitored (of the 17 sites) commonly violated MPCA and U.S. EPA recommendations for good in-stream quality. These recommendations were especially violated for metals, suspended solids, fecal coliform and nutrients. Recommendations did not exist for the chemical oxygen demand (COD) parameter that was measured, but it was equal in magnitude to the several other parameters exceeding recommendations. Where primary focus is to be paid to protection of tributary streams, it is proposesd that MPs be used that will minimize movement of the above mentioned pollutants into the streams. Where such tributaries also drain into a lake, primary focus should again be on minimization of nutrients.

Some insight can be gained on the impacts of point sources of pollution (sewage treatment plants) versus nonpoint sources of pollution (urban and rural runoff) in the three main rivers (Minnesota, Mississippi and St. Croix) in the Metropolitan Area, by evaluating those impacts on the Minnesota River. A mathematical computer model (RMA-12) was used to simulate the impacts on the Minnesota River of a continuous three-day storm during low-flow conditions. Unfortunately, the model is a steady-state, one-dimensional model. Therefore, many assumptions had to be made regarding how to model nonpoint runoff with its dynamic character. (Point source loadings are more or less continuous in both quality and quantity, while nonpoint source loads are highly variable.)

It was assumed that if the impact from the modeled ("worst case") event was negligible, it could be implied that nonpoint sources of pollution had very little impact on the water quality of the three main rivers. The tested assumption was invalid. There was a low concentration in the river violating water quality standards. Preliminary analysis indicates that the main cause of the low dissolved oxygen level in the river is nonpoint pollution as contained in the headwater (background) conditions and in local inputs to the river system.

The Mississippi and St. Croix Rivers were not actually modeled. However, the types of limitations encountered in modeling comparisons of point versus nonpoint loads in the Minnesota River would also apply to the Mississippi and St. Croix. Furthermore, the Mississippi is primarily affected by urban rather than agricultural runoff. The pollutants associated with urban runoff (heavy metals, chemical oxgen demand and suspended solids) do not readily lend themselves to modeling. Conversely, since there are so few point source discharges to the lower St. Croix, water quality there will be determined primarily by nonpoint source loadings. However, water quality in the St. Croix is not significantly degraded by existing nonpoint source loads.

Table 19 is a compilation of the median nonpoint source load (agricultural and urban) versus the 1980 point source load for the entire Region. The difficulty with comparing point to nonpoint source loads is that the receiving waters for the two sources are quite different. Point source discharges are made almost exclusively to one of the three major rivers, whereas nonpoint sources discharge to the smaller tributary streams and the numerous lakes.

Table 19 shows that loadings from nonpoint source discharges exceed those from point source discharges for TSS, COD and Pb. For nutrients (TKN and TP), loadings are larger for point sources, but it is very important to remember the receiving bodies. Nonpoint source nutrient discharges go primarily to lakes and smaller streams, which are greatly affected, as discussed previously. With the limited data available the nonpoint impact appears to be major, even though it does not exceed point discharges in weight.

In the combined sewer (CS) areas of the Region, that is, parts of Minneapolis, St. Paul and South St. Paul, a management program for minimizing CS overflow problems has been proposed. When the CSO study is completed and the Metropolitan Council and 208 Advisory Committee have fully reviewed the program, the 208 Program should adopt the accepted approach and attempt to reduce the surface loading of material into the CS system. Once the remaining pollutants reach the CS system and combine with sanitary sewage, the problem becomes point source-related and should be dealt with according to the prescribed 201 CSO program. Careful attention must be paid in the CSO review to recommendations, such as sewer separation and discharge to lakes, that might lead to surface runoff nonpoint pollution reaching bodies of water it formerly did not impact.

Table 19
MEDIAN NONPOINT POLLUTANT LOADS AS COMPARED TO 1980 POINT SOURCE LOADS
(in thousands of pounds)

Nonpoint	TSS	BOD*	COD*	TKN	TP	Pb
Agricultural (2,004 sq. mi.)	65,419 40.8%	5,511 22.2%	82,662 54.9%	2,396 16.1%	556.4 21.7%	-
Urban (964 sq. mi.)	42,950 26.8	2,751 11.1	41,264 27.4	1,542 10.3	416.6 16.3	33.8 51.6
Point						
Muncipal (MWCC**)	51,330 32.0	16,135 65.1	25,447 16.9	10,963 73.6	1,586 61.9	31.7 48.4
Municipal (non-MWCC)	87 0.0	52 0.2)	156 0.1	-	2.2 0.1	-
Industrial	377 0.2	342 1.4	1,026 0.7	-	-	-
Total	160,163 100%	24,791 100%	150,555 100%	14,901 100%	2,561.2 100%	65.5 100%

* For 1980 data on nonpoint, amount of COD is approximately 10 to 15 times amount of BOD.

** Sewage treatment plants of the Metropolitan Waste Control Commission.

Two concepts will be used when formulating nonpoint pollutant reduction approaches. First, the priorities system developed by the 208 Advisory Committee will be used to recommend appropriate treatment measures for specific watersheds. Those priorities in descending order are: health-related, multiple purpose recreation with public access priority, single purpose recreation with public access priority, and aesthetic. The second concept to be followed is one in which priority attention is given to "critical" watersheds, or those with identified water quality problems far worse than other watersheds. In the rural area, for example, a watershed might have a great number of feedlots or a large percentage of land not adequately treated; a similar situation might exist in the urban area where a watershed might be highly commercialized or industrialized and contribute large volumes of runoff. Situations such as these will be recommended for a higher level of MP application to bring them at least to a "noncritical" level.

EFFECTIVENESS OF MANAGEMENT PRACTICES

A multitude of possible MPs and application options exists for managers to use. The challenge then becomes selecting the practice or combination of practices that deliver the best water quality while meeting the financial, engineering and environmental constraints of the situation.

Data on actual water quality effects of MPs are surprisingly limited. In many instances in the past MPs were accepted and applied without full knowledge of their applicability for water quality improvement. Many MPs have been used only because they control sedimentation or limit stormwater runoff and coincidentally might help with other water quality constituents such as nutrients and metals.

There are essentially three alternative management approaches to select from in dealing with pollution from nonpoint sources. The first is source control where pollutants are kept on-site or in place and not allowed to migrate; the second is a collection system in which runoff and its associated pollutants are gathered at a collection area downstream from the pollution source area; and finally is a treatment system which accumulates pollutant-laden runoff and treats it by physical, chemical, biological or mixed methods prior to discharge to a receiving water body. In many cases two or more MPs might be combined to achieve pollutant removals above those expected from single MP application.

A word of caution should be introduced here about the validity of the available data on MPs. Many of the studies were done under conditions that might be quite different from those experienced in the Twin Cities Metropolitan Area. Studies reflected in this report were selected first for their scientific merit and method of reaching conclusions, and second for their similarity to conditions experienced in this Region. Some studies were used from areas quite different from Minnesota, but only in cases where widely applicable and significant conclusions on an MP were drawn after a well-thought-out and well-executed study. Occasionally results were used from a study which was conducted under near-perfect conditions, such as under a "rainulator" or in an actual laboratory environment. When such studies reflected conditions unlikely to occur in a field situation, judgment was used as to their applicability for MP evaluation. A significant shortcoming of many MP studies is lack of description of the design specifics that went into the MP evaluation. Typically, in such a case, a study might report effective results, but leave out the size of the facility and the storm frequency it is designed to catch. Again, judgment was used in these cases and they were evaluated against studies for which design specifics exist.

Cost data on the MPs used in the report were similarly compiled and were supplemented by interviews with various implementing agencies, communities and individuals. The MP cost report will then be used in this report in the actual recommendation of MPs to be applied to specific watersheds. Costing of MPs will be an integral part of the final management recommendations.

Table 20 is a summary of the extensive review of MPs. The values in Table 20 will be those pollutant reduction percentages that are associated with the MPs specified. The figures are the best approximation of the true in-field value of the respective MP. It should be emphasized that the Table 20 reduction figure might deviate from the value range identified in some literature. The reason for this is that literature values in most cases represent new, carefully maintained, field controlled MPs. In an actual field situation, experience has shown that the effectiveness of MPs might decrease significantly with age because of poor or inadequate maintenance and deviation from the original design caused by such things as sediment fill-in, change in the character of the tributary watershed and normal degradation expected from any physical facility. When Table 20 presents a range of possible pollutant reduction percentages, judgment will be used as to which end of the range is most

Table 20.
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
Agricultural: Source	Conservation tillage	A multitude of options exists for reducing the amount of tillage; conservation tillage leaves protective crop residue, minimizes soil exposure to the energy of raindrop impact and moving water and enhances infiltration; target pollutants include solids and nutrients; practices include limited tilling, chisel plowing, till planting, field cultivation and residue management.	- 50 percent sediment (TSS) - 50 percent N & P - Possible increase in pesticides - 35 percent chemical oxygen demand (COD)*
	No tillage	A form of conservation tillage in which no actual tillage is undertaken other than at planting time when a seed row is prepared in the same operation as planting; benefits same as conservation tillage, only enhanced because of no soil disturbance; likely increase in pesticide use and soluble nutrient export (total nutrients reduced).	- 75 percent TSS - 50 percent N & P - From 0 to 100 percent increase in pesticide runoff - 50 percent COD
	Contour plowing, strip-cropping	Often used together, these MPs dissipate runoff energy and allow infiltration; most effective relative to sediment mobilization and associated nutrients.	- 50-75 percent TSS when used in unison with sod crops. - 20 percent N & P alone or together - 30 percent COD
	Feedlot management system	Control of animal waste on-site with later incorporation into unfrozen fields; very effective for nutrient, bacteria and oxygen-demand reduction, although could be very expensive; includes collection, storage and disposal of waste; also fencing animals away from streams to minimize streambank erosion and waste directly entering receiving water (see also treatment section).	- 50 percent N & P at specific sites where problem feedlots occur - 50 percent COD at some sites - 50 percent erosion control where animal access to stream now exists - No discharge system would be 100% reduction.
	Crop rotation to less erosive crops	This approach tends to be very site-specific, depending upon soil type, slopes, crops chosen, and so on.	Indeterminate as category, but can reach 20 to 60 percent for most pollutants.
	Buffer strips, field borders	Vegetated border areas around fields or animal grazing areas serve to slow runoff, allow particles to settle and consume nutrients; effectiveness is a function of proper design and maintenance, plus type of runoff flowing over strip (feedlot, crop); can get 'background' with large strips.	- 25 percent TSS - 50 percent N & P - 15 percent COD

*D[illegible]t data not available; assumption based on behavior o[illegible]ved during 1980 field sampling program.

Ta. 20. (Contd.)
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
	Fertilizer and pesticide management	Proper and well-timed application of fertilizers and pesticides; could include decreased usage by such measures as addition of natural fertilizers, integrated pest management, scouting for pests, and better need analysis.	- up to 50 percent nutrient and pesticide reduction
	Terraces	Terraces are designed to reduce slope by leveling the field in which they occur in a step-wise manner; energy of runoff water is dissipated and infiltration enhanced, reducing both sediment and nutrient movement very efficiently; biggest problem is current cost of installing terraces; generally applied with contouring and might have tiled outlet.	- 75 percent TSS - 35 percent N & P (less if tiled outlet discharge) - 50 percent pesticides
	Residue management, sod, mulching, critical area vegetation	All of these practices are oriented toward protection of soil and dissipation of runoff energy; again variability of effectiveness can be large and design is the key to effectiveness; sediment and associated nutrients are the beneficiaries of these methods.	- 50 percent TSS - 25 percent N & P - 35 percent COD - 25 percent pesticides
Agricultural: Collection	Detention ponding, base-of-slope detention, "farm ponds"	Detention of runoff water usually affords very good treatment because sediments are allowed to drop from suspension along with associated nutrients and organics and nutrients are used in biological processes under way in the detention pond; infiltration is usually a by-product of detention, so water volume is slightly dissipated; cost and location of available acreage might present limitations;also proper design and maintenance is a key to success with detention facilities; fines and solubles usually pass through.	- 75 percent TSS - 50 percent N & P - 40 percent COD
	Grassed waterways	Vegetated (grass) swales through which runoff water can move minimizes mobilization of soil, allows for nutrient uptake and sediment disposition and increases infiltration; once again, proper design and maintenance are essential.	- 25 percent TSS - 10 percent N & P
	Diversions, berms	Diversion of runoff can be used to route runoff to appropriate handling areas, such as open fields, storage or drainageways; numerous options exist for disposition of water; can also be used to divert water away from fields and feedlots.	Indeterminate (depends on where water diverted)
	Wetland discharge	See urban section.	
	Water and sediment control basin	This basin is smaller than a detention pond, with less than 15 feet of fill height and a drainage area less than 30 acres; outlet usually slotted riser to small tile line; about 24-hour storage; very effective on small scale in lieu of waterway.	- Up to 90 percent TSS

Table 20. (Contd.)
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
	Grade stabilization structures	These check dams, drop boxes, and so on, serve to dissipate runoff energy and hence cut overall erosion losses; since they are placed directly in the drainageway, reductions are realized mostly from decreased downcutting and gullying and from land that otherwise might have been exposed to runoff water in a concentrated form.	- Benefit is reduced downcutting rather than reduction of existing pollution.
Agricultural: Treatment	Feedlot management system	Collection of animal waste in a feedlot management system with treatment by storage and land application at periods when fields not frozen; system possibly quite expensive, but generally very effective; discharge could also be into treatment lagoon.	(see Source section)
	Detention	A fair amount of physical and biological treatment can occur in the detention ponds described in the Collection section (previous section).	(see Collection section)
Urban: Source	Street sweeping	This most commonly recommended management technique is also perhaps the least effective because of sweeper ineffectiveness and infrequency of times streets are swept; sweeping would have to be increased to almost weekly before significant changes result and vacuum sweepers would have to be used; material picked up is concentrated in the larger size fractions, leaving behind the pollutants more detrimental to water quality.	- 50 percent TSS - 30 percent COD - 40 percent TKN - 30 percent TP - 45 percent most metals (All values for weekly sweeping program with mechanical sweeper; sweeping once or twice a year yields negligible results; vacuum sweeper results slightly higher.)
	Litter and pet waste control	Reduction of debris deposited in urban areas will certainly decrease solids movement to drainageways and receiving waters, but little data exists on pollutant removal benefits.	Indeterminate.
	Salt application and storage	Proper storage and careful application of road salt can lead to decreased Na and Cl pollution of both groundwater and surface water; again water quality data are not available on the effectiveness of lower application rates and covering of stockpiles but common sense and our 1980 urban sampling data indicate reduced salt application would be desirable.	Indeterminate.

Ta. - 20. (Contd.)
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
	Increased leaf pickup, maintenance of streets, increased disposal of garbage, oil and chemical disposal programs.	All of these "housekeeping" practices are targeted for specific urban runoff-related pollutants; although it is easy to determine the target pollutants, very little data exists on the pollutant reduction capabilities of any of these practices.	Indeterminate, but a gross estimate would be about 10 percent overall reduction in the target pollutants, that is, COD, nutrients, metals and hydrocarbons; possibly higher for P.
	Increased infiltration measures	Includes many different practices including infiltration trenches, porous pavement, lattice pavement, perforated discharge piping, pervious drainageways (grass, gravel), parking lot collection basins, underdrains and diversion with percolation; proper design essential to assure adequate infiltration rate; O & M very important.	- 50 to 100 percent runoff - Up to 100 percent all pollutants if full percolation results.
	On-site detention (sedimentation pond)	Small-scale storeage facilites installed on-site are very effective if properly designed and maintained; often best choice for construction area; target is usually limited to coarse-grained sediment and whatever will be associated with it; not well-suited to control solubles or fines-associated.	- 60 percent TSS - 50 percent N & P - 30 percent COD (Figures for approximately three-hour settling period.)
	Vegetative cover establishment	Various practices include immediate seeding, sodding mulching (straw, hydro, asphalt, stone) wood fiber, blankets (jute, excelsior, fiberglass), wattling and vegetative filters; institution of these practices includes fertilization at the time of establishment; primary target is sediment and associated nutrients; reduction capabilities and costs quite variable; recommended application rates must be followed to maximize effectiveness.	- 75 to 90 percent TSS (optimum design could reach 100 percent TSS) - 50 percent N & P
Urban: Collection	Off-site detention	Collection and storage of water on a regional or off-site basis has a cost-efficiency advantage over on-site approaches; from a water quality standpoint, off-site collection allows a larger area to be managed; this category would include large construction areas like a subdivision; as well as regional collection systems occurring in urban areas; much of existing data for CSO systems (not used in this analysis).	- 80 percent TSS (two-year storm design). - 50 percent COD - 25 percent TP - 50 percent TN - 75 percent metals

Table 20. (Contd.)
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
	Artificial storage	A number of storage systems are possible that would include storage in tanks, underground formations, in-line (sewers) and concrete; these approaches are usually used only in extreme conditions when above-ground area is limited; costs might be excessive.	Same as off-site detention except for in-line storage which merely slows volume prior to discharge.
	Floatables skimmers	Holding back floatable oil and grease, litter and organics can be accomplished with oil skimmers, baffle weirs or something as simple as a board across an outlet; unfortunately data does not exist for these practices but they are very effective for certain target pollutants.	Data not available.
	Wetland discharge	Use of the physical-biological treatment capabilities of natural wetland systems is an extremely good MP provided the wetland is not overloaded with sediment and pollutants toxic to plants; discharge of any sediment-laden stormwater to wetlands should not be permitted without prior settling; treatment variabilities exist depending upon wetland type and time of year; may be nutrient source in spring.	- 90 percent TSS - 50 percent COD - Variable N & P
	Streambank protection	Increased urbanization causes increased stormwater runoff rates and volumes which can severely impact urban stream channels; near 100 percent of streambank erosion is delivered into a receiving water; measures to use include grade stabilization structures (see Agricultural Collection section), rip-rap, gabions, vegetation and concrete pavement.	- Purpose to stabilize bank rather than reduce in-stream pollution.
	Energy dissipators	Somewhat similar to the above category, these practices are used to collect stormwater and move it along with the least amount of soil disturbance; practices include level spreaders, grade stabilization structures (see Agricultural Collection section), flexible or paved downdraws, grassed waterways (see Agricultural Collection section), diversion berms.	- Purpose to reduce energy of runoff rather than reduce in-stream pollution.
	Catch-basin cleaning	Severe levels of oxygen-demanding substances and associated pollutants can build up in sump-type catch-basins; cleaning basins before deposited material goes "septic" would likely reduce overall pollution loading; installation of sump-type catch basins is not a recommended practice for quality control.	- 10 percent TSS (for increased level of maintenance) - 5 percent COD

Table 20. (Contd.)
SUMMARY OF EFFECTIVENESS OF MANAGEMENT PRACTICES

Category	Management Practice	Purpose and Method of Application	Approximate Percent Reduction of Pollutant
Urban: Treatment	Clarification settling	(See Detention section)	
	Filtration	Can occur with or without intentional biological treatment; involves discharging stormwater through sand, stone, plastic, coal or other medium; very high solids removal efficiencies occur, but at high cost.	- 90 percent TSS - 50 percent COD - 75 percent N & P
	Screening	Many varieties of screening treatment systems exist, all fairly effective at stormwater treatment for solids but again quite expensive.	- 50 percent TSS - 35 percent COD - 40 percent N & P
	Swirl separation	System uses separation principle to funnel debris, without using moving parts; quite efficient at pollutant removal, yet requires a lot of capital and maintenance; very good system for installation in highly urbanized areas if enough room can be found for below-ground installation.	
	Treatment lagoons	Includes oxidation ponds, aerated lagoons (oxygen supplied) and facultative lagoons (combination of aerobic and anaerobic); treatment usually good but land requirement often excessive.	- 50 percent TSS - 90 percent bacteria - 40 percent COD
	Flocculation	Very effective when used in combination with settling pond; involves addition of lime, Fe or Al salts and/or polyelectrolytes to coagulate particles; especially efficient for soluble and fines-associated pollutants; can be applied to any detention system with varying degrees of difficulty.	- TSS function more of settling than flocculation - 75 percent organics - 80 percent TP - 75 percent N
	Disinfection	Elimination of pathogenic organisms by use of chlorine, ozone or hypochlorite salt; effective if costs can be met; can be installed on any collection system.	Up to 100 percent for pathogenic organism.

appropriate. In instances where specifics of application are not known, the low end of the range will be used to present a conservative figure; improvements above this conservative figure will be welcomed as extra benefits.

Two items do not occur in Table 19 because they are essentially nonquantifiable MPs; these items are comprehensive stormwater management and information/education (I/E). Comprehensive stormwater management (CSM) enables a community or land manager to assess the impact that stormwater could have on a particular piece of land or on an entire community/watershed. The water quality benefits associated with such an exercise are nearly impossible to quantify, yet it is obvious to those working in the stormwater area that those communities or managers that use a good CSM approach have far fewer problems with water in general than those that do not plan adequately. At a minimum, communities should be encouraged to undertake CSM programs in conformance with guidelines determined by an appropriate management agency and in conjunction with neighboring communities on a watershed basis.

I/E programs again are nonquantifiable from a water quality standpoint, but are inherently suited to yield water quality improvements. Perhaps the most often suggested MP in addressing water quality issues is a massive I/E program in which facts are disseminated in hopes of convincing the public of the obvious merit of nonpoint pollution control. However, people have known for decades about water quality and erosion problems, yet have met with limited success. A well-planned I/E program is essential and should be practiced as a low-cost management approach.

One final comment about Table 20 is that it is not intended to be a compilation of every conceivable MP ever considered for use. It is, however, an attempt to define MP categories into which similar, yet unmentioned, MPs could fit. The structural treatment categories are particularly void of entries although many other approaches exist. The reason for this is that most treatment systems are prohibitively expensive (they can easily be an order of magnitude more expensive than minimum or nonstructural MPs) and it is believed that less expensive techniques that yield similar results can be used. Furthermore, location of urban treatment systems would likely occur in the CSO areas already covered by the MWCC 201 study. The evaluation of low-cost, easily implementable MPs fits into the objective of the management program.

Now that the list of possible MPs has been compiled and evaluated for effectiveness, it is necessary to select individual or groups of MPs that can best be implemented to achieve desired results. The approach will stress minimum or nonstructural practices that will be effective, yet inexpensive.

Recommendations for MP application to achieve a certain pollutant reduction will likely involve putting together a series of related MPs; such "families" give communities and managers the flexibility needed to implement programs. The least costly family is that composed of housekeeping MPs. The housekeeping family applies predominantly to the urban/urbanizing areas and consists of MPs application at a more intensive scale than is currently under way. Recommended MPs that would fall in this family would be:

- Street sweeping (biweekly to monthly).

- Priority street sweeping in areas directly tributary to lakes.

- Catch-basin cleaning (monthly).

- Sweeping of industrial and commercial complexes (weekly).

- Oil and chemical disposal programs for each community.

- Leaf collection in autumn; seed collection in spring.

- Litter control at all public gathering points.

- Pet control in vicinity of lakes and streams.

- Control of disposing yard litter in streets or sewers.

- Control of chemical application (salt, pesticides, fertilizers).

Initiation of these controls is likely to result in pollutant reductions of 50 to 75 percent for most pollutants. The 75 percent side of the range would be reached by instituting an aggressive housekeeping program while the lower end could be reached with a less aggressive approach.

The second family of MPs would be construction runoff control, targeted at urbanizing communities or redeveloping urban areas. The goal of a good construction control program is to keep all nonpoint source pollutants on-site. Maintenance of existing water quality in an urbanizing area will depend upon eliminating any off-site effects of construction. Again, the following construction runoff control family should be designed for 100 percent elimination of off-site, nonpoint source pollution:

- Wetland discharge (if available) of presettled runoff.

- On-site erosion control designed to minimize soil disturbance; typically would include staged construction, seeding/mulching, enhanced infiltration, small-scale ponding, etc.

- Control of chemicals used in construction, such as petrochemicals, pesticides, fertilizers and sanitizers.

- Larger-scale detention at point of discharge from construction site (if applicable).

- MPs considered beneficial only when combined with others in the family include haybales, diversion berms and controlled access.

Somewhat related to the above instance but more widely applicable is the whole family of detention ponding and design. Without going into design details, the following detention approaches have proven most effective in dealing with nonpoint sources:

- Ponding with perforated riser outlet and perforated horizontal outlet to allow for infiltration prior to discharge (very effective for solubles and fine particles).

- Ponding followed by wetland discharge (again very effective for solubles and fines).

- Ponding with a highly pervious bottom to enhance infiltration.

- Overflow ponding when a certain in-pipe capacity is reached.

- Tandem ponding designed to first settle coarse particles, then finer particles, in succession.

- Ponding with floatables skimmer or baffle weir installation.

- Ponding with flocculation and/or chlorination.

Many other combinations exist, limited only by the ingenuity of the designer. Detention facilities are particularly appropriate for conjunctive use costing of benefits. Most detention facilities have at a minimum a dual-purpose role because they control quantity as well as quality. Caution must be exercised however, because a water quality design might vary considerably from a quantity design, depending upon the objectives of the detention system. This variance is caused by the difference in design storm frequencies, with quality concerns oriented toward high frequency events and quantity toward lower frequency. Other conjunctive uses for detention include recreation, aesthetics and possibly water supply, directly or indirectly. A well-designed detention system described in the family of design concepts above can easily yield pollutant reductions of 75 percent TSS, 50 percent COD and 50 percent nutrients. To emphasize again, maintenance of detention facilities is an absolute must if they are to continue with any effectiveness.

Another logical family of MPs would be those used by farmers to minimize soil and nutrient loss from their croplands and noncroplands. The conservation practice family would consist of a series of MPs such as the following:

- Minimum tillage to conserve soil and minimize nutrient/organics movement (crop).

- Fertilizer and pesticide timing and application management (crop).

- Dissipation of runoff energy with vegetated buffers, drainageways and grade stabilization structures (crop and noncrop).

- Select detention at the bottom of long grades or critical erosion areas (crop and noncrop).

- Critical area stabilization (crop and noncrop).

- Streambank erosion control and elimination of animal access to streams/lakes (crop and noncrop).

- Feedlot runoff management (noncrop).

This family of agricultural MPs alone, if implemented in appropriate areas, could eliminate 75 percent TSS, 50 percent nutrients, 40 percent COD and 50 percent pesticides. Portions of this family could of course be applied for lesser costs in those areas not needing intensive attention.

The final family of MPs that could easily be used to achieve pollutant reductions is the infiltration group. The primary goal of this family is minimization of runoff volumes and rates. Allowing stormwater to infiltrate and seep back slowly through the shallow groundwater system achieves both quantity and quality control. Although most nonpoint pollutants will readily adsorb to soils and not migrate far into the groundwater system, careful monitoring of groundwater quality is recommended because soil ion capacities are eventually exceeded and migration might result. Additionally, pollutants such as nitrates and chlorides are soluble enough to migrate easily into groundwater and might reach elevated concentrations in the vicinity of increased infiltration areas. The infiltration family might easily include:

- Lateral trenches in parking lots, construction sites, etc.
- Perforated outlets from ponds.
- Extremely pervious detention facilities.
- Enhanced soil infiltration capacity by breakup (chisel plow, limited scarification, vegetative establishment, etc.).
- Recharge pits, trenches, ponds.
- Preservation of natural resource areas such as wetlands and floodplains.
- Limited disturbance of natural soil profile during construction.

Increased infiltration can yield variable pollution reduction rates all the way up to 100 percent if no surface outflow results from an infiltration system. More realistic figures for common (not 100 percent infiltration) systems should yield reductions in the 25 percent to 50 percent range for most pollutants. Caution should be exercised with respect to types of pollution treated by infiltration. Concern has been expressed in Minnesota by state agencies that infiltration of chlorides and soluble nutrients might nullify the benefits of stormwater control, and on that basis, not be allowed as a management technique.

In summary, the use of individual MPs as identified in Table 20, and families of MPs as just described, yield almost limitless possibilities for putting together an effective and relatively low-cost management program. Specifics of design and individual watershed approaches will have to be done at the time of actual implementation. The next portion of this report identifies the general method that was used to apply and evaluate the possible results of MPs.

MANAGEMENT PRACTICE APPLICATION

Now that the effectiveness of various MPs or groups of MPs have been determined as well as possible, it is necessary to formalize the methodology for their application. The only currently existing goals towards which to work are those summarized in Table 5.

The development of the criteria that went into these guidelines did not consider nonpoint pollution input, but was rather oriented toward continuous point source discharges. For this reason, relating nonpoint source pollution and its control to water quality standards is very difficult. For example, the standard for total chromium (Cr) is 50 micrograms per liter (ug/l) in streams; the problem identification paper reports Cr levels reaching as high as 270 ug/l in storm sewers. The water quality standards allow for mixing, so the question becomes what level of Cr in a small storm sewer would be acceptable. Perhaps more difficult questions are those of TSS and COD, two very serious nonpoint pollutants for which specific standards do not exist. In agricultural areas, TSS and COD levels, respectively, reached as high as 6,900 mg/l and 676 mg/l, while urban area discharges for the same pollutants hit 26,610 mg/l and 1,505 mg/l. The standards generally state that sediment and organic pollution should not be allowed to enter streams, but specific standards for which to plan are absent. Similarly, the standards state that no toxic levels of any pollutant should exist in state streams; standards for some metals do also exist.

Of particular interest because of the identified lake problem, is the lack of a phosphorus standard. An effluent standard of 1.0 mg/l does exist, but this seems much too high an in-stream standard if our lakes are to improve.

To overcome the standards problem an approach is recommended that would reduce loading in watersheds by increments until a certain annual flow-weighted mean concentration is achieved. The annual flow-weighted mean concentration is determined by dividing the annual load by the annual runoff/flow volume; that is, the mass of pollutants is divided by the volume of water carrying that mass, thereby giving an indication of pollutant strength. This would allow load reductions to be proposed that would relate to recommended in-stream or in-lake conditions. Gross loads that generate concentrations an order of magnitude larger than those recommended will not be quickly eliminated. Proposals herein should be viewed as the first step toward establishing water quality goals. Obviously, all of the pollutants of concern cannot be cleaned up uniformly; priorities will have to come with further design of watershed management programs.

The MPs will be applied according to watershed load reduction needs and run through the statistical model. A statistical model was chosen because it is an easy, flexible planning level model that deals sith watershed and land use factors affecting water quality; that is, dependent water quality variables can be expressed as a function of certain independent variables observed from the statistical analyses. The final product of this exercise for each watershed will be a recommended approach for application of a management system, complete with water quality results and costs. This watershed recommendation will be based upon the severity of the water quality problem and the location and number of lakes within the watershed.

The various management approaches chosen for each particular watershed or set of watersheds will depend upon the unique conditions of the watershed(s). A watershed with several lakes will undoubtedly be treated differently than a relatively dry watershed; a watershed with high density residential use will mandate use of more structurally oriented practices; agricultural watersheds that contain a large percentage of conservation tillage will be much less costly to control than a watershed that contains a large amount of tenant farming and bad practices. Results of runoff and lakes monitoring programs and interpretation of results were very important in definition of critical problem areas and development of subsequent management approaches. The following portion of this report contains the suggested watershed management specifics. These suggestions are recommendations for how watershed implementation might proceed. The purpose of this suggestion is to obtain an idea of type and cost of MPs needed. Detailed management approaches can realistically be proposed only after an intensive watershed plan is finished.

WATERSHED ANALYSES

The water quality data collected from the 17 monitoring sites discussed earlier can be considered fairly representative of the land use and physical characteristics of comparable watersheds that were not monitored. Consequently, the water quality was approximated for all 44 secondary watersheds by mathematical modeling techniques. The statistical modeling method described previously accomplished the projection task for the Metropolitan Area; that is, the results of monitoring 17 subwatersheds were statistically applied to the 44 secondary watersheds of the Region to assess the impact of nonpoint source pollution. The results of the modeling were then evaluated for individual watersheds to determine management needs. The 44 secondary watersheds of the Region are shown in Figure 25. To account for differences in land use or physical features within watersheds, some of the larger watersheds were subdivided and an evaluation was done for each subwatershed. Table 21 lists the 44 secondary watersheds and their subwatersheds if used. Also included in Table 21 is an indication of the percent concentration reduction needed to achieve the goals for the priority pollutant assigned the watershed.

To focus attention on the most serious problems, this plan assigns "priority" pollutants to each watershed, depending on the type of water body that is most prevalent in the watershed (lakes or streams), as well as the type of watershed (urban or rural). A separate analysis was done for each subwatershed. Health-related watersheds are those immediately upstream of the Fridley intakes for the Minneapolis and St. Paul water supplies and watersheds discharging to the 13 St. Paul water supply lakes. In these watersheds, the priority pollutants differ according to land use. The urban area priority pollutant is lead (Pb) because of its toxic nature; the rural area priority pollutant is total phosphorus (TP) because this nutrient leads to degraded lake quality and additional treatment needs. For watersheds containing a substantial portion of the surface area in high-priority lakes (which total 97), the priority pollutant is TP because it promotes eutrophication. For watersheds with few or no high-priority lakes, the priority pollutant is total suspended solids (TSS) because it generally serves as a measure of good versus bad water quality. For watersheds draining to the combined sewer system in Minneapolis, St. Paul and South St. Paul, the priority pollutant is chemical oxygen demand (COD) because of the oxygen depletion problems caused by the effluent discharge to the Mississippi River. Finally, each of the 97 watersheds with priority lakes is evaluated for TP reduction needs; individual lakes are discussed along with their corresponding secondary watersheds.

It should be noted that the data presented in this section for the watersheds monitored during 1980 (Elm, Bevens, Bassett, Shingle, Cottage Grove, Credit, Vermillion, Carver, and Purgatory) will differ from the previously reported data. For example, Table 6 shows a TSS mean of 44 mg/l for Bevens Creek, whereas this section shows a value of 131 mg/l (watershed number 2). The reason for this discrepancy is that the monitored watershed did not include the entire secondary watershed. In the case of Bevens Creek, the monitored watershed included everything upstream of County Hwy. 41, whereas the modeled portion included the Metropolitan Area only down to the Minnesota River. The effect of this is that the model picked up an erosive bluff area and dropped out a low loading wetland area in the headwaters. Also, the data in Table 6

Table 21
METROPOLITAN AREA SECONDARY WATERSHEDS

Secondary Watershed	Subwatershed*	Percent Reduction Needed for Guideline**
Bassett Creek	Upper	43% TSS
	Lower	22% COD
Bevens Creek	Mainstem	77% TSS
	Silver Creek	40% TSS
Big Marine-Carnelian		68% TP***
Black Dog Lake (BLA)		0% TSS
Bluff Creek		63% TSS
Brown's Creek		0% TSS
Cannon River		22% TSS
Carver Creek		0% TSS
Chaska Creek		0% TSS
Chub Creek		0% TSS
Clark's Lake		72% TSS
Coon Creek	Mainstem urban	71% Pb
	Mainstem rural	85% TP
	Sand Creek	0% TSS
Cottage Grove		0% TSS
Cottage Grove Ravine		23% TSS
Credit River		12% TSS
Crow River	South Fork	0% TSS
	Mainstem	58% TSS
	Sarah Creek	84% TP
	Pioneer Creek	19% TSS
	Winsted Lake	84% COD
Elm Creek		77% TP
Gun Club Lake (GUN)		0% TSS
Hazeltine-Bavaria Creek		40% TSS
Lower Minnesota River (LMN)	LML, LMN	61% TSS

Table 21 (Contd.)
METROPOLITAN AREA SECONDARY WATERSHEDS

Secondary Watershed	Subwatershed*	Percent Reduction Needed for Guideline**
Lower Mississippi River (LMS)	Major (0-91)	9% TSS
	South (0-96)	44% TSS
Lower St. Croix River	Basswood Grove	73% TSS
	Afton	70% TSS
Marine-on-the St. Croix		6% TSS
Middle Minnesota River (MMN)	GRA (Grass Lake)	0% TSS
	UMN-4	0% TSS
Middle Mississippi River (MMS)	North	29% COD
	Middle	40% COD
	Southeast	6% COD
Minnehaha Creek	Upper	69% TP
	Lower	46% TSS
Nine Mile Creek		43% TSS
Purgatory Creek		0% TSS
Ramsey-Washington Metro	North	66% TSS
	South	0% TSS***
Rice Creek	Upper	69% TP
	Lower	0% TP***
Riley Creek		94% TP
Robert's Creek		0% TSS
Rum River	Cedar Brook	9% TSS
	Ford Brook	23% TSS
	Lower Rum urban	70% Pb
	Lower Rum rural	91% TP
	Seelye Brook	72% TSS
Sand Creek (Scott County)		0% TSS
Shakopee (8-136)		64% TSS
Shingle Creek	Upper	0% TSS
	Lower	45% COD

Table 21 (Contd.)
METROPOLITAN AREA SECONDARY WATERSHEDS

Secondary Watershed	Subwatershed*	Percent Reduction Needed for Guideline**
Spring-Prior Lake	Spring Lake	97% TP
	Prior Lake	89% TP
St. Paul-Ramsey	North	0% TP***
	South	62% TSS
Sunrise River	South Branch	80% TSS
	West Branch	79% TSS
Upper Minnesota River (UMN)	Minn 8-126	61% TSS
	Belle Plaine	78% TSS
Upper Mississippi River (UMS)	Anoka (Rum 7)	50% Pb
	Coon Rapids	89% TP
	UMS 1-2	30% Pb
	Osseo	64% Pb
Valley Branch and Middle St. Croix(2)	Stillwater	36% TSS
Vermillion River	North Branch	71% TSS
	Mainstem	53% TSS
	Hardwood Creek (0-97)	79% TSS

* Listed only if subwatershed used in subsequent analysis.
** Does not include priority lakes' recommendations.
*** See text for special explanation.

are for 1980, a somewhat drier year than normal. The data in this section are modeled for the median year and would, therefore, be higher than 1980. Also note that a total of 14 secondary watersheds have been identified as "critical" because they severely violate the recommended water quality guidelines appearing in an earlier section and/or they contain a substantial number of the 97 high-priority lakes. These critical watersheds will be identified as they are discussed individually. Finally, all of the results of the water quality work in this phase of the 208 program are based upon data obtained under limited conditions, that is, on 17 sites over one calendar year. The monitoring results obtained are believed to be extremely good because 15 to 30 snowmelt and rainfall runoff events were monitored at each site, but caution should be used not to overestimate the validity of the data.

Table 22 individually tabulates the management practice recommendations for the 44 secondary watersheds. Appendix F gives the narrative watershed analyses and locates the watershed within the Region. Table 22 steps through the management needs and lists the resultant priority pollutant load reduction and flow-weighted mean concentration. Note that incremental steps are taken for each watershed and that each management practice recommended has an associated cost and load reduction. In most cases, practices are recommended until the guideline for the priority pollutant is reached. Table 23 is a summary of the practices recommended in Table 22. The management practices costs total about $40 million, with about $10 million annual for operation and maintenance; these costs do not include planning, administrative and financing costs (for these costs see Metropolitan Council Surface Water Management Guide chapter). The $40 million would pay for MPs that would theoretically lead to all watersheds meeting water quality recommendations.

MANAGEMENT RECOMMENDATIONS

The technical findings of the nonpoint source study lead to several management recommendations that can be made to reduce the impact of stormwater runoff. The recommendations are:

1. Agricultural areas should focus management efforts on snowmelt and spring rainfall runoff because of the high loading that occurs prior to vegetative cover establishment.

2. Urban areas should focus on control of the numerous small events (less than half inch) because every one of these events contributes a substantial load.

3. Runoff from construction areas should be treated in such a manner that sediment and associated pollutants are not allowed to migrate off-site.

4. All management scenarios should be proposed on a watershed basis and implemented with low-cost, minimum or nonstructural management practices.

5. Natural drainage systems, including wetlands, should be retained to the maximum extent possible and used for water storage and transmission.

6. Heavily sediment- and pollutant-laden stormwater should be presettled prior to discharge to any receiving water or wetland area; this applies especially to construction and disturbed areas.

Table 22
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
Bassett Creek	Upper Bassett	- 356 acre-feet of detention at $250 per acre-foot.	89.0	TSS	58,000	41.5
		- Additional 356 acre-feet of detention focusing on commercial/industrial and residential areas at $500 per acre-foot.	178.0	TSS	58,000	30.0
	Medicine Lake*	- Information and education program for owners directly tributary to lake for $2,000 per year.	2.0	TP	52	0.28
		- Intensive housekeeping: 1,160 curb miles** of street sweeping at $100 per curb mile; leaf/litter removal program at $10,000 per year.	126.0	TP	475	0.19
		- 588 acre-feet of detention focusing on discharge to wetlands at $500 per acre-foot.	294.0	TP	525	0.10
	Lower Bassett	- Intensive housekeeping: 1,500 curb miles of street sweeping at $150 per curb mile; clean 2,500 basins per year at $15 per basin.	262.5	COD	100,000	57.00
		- Repeat of above on additional curb miles to achieve further reduction.	262.5	COD	100,000	50.00
Bevens Creek	Mainstem	- 2,345 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	23.5	TSS	440,000	80.00
		- 255 additional acres of cropland conservation at $10 per acre.	2.6	TSS	48,500	75.00
		- 13,800 feet of streambank protection (both sides) on worst erosion area at $10 per foot of channel.	138.0	TSS	113,500	62.00
		- 3,000 acres of noncropland critical area treatment at $75 per acre.	225.0	TSS	275,000	30.00
	Silver Creek	- 470 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	4.7	TSS	410,000	40.00
		- 470 additional acres of cropland conservation at $10 per acre.	4.7	TSS	410,000	30.00
Big Marine - Carnelian	Big Marine Lake*	- 400 acres cropland conservation practices on acreage needing treatment at $10 per acre.	4.0	TP	526	0.23
		- 400 additional acres cropland conservation at $10 per acre.	4.0	TP	526	0.10
	Big Carnelian Lake*	- 480 acres cropland conservation practices on acreage needing treatment at $10 per acre.	4.8	TP	520	0.22
		- 240 additional acres cropland conservation at $10 per acre.	2.4	TP	256	0.15
		- Wetland diversion of runoff.	5.0	TP	170	0.10

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Mainstem	- 3,264 acres cropland conservation practices on acreage needing treatment at $10 per acre.	32.6	TP	3,920	0.21
		- 1,088 additional acres cropland conservation at $10 per acre.	10.9	TP	1,306	0.18
		- 1,075 acres noncropland critical area treatment at $75 per acre.	80.6	TP	1,600	0.10
Black Dog Lake		- Guideline met for TSS; no further management practices recommended.				
Bluff Creek	Mainstem	- 1,000 acres of cropland conservation practices on acreage needing treatment at $20 per acre.	20.0	TSS	140,000	55.00
		- 137 additional acres of cropland conservation at $20 per acre.	2.7	TSS	19,000	52.00
		- 915 feet of channel erosion stabilization on worst erosion area at $60 per foot (one side).	54.9	TSS	120,000	30.00
Brown's Creek		- Guideline met for TSS; no further management practices recommended.				
Cannon River	Mainstem	- 4,395 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	44.0	TSS	494,700	30.00
Carver Creek	Mainstem	- Guideline met for TSS; no further management practices recommended.				
	Burandt, Hydes, Miller, Reitz, Waconia*	- 3,370 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	33.7	TP	6,960	0.52
		- 1,760 acres of noncropland critical area treatment at $75 per acre.	132.0	TP	7,900	0.20
Chaska Creek		- Guideline met for TSS; no further management practices recommended.				
Chub Creek		- Guideline met for TSS; no further management practices recommended.				
Clarks Lake	Mainstem	- 1,337 acres of cropland conservation practices on acreage needing treatment at $15 per acre.	20.0	TSS	400,000	49.00
		- 160 feet of channel erosion stabilization in worst erosion area at $60 per foot.	9.6	TSS	400,000	30.00

* One of 97 priority lakes.
** Indicates miles per year; e.g., 145 actual curb miles swept eight times per year equals 1,160 curb miles.
*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
Coon Creek	Mainstem (urban)	- 784 acre-feet of detention in urban area at $50 per acre-foot.	39.2	Pb	310	0.11
		- Intensive housekeeping in Coon Rapids and Blaine; 2,400 curb miles street sweeping at $20 per curb mile; $10,000 for leaf/litter program.	58.0	Pb	310	0.05
	Mainstem (rural)	- 1,211 acres of cropland conservation practices needing treatment at $10 per acre.	12.1	TP	3,426	0.50
		- 2,006 acres of noncropland critical area treatment at $75 per acre.	150.5	TP	2,564	0.38
		- 3,274 additional acres of noncropland critical area treatment at $75 per acre.	245.6	TP	4,313	0.15
		- Information and education program on phosphorus fertilizer use/overuse.	10.0	TP	1,675	0.10
	Crooked, Ham, Netta Lakes*	- 682 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	6.8	TP	195	0.39
		- Additional 682 acres of cropland conservation.	6.8	TP	195	0.10
	Sand Creek	- Guideline met for TSS and TP; no further management practices recommended.				
Cottage Grove	Mainstem	- Guideline met for TSS; no further management practices recommended.				
Cottage Grove Ravine	Mainstem	- 4,400 acres of cropland conservation practices on acreage needing treatment at $20 per acre.	88.0	TSS	570,000	30.00
Credit River	Mainstem	- 3,655 acres of cropland conservation practices on acreage needing treatment at $20 per acre.	58.5	TSS	192,000	30.00
	Orchard Lake*	- 596 acres around lake managed for stormwater; wetland discharge.	5.7	TP	450	0.28
		- 23 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	0.2	TP	130	0.22
		- 225 acre-feet of detention at $100 per acre-foot.	22.5	TP	320	0.10
Crow River	Mainstem	- 2,056 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	20.6	TSS	390,000	50.00
		- 2,056 additional acres of cropland conservation at $10 per acre.	20.6	TSS	390,000	30.00
	Lake Rebecca*	- Guideline met for TP; no further management practices recommended.				

SECONDARY WATERS..D M..NAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Sarah Creek ***	- 136 acres of cropland conservation practices on acreage needing treatment at $15 per acre.	2.0	TP	1,535	0.35
		- 24 additional acres of cropland conservation at $15 per acre.	0.4	TP	270	0.30
		- 931 acres noncropland critical area treatment at $75 per acre.	69.8	TP	1,200	0.10
	Pioneer Creek	- 1,420 acres of cropland conservation practices on acreage needing treatment at $15 per acre.	21.3	TSS	230,000	30.00
	Independence and Whaletail Lakes*	- 169 acres of cropland conservation practices on acreage needing treatment at $15 per acre.	2.5	TP	1,050	0.35
		- 113 acres of cropland conservation at $15 per acre.	1.1	TP	680	0.19
		- 149 acres noncropland critical area treatment at $75 per acre.	11.2	TP	375	0.10
	Little Long Lake*	- Guideline met for TP; no further management practices recommended.				
	Lower South Fork	- Guideline met for TSS; no further management practices recommended.				
	Winsted Lake	- 1,540 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	15.4	COD	66,225	65.00
		- Fencing and watering system at animal access points.	10.5	COD	66,225	50.00
Elm Creek	Mainstem	- 5,980 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	59.8	TP	12,425	0.26
		- 4,390 additional acres cropland conservation at $10 per acre.	43.9	TP	9,050	0.14
		- 4,872 acres intensive management on worst cropland needing treatment at $30 per acre.	146.2	TP	3,375	0.10
	Fish Lake*	- Information and education program for home-owners around lake.	5.0	TP	80	0.97
		- 162 acre-feet of detention at $50 per acre-foot.	8.1	TP	270	0.59
		- 80 curb miles of street sweeping at $100 per curb mile.	8.0	TP	350	0.10

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*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Weaver Lake*	- 48 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	0.5	TP	70	0.25
		- 40 additional acres of cropland conservation at $10 per acre.	0.4	TP	57	0.12
		- Information and education program for home-owners around lake.	1.0	TP	18	0.10
Gun Club Lake		- Guideline met for TSS; no further management practices recommended.				
Hazeltine-Bavaria Creek	Mainstem	- 2,112 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	21.1	TSS	193,500	54.00
		- 900 acre-feet of lowland and wetland detention at $250 per acre-foot.	225.0	TSS	210,000	30.00
	Bavaria Lake*	- 126 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	1.3	TP	210	0.33
		- 84 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	0.8	TP	140	0.18
		- 35 acres noncropland critical area treatment at $75 per acre.	2.6	TP	74	0.10
Lower Minnesota River	Mainstem	- 1,920 feet of channel erosion control along Minnesota River bluff focusing on worst areas at $100 per foot.	192.0	TSS	442,000	53.00
		- 240 acre-feet of detention associated with I-494 strip and new stadium development at $3,000 per acre-foot plus 520 curb miles street sweeping along 494 and commercial strip.	746.0	TSS	116,700	47.00
		- 2,100 curb miles of residential street sweeping at $100 per curb mile plus $25,000 leaf/litter program.	235.0	TSS	265,500	32.50
		- 200 additional feet of bluff erosion control.	20.0	TSS	46,000	30.00
Lower Mississippi River	Mainstem	- 600 curb miles of street sweeping in urbanized portion of watershed at $150 per curb mile plus 200 catch basins cleaned at $15 per catch basin.	93.0	TSS	222,000	30.00
	South Portion	- 1,382 acres of cropland conservation practices on acreage needing treatment at $25 per acre.	34.6	TSS	107,300	42.00
		- 1,382 additional acres cropland conservation at $25 per acre.	34.6	TSS	107,300	30.00
Lower St. Croix River	Basswood Grove	- 4,080 acres of cropland conservation practices on acreage needing treatment at $25 per acre.	102.0	TSS	601,000	74.00
		- 720 additional acres cropland conservation at $25 per acre.	18.0	TSS	106,000	67.00
		- 675 feet of channel stabilization in worst erosion areas along bluff at $60 per foot.	40.5	TSS	545,000	30.00

. 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Afton	- 2,260 acres of cropland conservation practices on acreage needing treatment at $25 per acre.	56.5	TSS	682,500	66.00
		- 272 feet of channel stabilization in worst erosion areas along bluff at $60 per foot.	16.3	TSS	682,000	30.00
Marine on St. Croix	Mainstem	- 884 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	8.8	TSS	88,500	30.00
	Square Lake*	- Guideline met for TP; no further management practices recommended.				
Middle Minnesota River	Grass Lake	- Guideline met for all pollutants; no further management practices recommended.				
	UMN-4	- Guideline met for all pollutants; no further management practices recommended.				
Middle Mississippi River	North	- 1,050 curb miles street sweeping in Minneapolis at $300 per curb mile plus clean 225 catch basins at $16.80 per basin.	318.8	COD	236,000	50.00
	Middle	- 300 curb miles street sweeping in Minneapolis at $300 per curb mile plus clean 100 catch basins at $16.80 per basin.	91.4	COD	98,000	62.00
		- 420 acre-feet of detention in residential area; type of detention focus on infiltration (i.e., trench, swale) at $5,000 per acre-foot.	2100.0	COD	107,500	50.00
	Southeast	- 30 curb miles street sweeping in Minneapolis at $300 per curb mile plus clean 25 basins at $6.80 per basin.	9.4	COD	4,250	50.00
Middle St. Croix River		See Valley Branch.				
Minnehaha Creek	Upper***	- 19.2 square miles cropland conservation practices on acreage needing treatment at $20 per acre.	245.8	TP	6,730	0.21
		- 6.37 additional square miles cropland treatment.	81.5	TP	2,240	0.17
		- 4,570 acre-feet of lowland and wetland detention at $250 per acre-foot.	1142.5	TP	4,500	0.10

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*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Lower	- 1,800 curb miles of street sweeping priority in residential area at $200 per curb mile plus clean 3,000 catch basins at $15 per basin.	405.0	TSS	665,000	43.00
		- 900 additional curb miles and 1,500 additional catch basins.	202.5	TSS	332,500	36.00
		- 1,930 acre-feet of detention focusing on infiltration type at $3,000 per acre-foot.	5790.0	TSS	332,500	30.00
	Minneapolis Chain*	- 2,640 curb miles of lakes priority street sweeping at $300 per curb mile plus clean 5,000 priority catch basins at $16.80 per basin.	873.4	TP	3,570	0.28
		- 1,320 acre-feet of detention focusing on infiltration type at $3,000 per acre-foot.	3969.0	TP	2,320	0.10
	Nokomis*	- 1,560 curb miles of lake priority street sweeping at $300 per curb mile plus clean 3,000 priority catch basins at $16.80 per basin.	516.8	TP	350	0.28
		- 128 acre-feet of detention focusing on infiltration type at $3,000 per acre-foot.	384.0	TP	225	0.10
Nine Mile Creek	Mainstem	- 2,654 acre-feet of detention and/or retrofit on existing storage at $250 per acre-foot.	663.5	TSS	433,000	41.00
		- 800 curb miles of street sweeping with priority catch basin attention at $100 per curb mile plus $10,000 for basins and $10,000 for leaf/litter program.	100.0	TSS	435,000	30.00
	Bryant Lake*	- 336 acre-feet of detention at $250 per acre-foot.	84.0	TP	725	0.40
		- 336 additional acre-feet of detention at $250 per acre-foot.	84.0	TP	725	0.10
	Glen Lake*	- Information and education program for lakeshore homeowners.	1.0	TP	180	0.35
		- 43 acre-feet of detention at $250 per acre-foot.	15.0	TP	130	0.10
	Bush Lake*	- Information and education program for lakeshore homeowners.	1.0	TP	310	1.04
		- 60 acre-feet of detention at $250 per acre-foot.	10.8	TP	280	0.10
Purgatory Creek	Mainstem	- Guidelines for all pollutants met; no further management practices recommended.				
	Lotus Lake*	- 270 acre-feet of detention focusing on lowlands and wetlands at $250 per acre-foot.	67.5	TP	200	0.10

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Staring Lake*	- 1,300 acre-feet of detention in developed/developing portion of watershed at $500 per acre-foot.	480.0	TP	960	0.10
	Mitchell Lake*	- 512 acres of critical area treatment in agricultural/vacant area of watershed at $10 per acre.	5.1	TP	122	0.10
Ramsey-Washington Metro	North Portion	- 600 curb miles of street sweeping at $150 per curb mile plus clean 100 catch basins at $15 per basin.	91.5	TSS	338,600	66.00
		- 410 acre-feet of detention retrofit in existing storage area and in lowland/wetland areas at $500 per acre-foot.	205.0	TSS	110,000	59.00
		- 1,662 additional acre-feet of detention in urbanized portion of watershed focusing on infiltration type at $1,000 per acre-foot.	1662.0	TSS	450,000	30.00
	Phalen and Gervais Lakes*	- 600 curb miles of priority street sweeping at $150 per curb mile plus clean 50 catch basins at $15 each plus institute information and education program for lakeshore homeowners.	95.8	TP	1,495	0.59
		- 344 acre-feet of detention at $1,000 per acre-foot.	344.0	TP	1,240	0.10
	South Portion	- Full attention in this portion should go for remedial action on Battle Creek as proposed by watershed district; attention on Fish Creek should follow after Battle Creek.				
Rice Creek	Upper Mainstem***	- 800 curb miles of street sweeping at $20 per curb mile plus intensive housekeeping and information program for communities around lakes (Birchwood, Centerville, Dellwood, Mahtomedi, White Bear Lake and Willernie).	66.0	TP	6,640	0.28
		- 6,080 acres of cropland conservation practices on acreage needing treatment at $10 per acre.	60.8	TP	8,830	0.24
		- 4,270 acre-feet of slow-release detention in numerous lowlands/wetlands of watershed, perhaps retrofit in existing storage.	213.5	TP	4,500	0.21
		- 8,800 acres noncropland critical area treatment at $75 per acre.	660.0	TP	20,600	0.22

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*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Lower Mainstem	- This watershed subject of $2 million Clean Lakes (Section 314) study for priority Long, Johanna and Josephine Lakes; therefore, no additional recommendations for management.				
	Turtle Lake*	- Information and education program for lake-shore owners.	5.0	TP	41	0.57
		- 360 curb miles of priority street sweeping at $70 per curb mile.	44.1	TP	132	0.36
		- 89 acre-feet of detention at $250 per acre-foot.	22.2	TP	173	0.10
Riley Creek	Mainstem***	- 1,115 acres cropland conservation practices on acreage needing treatment at $15 per acre.	16.7	TP	3,815	0.80
		- 193 acre-feet of detention at $850 per acre-foot.	164.0	TP	565	0.50
		- 343 acres noncropland critical area treatment at $75 per acre.	25.7	TP	1,300	0.10
Robert's Creek	Mainstem	- Guideline for TSS met; no further management practices recommended.				
Rum River	Cedar Creek	- 560 acres cropland conservation practices on acreage needing treatment at $10 per acre.	5.6	TSS	124,000	30.00
	Ford Brook	- 2,880 acres cropland conservation practices on acreage needing treatment at $10 per acre.	28.8	TSS	130,000	30.00
	East Twin Lake*	- 38 acres cropland conservation practices on acreage needing treatment at $10 per acre.	0.4	TP	50	0.54
		- 24 acres noncropland critical area treatment at $75 per acre.	1.8	TP	66	0.10
	Lower Rum (urban)	- 400 curb miles of street sweeping in City of Anoka at $20 per curb mile plus $10,000 for leaf/litter and maintenance plan.	18.0	Pb	350	0.11
		- 373 acre-feet of detention at $100 per acre-foot.	37.3	Pb	146	0.05
	Lower Rum (rural)	- 948 acres cropland conservation practices on acreage needing treatment at $10 per acre.	9.5	TP	6,730	0.53
		- 1,568 acres noncropland critical area treatment at $75 per acre.	117.6	TP	3,022	0.28
		- 1,229 acre-feet of rural area wetland/lowland detention at $25 per acre-foot.	30.7	TP	2,080	0.10
	Lake George*	- Subject of 1982 Clean Lakes study; recommendations will be made after study.				

22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Seelye Brook	- 300 acres cropland conservation practices on acreage needing treatment at $10 per acre.	3.0	TSS	303,530	30.00
St. Paul - Ramsey	North Portion***	- Information and education program for home-owners tributary to high priority water supply lakes.	5.0	TP	445	0.31
		- 1,575 acre-feet of detention in lowlands/wetlands of developing area at $500 per acre-foot.	788.0	TP	1,650	0.22
		- 1,062 acre-feet of detention in rural part of watershed at $250 per acre-foot.	265.5	TP	1,112	0.16
		- 936 additional acre-feet of urban area detention at $500 per acre-foot.	468.0	TP	980	0.10
	South Portion	- 3,900 curb miles of street sweeping at $200 per curb mile plus clean 650 catch basins at $15 per basin.	790.0	TSS	1,760,000	39.00
		- 1,625 acre-feet of urban area detention focusing on infiltration-type MPs at $3,000 per acre-foot.	4875.0	TSS	400,000	30.00
Sand Creek	Mainstem	- Guideline for TSS met; no further management practices recommended.				
	Cedar Lake*	- 263 acres cropland conservation practices on acreage needing treatment at $10 per acre.	2.6	TP	130	0.10
	McMahon Lake*	- 55 acres cropland conservation practices on acreage needing treatment at $10 per acre.	0.6	TP	32	0.10
Shakopee	Mainstem	- 5,864 acres cropland conservation practices on acreage needing treatment at $15 per acre.	88.0	TSS	769,000	58.00
		- 773 acre-feet of detention at $100 per acre-foot plus $10,000 each for Shakopee and Savage to institute program for intensive housekeeping in developed area.	93.7	TSS	256,500	50.00
		- 1,680 acres noncropland critical area treatment at $75 per acre.	126.0	TSS	615,000	30.00
	O'Dowd and Thole Lakes*	- 350 acres cropland conservation practices on acreage needing treatment at $10 per acre.	3.5	TP	500	0.45
		- 86 acres noncropland critical area treatment at $75 per acre.	6.4	TP	345	0.10

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*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
Shingle Creek	Upper Mainstem	- Guideline for TSS met; no further management practices recommended.				
	Eagle Lake*	- 204 acre-feet of detention at $250 per acre-foot.	51.0	TP	226	0.10
	Bass Lake*	- 332 acre-feet of detention at $250 per acre-foot.	83.0	TP	368	0.10
	Lower Mainstem	- 2,700 curb miles of street sweeping at $150 per curb mile plus clean 4,500 catch basins at $15 per basin.	472.5	COD	244,000	71.00
		- 862 acre-feet of detention possibly retrofit into existing storage.	862.0	COD	244,000	50.00
	Twin Lakes*	- Information and education program for lakeshore homeowners.	5.0	TP	96	0.16
		- 360 curb miles of priority street sweeping at $200 per curb mile.	72.0	TP	307	0.10
Spring-Prior Lakes	Spring Lake***	- 5,900 acres cropland conservation practices on acreage needing treatment at $75 per acre.	442.5	TP	3,900	0.89
		- Information and education program for lakeshore homeowners.	1.0	TP	285	0.78
		- Change outlet discharge from holding pond to enhance water quality.	5.0	TP	445	0.61
		- No further management practices recommended until after 1982 Clean Lake study.				
	Prior Lake***	- 112 curb miles of priority street sweeping at $100 per curb mile plus clean 1,100 catch basins at $25 per basin plus leaf/litter program at $20,000.	58.7	TP	1,300	0.52
		- Information and education program for lakeshore homeowners.	5.0	TP	216	0.45
		- 375 acre-feet of detention possibly retrofit on existing watershed storage at $250 per acre-foot.	93.8	TP	1,085	0.10
Sunrise River	South Branch	- 5,024 acres cropland conservation practices on acreage needing treatment at $10 per acre.	50.2	TSS	882,300	98.00
		- 2,158 acres noncropland critical area treatment at $75 per acre.	161.8	TSS	846,500	49.00
		- 4,060 acre-feet of detention in lowlands/wetlands at $100 per acre-foot.	406.0	TSS	1,000,000	30.00

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Forest Lake*	- 800 curb miles of residential street sweeping and 470 curb miles of commercial industrial sweeping.	25.5	TP	600	0.71
		- 245 acres cropland conservation practices on acreage needing treatment at $10 per acre.	2.5	TP	940	0.53
		- 195 acre-feet of detention at $25 per acre-foot.	4.9	TP	600	0.10
	Coon Lake*	- Information and education program for home-owners and development of a housekeeping program.	6.0	TP	165	0.89
		- 153 acre-feet of detention in wetlands at $100 per acre-foot.	15.3	TP	470	0.55
		- 206 additional acre-feet of wetland detention.	20.6	TP	635	0.10
	Bone Lake*	- 466 acres cropland conservation practices on acreage needing treatment at $10 per acre.	4.7	TP	475	0.63
		- 466 acre-feet of detention in lowlands/wetlands at $100 per acre-foot.	46.6	TP	922	0.10
	West Branch	- 1,160 acres cropland conservation practices on acreage needing treatment at $10 per acre.	11.6	TSS	256,300	30.00
	Island, Linwood and Martin Lakes*	- 213 acres cropland conservation practices on acreage needing treatment at $10 per acre.	2.1	TP	612	0.74
		- 490 acres noncropland critical area treatment at $75 per acre.	36.8	TP	1,090	0.10
Upper Minnesota River	MN 8-126	- 725 acres cropland conservation practices on acreage needing treatment at $15 per acre.	10.7	TSS	212,000	30.00
	Belle Plaine	- 1,810 acres cropland conservation practices on acreage needing treatment at $10 per acre.	18.1	TSS	186,440	73.00
		- 215 feet of channel stabilization on worst erosion area at $60 per foot.	12.9	TSS	93,600	30.00
Upper Mississippi River	Anoka Rum 7	- Use same plan for City of Anoka as recommended previously.		Pb	154	0.05
	Coon Rapids	- 300 curb miles of priority street sweeping at $100 per curb mile plus $20,000 for catch basins and leaf/litter program.	50.0	TP	1,420	0.63
		- 210 acre-feet of detention at $250 per acre-foot.	52.5	TP	600	0.51
		- 705 acre-feet of additional storage in urban/urbanizing area at $500 per acre-foot.	352.5	TP	2,020	0.10

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	UMS 1-2	- 1,068 acre-feet of detention at $250 per acre-foot.	267.0	Pb	172	0.05
		- 776 curb miles of street sweeping at $100 per curb mile plus $20,000 for priority catch basins and leaf/litter program.	99.1	Pb	1,295	0.07
		- 725 acre-feet of detention at $250 per acre-foot.	181.2	Pb	220	0.05
Valley Branch and Middle St. Croix	Stillwater Basin	- 4,715 acres cropland conservation practices on acreage needing treatment at $10 per acre.	47.2	TSS	1,338,000	35.00
		- 864 acre-feet of detention in upper watershed lowlands and wetlands at $25 per acre-foot plus $10,000 to institute housekeeping program along St. Croix.	31.6	TSS	500,000	30.00
	Tri-Lakes*	- 76 acres cropland conservation practices on acreage needing treatment at $10 per acre.	0.8	TP	330	0.47
		- 144 acre-feet of detention at $100 per acre-foot.	14.4	TP	360	0.10
	Lake Elmo*	- 52 acres cropland conservation practices on acreage needing treatment at $10 per acre.	0.5	TP	210	0.45
		- 92 acre-feet of detention at $100 per acre-foot.	9.2	TP	230	0.10
Vermillion River	North Branch	- 5,978 acres cropland conservation practices on acreage needing treatment at $10 per acre.	59.8	TSS	810,000	76.00
		- 547 acre-feet of urban area detention in lowland areas at $100 per acre-foot.	54.7	TSS	175,000	70.00
		- 3,013 acres noncropland critical area treatment at $75 per acre.	226.0	TSS	1,215,000	30.00
	Mainstem	- 17,820 acres cropland conservation practices on acreage needing treatment at $10 per acre.	178.2	TSS	2,854,000	45.00
		- 7,094 acres noncropland critical area treatment at $75 per acre.	532.0	TSS	2,320,000	30.00
	Marion Lake*	- 328 acres cropland conservation practices on acreage needing treatment at $10 per acre.	3.3	TP	2,450	0.49
		- 230 acres noncropland critical area treatment at $75 per acre.	17.2	TP	715	0.10

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*** All management practices in watershed focused on priority lake cleanup.

Table 22 (Contd.)
SECONDARY WATERSHED MANAGEMENT PRACTICE RECOMMENDATIONS

Watershed	Subwatershed	Practice and Unit Cost	Total Cost (x $1,000)	Priority Pollutant	Load Reduction (lbs)	Flow-Weighted Mean Concentration (mg/l)
	Crystal Lake*	- Information and education program for homeowners.	1.0	TP	360	0.75
		- 115 acre-feet of detention at $50 per acre-foot.	5.8	TP	425	0.10
	Hardwood Creek	- 5,248 acres cropland conservation practices on acreage needing treatment at $10 per acre.	52.5	TSS	1,462,500	82.00
		- Continued efforts to mitigate impact of Etter erosion problem; no additional management practices beyond current effort.				

Table 23
SUMMARY BY MANAGEMENT PRACTICE FAMILY (WITH COSTS)

Category	Family	Application Amount	Cost Range	Total Cost
Rural Watershed	Conservation treatment rowcrops	111,962 acres	$10-25/acre	$1,495,800
	Noncrop treatment	31,943 acres	$75/acre	2,396,000
	Nonstructural detention	9,153 acre-feet	$50-250/acre-foot	919,100
	Intensive house-keeping	4 urban areas	$10,000-56,000 each	94,000
	Channel stabilization	16,037 feet	$10-60/foot	272,200
Rural Lakes	Conservation treatment rowcrops	17,228 acres	$10-15/acre	188,700
	Noncrop treatment	11,571 acres	$75/acre	867,800
	Nonstructural detention	6,221 acre-feet	$20-850/acre-foot	518,400
	Intensive house-keeping	5 urban areas	$10,000-66,000 each	90,500
	Stormwater management	569 acres	$10/acre	5,700
	Information and Education (Lakeshore owners)	3 lakes	$1,000-$5,000	7,000
Urban Watershed	Detention/storage	13,031 acre-feet	$250-5,000/acre-foot	17,997,800
	Intensive house-keeping			
	- Street sweeping	20,001 curb miles	$50-299/curb mile	3,192,600
	- Catch basin cleaning	18,177 catch basins	$15-17/basin	271,500
	- Leaf/litter program	3 cities	$10,000-35,000 each	65,000
	Channel stabilization	2,122 feet	$100/foot	212,200

Table 23 (Contd.)
SUMMARY BY MANAGEMENT PRACTICE FAMILY (WITH COSTS)

Category	Family	Application Amount	Cost Range	Total Cost
Urban Lakes	Detention/storage	14,068 acre-feet	$250-3,000/ acre-foot	8,645,400
	Intensive house-keeping			
	- Street sweeping	7,062 curb miles	$70-299/ curb mile	1,589,100
	- Catch basin cleaning	9,150 catch basin	$17-25/basin	162,700
	- Leaf/litter program	2 lakes	$10,000-20,000 each	30,000
	Information and Education (Lakeshore owners)	8 lakes	$1,000-5,000	29,000
	Total Initial Costs			$39,382,300
	Annual Operation and Maintenance			$10,051,800

7. Watersheds differ so markedly in character that a specific program should be designed to manage each watershed. "Across-the-board" application of management practices will not achieve water quality goals, nor will it allow local managers the flexibility to address problems in the most cost-effective manner.

8. Watershed management should be designed to address the primary problem of the drainage basin; that is, lake watersheds should address phosphorus reduction, water supply watersheds should address toxic pollutants, combined sewer watersheds should address dissolved oxygen depletion, etc.

9. Because of limited financial capacity evident in today's economy, priorities should be placed on watershed clean-up, beginning with those experiencing the worst receiving water impacts; within these watersheds, "critical areas" causing the worst problems should be defined and addressed first.

10. In heavily urbanized areas where management practice options are likely minimized, attention should be placed on keeping impervious surfaces clean, with priority cleaning given to areas directly tributary to lakes.

11. Conjunctive uses for management practice approaches should be stressed so that multiple benefits can be shown.

12. Traditional management practices oriented toward removal of coarse-grained particulates should be supplemented with equal attention to soluble and fines-associated pollutants.

13. Comprehensive stormwater management should be undertaken by every secondary watershed, with local community plans then developed within the watershed framework.

14. A well-planned information and education program is a nonquantifiable management practice that should be initiated as an integral part of any management program.

VII. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn relative to the nonpoint source runoff problem in the Metropolitan Area.

1. Nonpoint source pollution is a widespread and serious problem in the Region.

2. Concentration levels for many pollutants in nonpoint runoff can reach many times the level recommended for good quality water.

3. It appears that detectable levels of pesticides are moving with runoff, particularly when such events occur shortly after pesticide application.

4. Rural area loading, and subsequent elevated pollutant concentrations, are highest during the snowmelt and spring periods when vegetative cover is low, the ground is frozen, and wetlands are dormant.

5. Urban area loading and high concentrations occur continuously, responding to essentially every snowmelt and rainfall event.

6. Rural and urban area loading is more a function of water loading than of concentration; that is, flow determines load more than concentration level.

7. Wetland and surface water area in a watershed play a very important role in reducing pollution, with urban area wetlands seemingly more important than rural because of the nature of loading (discussed in conclusions no. 4 and 5, and Appendix H).

8. Watersheds with even a small amount of construction contribute extraordinarily high loads of particulate and soluble pollutants; properly designed and operated detention systems do appear to handle this loading problem sufficiently.

9. Soluble pollutants are at least as important a contributor as particulate pollutants and should be addressed to a greater extent in management approaches.

10. Normalized pollutant loading seems to decrease with increasing drainage area, indicating the effect of various chemical, physical and biological processes on the pollutants.

11. Snowmelt loading is a very significant part of total annual loading and can be the dominant part in rural areas.

12. Atmospheric sources of various pollutants can be quite high, particularly for nitrogen and lead.

13. Modeling results for the 3,000-square-mile Region show that secondary or tributary receiving streams are severely impacted by nonpoint source pollution; recommended water quality guidelines are commonly exceeded.

14. A lakes sampling program conducted by the Metropolitan Council and reported by Osgood (Metropolitan Council, 1981a) shows that lakes within the Region are also negatively impacted by nonpoint source pollution.

15. Nonpoint source pollution can best be dealt with by a comprehensive stormwater management approach that utilizes the natural drainage system and approaches the problem on a watershed basis, rather than a political boundary basis.

16. Low-cost, easily implementable, non- or minimum-structural management practices are best suited to minimize nonpoint pollution impacts.

17. A conjunctive-benefits approach to implementation is appropriate because stormwater management yields multiple benefits beyond water quality.

18. Because each watershed has unique characteristics and problems, management solutions have to be individually designed to address identified priorities.

19. A preliminary evaluation of management practices likely needed to mitigate the nonpoint runoff pollution problem in the Region shows that about $40 million will be needed to implement a program to clean up noncatastrophic problems.

These conclusions form the basis for the recommendations for management contained in the management section (section VI).

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Appendix A
LABORATORY METHODS

METROPOLITAN WASTE CONTROL COMMISSION
QUALITY CONTROL LABORATORIES

208 Non-Point Discharge Study
1980
Analytical Methods

Parameter	Laboratory Method	Reference
1. Metals: Pb, Zn, Cd, Fe, Mn, Cr, Cu, Ni	Low Level: Flameless Atomic Absorption Spectrophometric	3
	High Level: Atomic Absorption, Flame Spectroscopy, direct aspiration	3
2. Total Phosphorus	Persulfate digestion (semi-micro), automated phosphomolybdate color development, ascorbic acid reduction	3
3. Dissolved Phosphorus	0.45u filtration (prior to delivery to lab), Persulfate digestion (semi-micro), automated phosphomolybdate color development, ascorbic acid reduction	3
4. Dissolved NO_2-NO_3-N	Sample filtered as part of automated analysis, Hydrazine reduction to nitrite, Diazo color development	3
5. Dissolved NH_4-N	Sample filtered as part of automated analysis, automated colorimetric phenate method	3
6. Total Kjeldahl-N	Manual digestion with automated phenate (Salicylate) color development	3
7. Dissolved Kjeldahl-N	0.45u membrane filtration (prior to delivery to lab). Manual digestion with automated phenate (Salicylate) color development	3
8. Total Kjeldahl-N less than 4u	See Total Kjeldahl-N, particle size discrimination done prior to delivery to lab	3
9. Total Phosphorus less than 4u	See Total Phosphorus, particle size discrimination done prior to delivery to lab	3
0. Total Suspended Solids	Gravimetric; sample filtered through glass fiber filter, dried at 103°C and weighed.	1
1. Dissolved Solids	Gravimetric, filtrate sample evaporated to dryness on a steambath and dried at 103°C (filtration done prior to delivery to lab).	5
2. Volatile Suspended Solids	Suspended Solids filter ashed at 550°C	1

	Parameter	Laboratory Method	Reference
13.	Total COD	Dichromate reflux method	1
14.	Total Organic Carbon	Automated analysis of homogenized acidified sample using a Dohrman DC-50A/52A Carbon Analyzer	5
15.	Dissolved Organic Carbon	See Total Organic Carbon Analysis done on filtrate (filtration done prior to delivery to lab)	5
16.	Dissolved COD	Filtrate analyzed using dichromate reflux method (filtration done prior to delivery to lab)	5
17.	Fecal Coliform	0.45u membrane filtration, M-FC agar	4
18.	Fecal Streptococcus	0.45u membrane filtration, KF Strep agar	4
19.	BOD_5	Standard Dilution technique Membrane Electrode Readout for Dissolved Oxygen	1
20.	Carbonaceous BOD_5	Standard Dilution Technique Membrane Electrode Readout for Dissolved Oxygen, N-Serve used as nitrification inhibitor	1
21.	Ultimate BOD	Glass Bead Method, Standard Dilution Technique, Dissolved Oxygen read on Days 1, 3, 5, 7, 10, 15, 20, reaerated as necessary.	1,
22.	PCB	Liquid-liquid extraction with methylene chloride. Extract dried and concentrated to 5 ml. Concentrate (2 ml) cleaned with florisil and hexane followed by mercury and sulfuric acid. 5 ul of cleaned extract is injected on an OV-17/OV 210 GC column and detected by electron capture	6

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1. American Public Health Assn., American Water Works Assn., Water Pollution Control Federation; Standard Methods for the Examination of Water and Waste Water, Fourteenth Edition.

2. Metropolitan Waste Control Commission, Report of the Carbonaceous and Nitrogenous BOD Studies as authorized Under 208 of PL 92-500, August 1979.

3. United States Environmental Protection Agency, Methods for Chemical Analysis of Water and Waste, March, 1979.

4. United States Environmental Protection Agency, Microbiological Methods for Monitoring the Environment, Water and Wastes, 1978.

5. United States Geological Survey, Methods for Determination of Inorganic Substances in Water and Fluvial Sediments, Book 5, Chapter A1, 1979.

6. Federal Register, Volume 44, No. 233, December 3, 1979, Pas 69501-69509.

Appendix B
ATMOSPHERIC DEPOSITION DATA

Table B-1
ATMOSPHERIC COLLECTION STATISTICS

Station			TKN	N/N	TN	TP	SO_4	Cl	Pb
			Normalized Loads*						
1. Bevens:									
	Dryfall	Mean (n=9)	.161	.037	.198	.024	.175	.047	.0008
		S. D.	.225	.042	.265	.039	.140	.044	.0009
	Wetfall	Mean (n=9)	2.32	1.24	3.57	.077	5.18	.77	.015
		S. D.	1.0	.56	1.37	.05	2.2	.59	.007
2. Cottage Grove:									
	Dryfall	Mean (n=5)	.048	.031	.079	.004	.176	.022	.001
		S. D.	.019	.008	.026	.004	.087	.007	.0007
	Wetfall	Mean (n=4)	1.36	.79	2.17	.061	4.6	.31	.008
		S. D.	.45	.17	.64	.037	2.4	.24	.006
	Compos-ite	Mean (n=3)	.147	.063	--	.005	.77	.11	.002
		S. D.	.075	.04		.004	.35	.06	.001
3. Eden Prairie:									
	Dryfall	Mean (n=9)	.056	.034	.092	.011	.186	.02	.002
		S. D.	.044	.033	.073	.007	.107	.01	.002
	Wetfall	Mean (n=9)	2.04	.98	3.03	.034	4.5	.50	.012
		S. D.	2.56	.27	2.60	.019	1.3	.41	.007
4. Minneapolis:									
	Dryfall	Mean (n=8)	.059	.026	.085	.007	.22	.032	.002
		S. D.	.04	.01	.002	.008	.47	.179	.001
	Wetfall	Mean (n=8)	1.45	.87	2.31	.112	5.2	.56	.023
		S. D.	.42	.29	.62	.09	3.7	.38	.012
5. Maplewood:									
	Dryfall	Mean (n=7)	.06	.03	.091	.007	.179	.021	.0012
		S. D.	.039	.007	.041	.005	.051	.012	.0006
	Wetfall	Mean (n=7)	1.44	.96	2.4	.091	4.4	.63	.019
		S. D.	.68	.21	.8	.071	2.4	.33	.012
6. Shingle:									
	Dryfall	Mean (n=5)	.088	.023	.109	.016	.147	.043	.0016
		S. D.	.044	.014	.047	.022	.049	.028	.001
	Wetfall	Mean (n=4)	3.06	2.36	5.45	.173	14.1	1.5	.034
		S. D.	2.55	1.87	4.37	.133	17.6	.85	.043
	Compos-ite	Mean (n=4)	.31	.11	--	.008	.96	.019	.003
		S. D.	.10	.09		.008	.55	.02	.002

* Dryfall and composite in mg/sq ft/day.
Wetfall in mg/sq ft/inch of precipitation.

Table B-2
WETFALL/DRYFALL TOTALS (pounds)

Site		TKN	N/N	TN	TP	SO	Cl	Pb
Bevens	Dryfall	269,000	63,600	338,400	44,200	191,300	80,000	1,380.0
	Wetfall	251,000	120,000	371,000	7,700	509,000	83,000	1,720.0
	Total	520,000	183,600	709,400	51,900	700,300	163,000	3,100.0
Carver	Dryfall	202,800	50,000	253,000	14,600	244,000	62,700	1,081.0
	Wetfall	202,000	97,000	299,000	6,200	407,000	66,000	1,378.0
	Total	404,800	147,000	552,000	40,800	751,000	128,700	2,459.0
Raven	Dryfall	107,600	25,000	132,600	17,000	122,000	31,300	541.0
	Wetfall	83,000	40,000	123,000	2,700	171,000	28,000	560.0
	Total	190,600	65,000	255,600	19,700	293,000	59,300	1,101.0
Credit	Dryfall	28,000	17,600	45,500	5,300	93,300	11,000	946.0
	Wetfall	85,000	40,700	125,700	1,400	172,000	21,300	557.0
	Total	113,000	58,300	171,200	6,700	265,300	32,300	1,503.0
Vermillion	Dryfall	37,200	23,300	50,000	7,200	124,000	14,700	1,254.0
	Wetfall	113,000	54,000	167,000	1,900	228,000	27,600	741.0
	Total	150,000	77,300	217,000	9,100	352,000	42,300	1,995.0
Elm	Dryfall	17,200	10,800	28,000	3,300	57,400	6,800	585.0
	Wetfall	48,000	25,000	73,000	800	99,000	11,400	318.0
	Total	65,200	35,800	101,000	4,100	156,400	18,200	903.0
Shingle	Dryfall	33,000	8,500	51,500	6,500	59,000	17,500	600.0
	Wetfall	81,000	62,000	143,000	4,100	425,000	30,000	1,040.0
	Composite	43,600	13,400	57,000	1,000	110,800	5,900	458.0
	Total	157,600	83,900	251,500	11,600	594,800	53,400	2,098.0
Bassett	Dryfall	41,200	18,000	59,000	5,500	149,000	23,600	1,382.0
	Wetfall	63,000	32,000	95,500	5,800	196,000	23,000	1,160.0
	Total	104,200	50,000	154,000	11,300	345,000	46,600	2,542.0
Purgatory	Dryfall	29,000	18,000	47,000	5,600	97,000	11,400	977.0
	Wetfall	71,000	31,700	102,700	1,100	131,000	18,000	416.0
	Total	100,000	49,700	149,700	6,700	228,000	29,400	1,393.0
80th St.	Dryfall	1,210	800	2,000	110	4,790	590	28.0
	Wetfall	2,270	1,270	3,540	104	7,030	520	15.0
	Composite	1,000	400	1,400	34	4,883	645	13.2
	Total	4,480	2,470	6,940	248	16,703	1,755	56.2
Iverson	Dryfall	118	78	194	10	464	58	2.8
	Wetfall	2,270	1,270	3,540	104	7,030	520	15.0
	Composite	97	39	136	3	474	59	1.2
	Total	387	217	602	21	1,491	158	5.2
Hwy. 100	Dryfall	652	274	924	86	2,400	360	22.5
	Wetfall	936	531	1,467	85	2,764	342	17.4
	Total	1,588	805	2,391	171	5,164	702	39.9
Wesley	Dryfall	445	186	631	57	1,621	236	16.3
	Wetfall	655	373	1,028	60	1,936	239	12.1
	Total	1,100	559	1,659	117	3,557	475	28.4
Sandburg	Dryfall	161	69	230	21	5,921	88	5.5
	Wetfall	240	136	376	22	706	87	4.5
	Total	401	205	606	43	1,298	175	10.0
Estates	Dryfall	315	82	394	62	564	169	5.5
	Wetfall	777	589	1,366	40	4,113	291	10.0
	Composite	416	128	544	9	1,055	56	4.3
	Total	1,508	799	2,304	111	5,732	516	19.8
Yates	Dryfall	504	130	630	99	897	306	9.1
	Wetfall	1,236	938	2,174	63	6,536	461	15.8
	Composite	669	205	874	15	1,696	89	6.9
	Total	2,409	1,273	3,678	177	9,129	856	31.8
PDQ	Dryfall	156	98	254	31	522	62	5.4
	Wetfall	386	174	560	6	740	99	6.6
	Composite	542	272	814	37	1,262	161	12.0
	Total	2,409	1,273	3,678	177	9,129	856	31.8

Appendix C
PRECIPITATION ANALYSIS USING SYNOP

PRECIPITATION DATA (SYNOP)

Long-term precipitation records are available from the Minneapolis-St. Paul International Airport for the period 1948-1980. Several analyses of these data have been done for the Metropolitan Area, but the ones referenced here will be those of the Metropolitan Waste Control Commission (MWCC, 1979) which used 1948-1975 and the Metropolitan Council-USGS for the present 208 program which used 1952-1980. Program SYNOP (U.S. EPA, 1976) was used in both evaluations and updated data to 1980 was entered by USGS for the current effort. Table C-1 shows the long-term characteristics for the Minneapolis-St. Paul Airport for 1948-1975, as well as similar characteristics for several neighboring stations (MWCC, 1979); the 1952-1980 figures are nearly identical to those in Table C-1. Figure C1 shows the average monthly behavioral characteristics of the aiport station for the 1948-1975 period.

Table C-1
SUMMARY OF LONG-TERM RAINFALL ANALYSIS
(Minimum Six Dry Hours Between Storms)

Gage	Years of Record	Average Storm Duration (Hours)	Average Storm Intensity (Inches/ Hour)	Average Storm Depth (Inches)	Average Time Between Storms (Hours)	Number of Storms Evaluated
Minneapolis/ St. Paul Airport	28	6.30	0.047	0.25	84.0	2,858
Buffalo	27	7.38	0.058	0.35	102.1	2,079
Plymouth (Golden Valley)	13	5.21	0.096	0.35	104.4	845
LeSueur	28	7.09	0.054	0.31	104.7	2,259
Northfield	28	6.44	0.069	0.33	99.1	2,394

To gain a further insight into the precipitation characteristics, a statistical program was run using individual precipitation events from 1952-1980 for specific durations. The purpose of this was to see the precipitation volumes associated with various return frequencies at different durations. Table C-2 shows the results of this analysis, including the number of events at the specific duration for the period of 29 years; for example the two-year return interval value of rain based on all of the two-hour storms is 0.65 inch. Table C-1 shows that over the long term, the average precipitation duration is about six hours. Programs focusing on remedial stormwater efforts, therefore, should use the six-hour duration data to obtain maximum results since quantity and quality data show beneficial results from controlling frequently occurring events.

Figure C-1. LONG-TERM PRECIPITATION CHARACTERISTICS, MINNEAPOLIS-ST. PAUL AIRPORT (FROM MWCC, 1979)

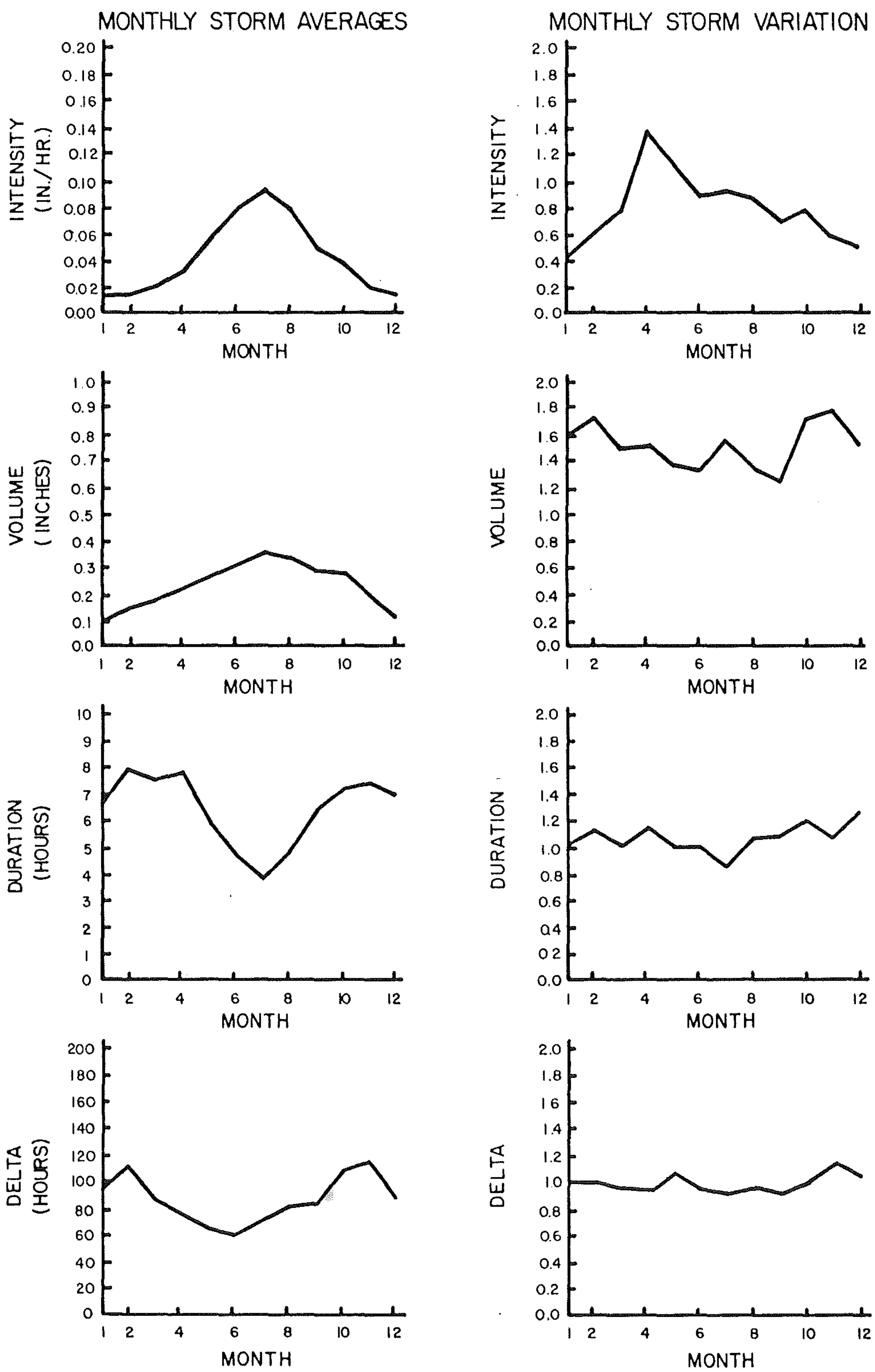


Table C-2
PRECIPITATION VOLUMES (INCHES) AS FUNCTION OF DURATION

Duration (Hours)	Number of Events	Return Interval 2 Years	5 Years	10 Years
2	395	0.65	0.81	1.14
6	136	0.63	1.12	1.51
12	45	0.47	1.01	1.45

The data presented in Table C-1 for the Minneapolis-St. Paul Airport were further evaluated by MWCC (1979). Figures C2 and C3 are cumulative density functions for gamma distributed storm data. A discussion of the background for this evaluation occurs in the referenced MWCC publication and in an EPA document (U.S. EPA, 1976). The graphs presented in Figures C2 and C3 are based upon the coefficients of variation associated with the data in Table C-1. A large coefficient of variation indicates a wide distribution of data and enhanced likelihood of large or small events.

To use these figures select a percent duration value along the y-axis and move to the right until the dotted line is intersected; move down to read the multiple of the mean expected for the desired duration. Using the 90 percent duration example and Figures C2 and C3 one can make the following statements.

Intensity: 90 percent of the time the intensity of precipitation is 0.10 inch per hour (2.2*0.047) or less.

Duration: 90 percent of the time the duration of precipitation is 15.1 hours (2.4*6.3) or less.

Volume: 90 percent of the time the volume of precipitation is 0.7 inch (2.8*0.25) or less.

Time Between Storms: 90 percent of the time the time between storms is 185 hours (2.2*84) or less.

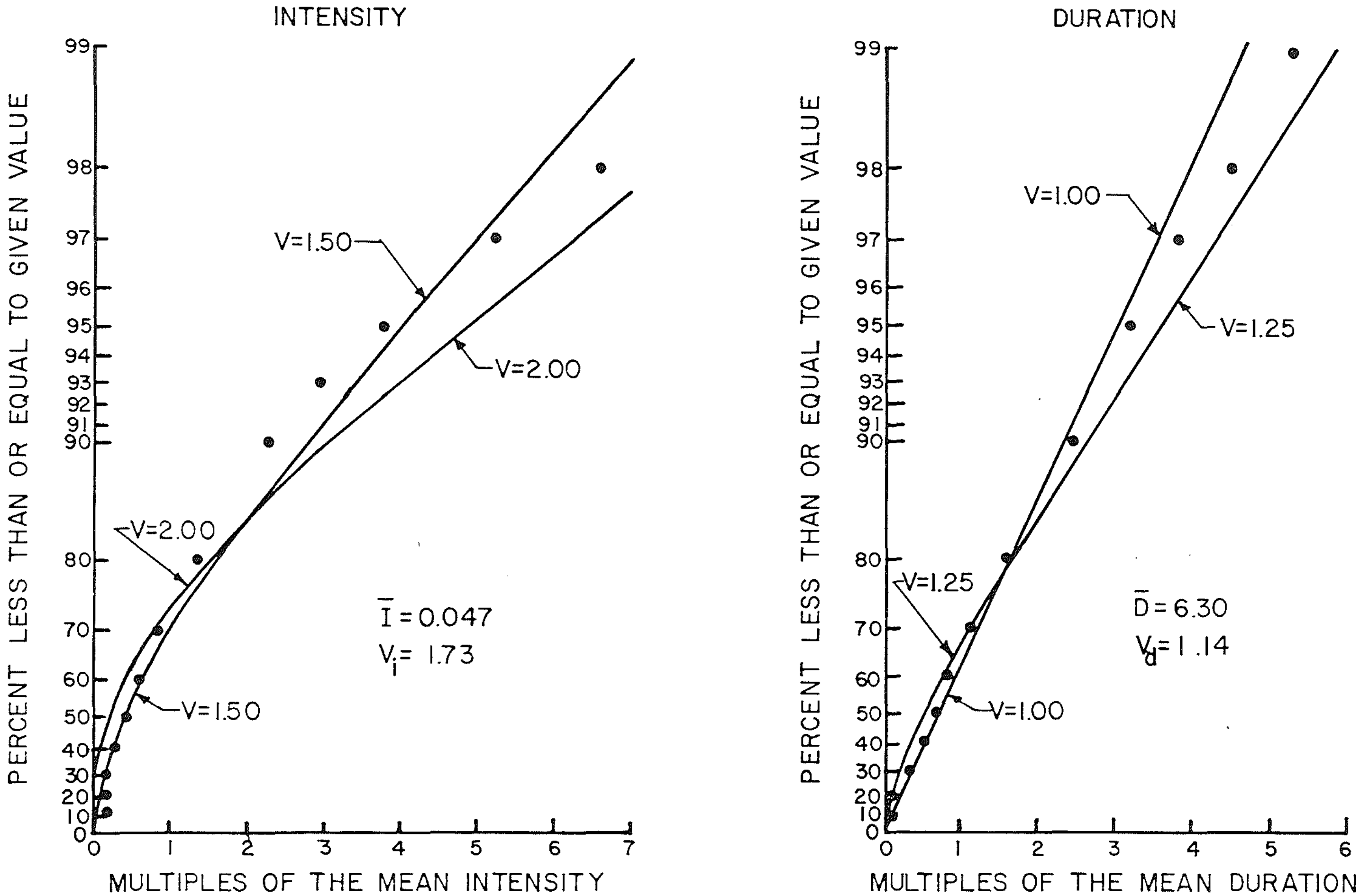
The number of storms greater than a given value on an annual basis can then be determined. Again, the background explanations occur in the previously mentioned MWCC and U.S. EPA documents.

The data in Table C-1 and Figures C2 and C3 show that the average number of storms in a year equals the length of period divided by the time between storms. For the above data:

$$\text{Average number of storms} = \frac{\text{8,760 hours per year}}{\text{84 hours}} = 104$$

The expected number of storms greater than a given value is then the fraction of storms greater than the given values (1-percent duration/100) times the average number of storms. Using the 90 percent duration figures presented previously, there will be on the average .10*104=10.4 storms per year with a volume greater than 0.7 inch.

Figure C-2. CUMULATIVE DISTRIBUTIONS FOR STORM INTENSITY AND DURATION (FROM MWCC, 1979)



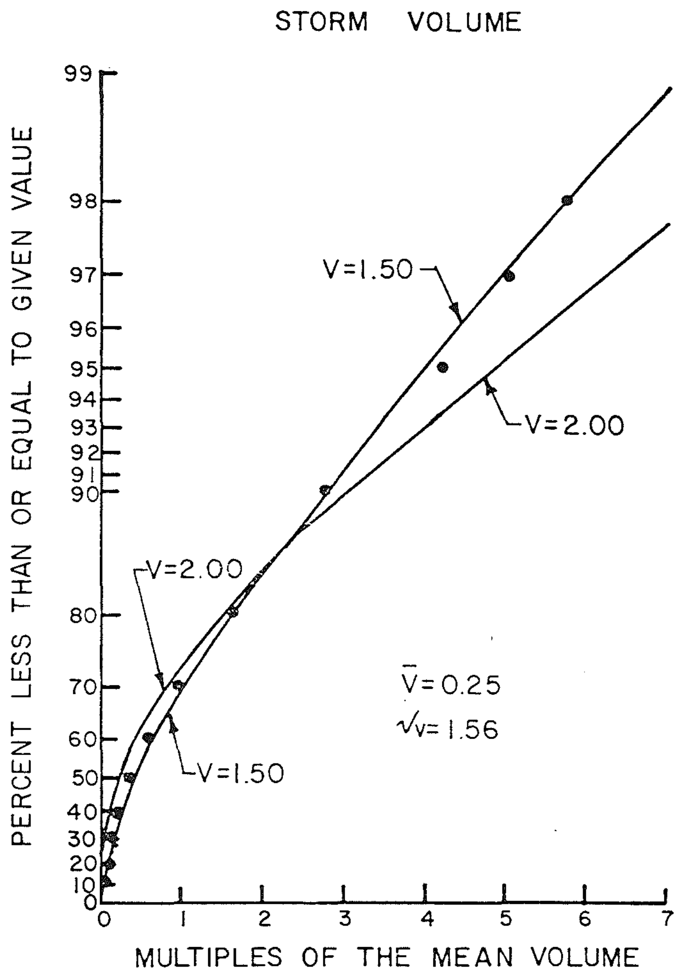
LEGEND

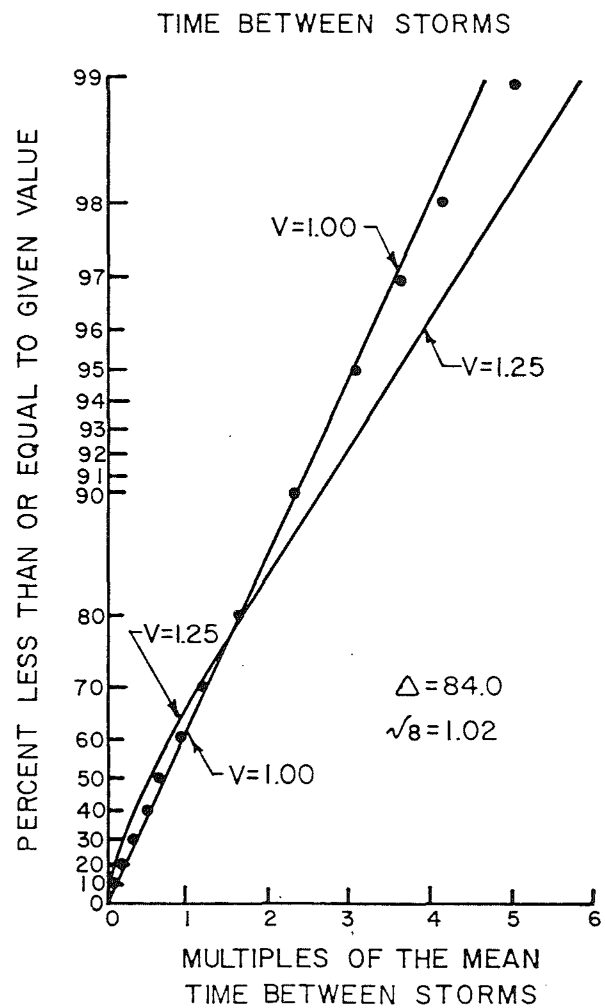
—— THEORETICAL GAMMA DISTRIBUTION

• OBSERVED DISTRIBUTION

NOTE: DATA FROM AIRPORT GAUGE, NO. 215435
(as reported in MWCC, 1979)

Figure C-3. CUMULATIVE DISTRIBUTIONS FOR STORM VOLUME AND TIME BETWEEN STORMS (FROM MWCC, 1979)





LEGEND

—— THEORETICAL GAMMA DISTRIBUTION
• OBSERVED DISTRIBUTION

NOTE: DATA FROM AIRPORT GAUGE, NO. 215435
(as reported in MWCC, 1979)

The type of information presented in this appendix is readily available and should be used in design considerations for stormwater facilities.

REFERENCES

Metropolitan Waste Control Commission, 1979. Calibration Report for the SPAM Statistical Model. Chapter II. Rainfall Analysis. Prepared by GANORAM and Hydroscience for Combined Sewer Overflow Study, November 1979. pp. 7-63.

U.S. Environmental Protection Agency, 1976. 208 Areawide Assessment Procedures Manual; Volume I, Chapter 3, Procedures for Assessment of Urban Pollutant Sources and Loadings. U.S. EPA Report 600/9-76-014, Prepared for EPA by Hydroscience, Inc., July 1976, Pp. 3-1 -3-89.

Appendix D
BASIN CHARACTERISTICS FOR 17 MONITORED SITES

Table D1. Basin Characteristics for Urban Sites

NAME	LUAGI	LUURB	LUVET	LUWTR	LUWTWR	LURMF	LURSF	LURLD	LURMD	LURHD	LUCI	LUOS	POPDN	ACCON
BASET	36.0	64.0	8.1	6.4	14.5	2.7	37.9	18.6	19.3	0	18.1	5.3	3.4	342
PURGA	40.7	59.3	14.5	4.9	19.4	2.4	43.1	43.1	0.0	0	8.3	5.5	1.6	533
SHING	54.8	45.2	8.2	4.6	12.8	2.1	17.8	6.2	11.6	0	20.4	4.9	1.9	260
EIGHT	10.8	89.2	1.5	0.0	1.5	0.0	67.8	0.2	67.6	0	4.1	17.3	5.5	23
VERS	53.7	46.3	0.0	0.0	0.0	0.0	32.5	0.0	32.5	0	0.0	13.8	406.0	33
DU	0.3	100.7	0.0	0.0	0.0	18.8	69.4	69.4	0.0	0	1.0	11.5	678.0	9
D100	0.0	100.0	0.3	0.0	0.3	0.0	80.5	0.0	80.5	0	19.5	0.0	2008.0	1
ESLY	10.3	89.7	4.0	0.0	4.0	0.0	83.0	0.0	83.0	0	0.0	6.7	1390.0	1
STAT	0.0	100.0	0.0	0.0	0.0	0.0	96.5	2.7	93.8	0	3.5	0.0	1271.0	0
AIES	18.4	81.6	0.0	0.0	0.0	24.9	53.3	1.2	52.1	0	1.7	1.7	1644.0	16

NAME	TAREA	ICAREA	IAREA	EAREA	RELEF	CSLOPE	DRDNS	AOFLOW	MDITCH	PORSO	PAHOR	AWCA	HYSGR	MANRT
BASET	31.70	29.4	13.0	8.4	305	18.3	3.67	3750	13.6	28	1.2	0.19	2.6	30.0
PURGA	24.00	16.5	7.0	5.0	215	12.2	3.51	3750	9.9	24	1.9	0.19	2.6	29.0
SHING	22.90	16.7	15.5	12.2	189	6.4	2.81	3300	8.7	23	2.4	0.17	2.3	30.0
EIGHT	1.55	1.5	16.0	11.2	160	44.9	40.30	500	0.0	0	1.9	0.21	2.0	29.0
VERS	0.15	.	4.0	4.0	60	24.1	22.00	375	.	0	2.0	0.23	2.0	29.0
DU	0.13	.	11.0	8.0	95	103.2	33.00	500	.	0	5.4	0.15	2.1	29.0
D100	0.47	.	35.0	26.3	45	85.2	36.00	750	.	0	.	.	.	30.0
ESLY	0.33	.	22.0	15.3	60	43.2	56.00	500	.	6	1.9	0.19	2.2	30.0
STAT	0.22	.	29.0	16.5	16	22.5	50.30	500	.	2	6.2	0.06	1.6	30.5
AIES	0.35	.	23.0	13.3	7	10.0	55.20	450	.	1	8.0	0.13	2.3	30.5

Table D2. Basin Characteristics for Rural Sites

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:06 FRIDAY, DECEMBER 11, 1981   3

NAME	TAREA	ICAREA	IAREA	EAREA	RELEF	CSLOPE	DRDNS	AOFLOW	MDITCH	PDRSC	PAHCR	AWCA	HYSGR	MANRT
BEVNS	82.9	80.3	1.7	1.2	126	4.1	2.41	3500	82.5	44	1.1	0.22	2.6	30.0
CARVR	65.2	63.8	2.0	1.3	160	4.3	1.87	2400	40.7	31	1.5	0.25	2.6	30.0
CREDT	23.2	20.9	2.0	1.5	240	13.4	3.42	1640	18.0	26	1.6	0.21	2.2	27.5
ELMRV	14.3	13.1	3.0	2.1	165	8.9	4.21	2000	9.6	39	0.8	0.20	2.8	30.0
RAVEN	32.4	31.5	1.5	1.0	135	8.4	3.27	3300	29.4	45	1.2	0.24	2.6	28.0
VERMI	30.8	30.5	1.5	1.0	198	8.8	2.11	2600	24.9	19	2.2	0.21	2.0	29.0

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:06 FRIDAY, DECEMBER 11, 1981   4

NAME	LUAGI	LUURB	LUAET	LUWTR	LUWTWR	LUCRCP	LUROW	LUSMGR	LUCRN	LUBN	LUOAT	LUWHT	LUMEAD	LUPASG	LUWOD
BEVNS	90.0	4	5.2	0.8	6.0	62.0	52.5	9.8	41.4	10.9	6.9	2.8	15.7	7	5
CARVR	74.1	7	7.6	9.3	16.9	43.0	35.8	7.2	27.2	8.6	4.7	2.5	17.5	8	8
CREDT	75.0	11	11.0	1.6	12.6	33.0	29.1	3.9	18.3	10.8	3.8	0.1	9.3	16	18
ELMRV	74.5	9	16.3	0.9	17.2	33.5	26.8	6.7	18.1	8.9	6.7	0.0	11.3	18	10
RAVEN	90.0	4	3.1	0.2	3.3	73.8	67.0	6.8	41.2	25.7	4.2	2.6	8.9	8	2
VERMI	87.2	8	4.8	0.0	4.8	69.9	62.2	7.7	34.9	27.3	4.6	3.1	5.8	5	7

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   13:06 FRIDAY, DECEMBER 11, 1981   5

NAME	PCRPAT	PHNAT	PCRNAT	ROTF	USLER	NUMAU	MANRT	ROTFAC
BEVNS	3052.7	632.2	1996.8	18	3.21	6433	30.0	0.239
CARVR	2494.0	731.0	1659.2	24	3.50	5419	30.0	0.234
CREDT	2442.0	853.2	1445.7	24	6.58	1365	27.5	0.210
ELMRV	837.5	222.5	447.5	.	3.28	167	30.0	0.085
RAVEN	3616.2	1490.6	1982.4	17	3.63	1577	28.0	0.347
VERMI	4823.1	2020.2	2617.5	15	7.47	1714	29.0	0.394

Appendix E
REGIONAL LOADING DATA

(See also Payne et al., 1982)

Table E-1. METROPOLITAN AREA WATERSHED CODES

COUNTY	WATERSHED	WATERSHED CODE
Anoka	Coon Creek	COO
	Rum River	RUM
	Sunrise River	SUN
	Upper Mississippi River	UMS
Carver	Bevens Creek	BEV
	Bluff Creek	BLU
	Buffalo Creek	BUF
	Carver Creek	CAR
	Chaska Creek	CHA
	Crow River	CRO
	Hazeltine-Bavaria Creek	HBC
	Riley Creek	RIL
	Upper Minnesota River	UMN
Dakota	Black Dog Lake	BLA
	Chub Creek	CHU
	Gun Club Lake	GUN
	Lower Cannon River	LCR
	Lower Mississippi River	LMS
	Upper Cannon River	UCR
	Vermillion River	VER
Hennepin	Bassett Creek	BAS
	Crow River	CRO
	Elm Creek	ELM
	Grass Lake	GRA
	Long Meadow Lake	LML
	Lower Minnesota River	LMN
	Minnehaha Creek	MIN
	Nine Mile Creek	NIN
	Purgatory Creek	PUR
	Shingle Creek	SHI
	Upper Mississippi River	UMS
Ramsey	Ramsey,Washington,Metro	RWM
	Rice Creek	RIC
	St. Paul	STP
Scott	Clarks Lake	CLA
	Credit River	CRE
	Prior Lake	PRI
	Robert Creek	ROB
	Sand Creek	SAN
	Upper Minnesota River	UMN
Washington	Big Marine Lake	BML
	Brown Creek	BRO
	Conners Lake	CON
	Cottage Grove	COT
	Cottage Grove Ravine	CGR
	Lower Mississippi River	LMS
	Marine on St. Croix	MSC
	St. Croix River	STC
	Trout Brook	TRO
	Valley Branch	VAL

Table E-2. METROPOLITAN AREA WATERSHEDS LAND USE (1980)

Tertiary Watersheds	Total Area (miles^2)	Percent in Single Family Housing: Low Density	Percent in Single Family Housing: Medium Density	High Density	Percent in Multifamily Housing	Percent Commercial and Industrial	Percent in Agriculture and Vacant Land	Percent in Lakes and Open Water	Percent in Open Space
Anoka Co.									
COO-1	1.9	5	17	-	-	2	65	11	-
-2	19.7	9	2	-	-	3	81	-	5
-3	13.8	4	21	-	1	11	55	*	8
-4	11.4	11	1	-	-	1	84	3	*
-5	2.6	1	15	-	-	9	38	-	37
-6	14.4	2	17	-	*	19	61	-	1
-7	1.9	6	-	-	-	4	72	18	*
-8	4.6	1	-	-	-	-	99	-	-
-9	21.6	*	-	-	-	*	55	1	44
RUM-1	14.0	6	-	-	-	*	91	2	1
-2	31.3	1	-	-	-	1	93	1	-
-3	13.7	*	-	-	-	1	97	-	2
-4	57.4	9	2	-	-	3	80	2	4
-5	34.7	4	-	-	-	*	88	*	8
-6	17.3	2	2	-	-	1	93	2	*
-7	6.9	-	43	-	2	20	22	7	6
SUN-1	30.7	3	-	-	-	*	82	8	7
-2	41.7	4	*	-	-	*	57	7	31
-3	27.6	5	3	-	*	2	73	15	2
Carver Co.									
BEV-1	48.9	*	1	-	-	1	97	1	*
-2	31.1	-	-	-	-	*	100	-	*
-3	2.7	1	-	-	-	1	98	-	-
BLU	8.4	1	-	-	-	1	87	7	4
BUF	2.4	-	-	-	-	-	100	-	-
CAR-1	72.7	*	*	-	-	1	95	2	1
-2	12.6	2	1	-	-	1	57	38	1
CHA	12.7	1	2	-	-	1	94	2	-
CRO-1	80.6	*	*	-	-	1	98	-	*
-2	8.7	*	-	-	-	*	99	-	-
-3	2.3	-	-	-	-	1	99	-	-
-4	4.8	*	-	-	-	1	85	14	*
-5	2.8	-	2	-	-	1	79	11	7
-6	2.6	-	-	-	-	-	100	-	-
-7	4.9	*	-	-	-	-	89	11	-
-8	50.4	3	1	-	-	1	83	7	5
-9	4.5	3	-	-	-	1	63	1	32
-10	3.2	1	-	-	-	-	36	18	45
-11	8.6	5	-	-	-	1	77	10	7
-12	2.6	4	-	-	-	3	86	5	2
-13	5.4	1	-	-	-	-	99	*	-
-14	26.2	3	*	-	-	2	76	4	15
HBC	13.4	3	5	-	1	9	75	5	2

Table E-2. METROPOLITAN AREA WATERSHEDS LAND USE (1980) (Cont.)

Tertiary Watersheds	Total Area (miles^2)	Percent in Single Family Housing: Low Density	Percent in Single Family Housing: Medium Density	Percent in Single Family Housing: High Density	Percent in Multifamily Housing	Percent Commercial and Industrial	Percent in Agriculture and Vacant Land	Percent in Lakes and Open Water	Percent in Open Space
RIL	10.0	7	2	-	-	3	74	12	2
UMN-1	6.3	-	-	-	-	-	75	8	17
-2	9.4	1	-	-	-	1	93	5	-
-3	19.8	*	2	-	-	3	64	5	26
-4	3.3	1	-	-	-	5	86	7	1
Dakota Co.									
BLA	22.2	2	23	-	3	13	51	2	6
CHU-1	26.1	*	-	-	-	*	97	2	*
-2	49.0	*	*	-	-	1	98	-	*
GUN	35.1	6	6	-	2	6	60	2	18
LCR-1	12.4	2	*	-	-	1	83	10	4
-2	22.0	*	-	-	-	1	99	-	*
-3	27.0	*	*	-	-	*	99	-	*
-4	2.7	1	-	-	-	-	99	-	-
-5	1.2	-	-	-	-	-	100	-	-
LMS-1	13.3	9	5	-	1	9	64	1	11
-2	53.9	4	15	2	2	15	34	13	15
-3	22.7	2	13	-	*	8	53	23	1
-4	1.4	-	-	-	-	26	34	40	-
-5	11.0	2	-	-	-	1	87	10	-
UCR	16.0	2	-	-	-	1	93	-	4
VER-1	8.8	2	11	-	1	8	60	9	9
-2	23.6	3	3	-	*	3	79	4	8
-3	37.9	1	*	-	-	1	96	1	*
-4	31.4	2	9	-	*	3	85	-	1
-5	14.9	2	13	-	*	3	74	-	8
-6	35.6	1	1	-	*	4	66	-	28
-7	30.6	1	*	-	-	*	98	-	*
-8	43.8	3	*	-	-	2	82	-	13
-9	18.4	-	3	-	*	1	94	-	2
-10	29.2	1	1	-	*	3	94	1	*
-11	52.0	2	*	-	-	1	95	1	1
Hennepin Co.									
BAS-1	18.1	2	23	-	2	20	42	9	2
-2	3.4	-	51	-	8	10	20	-	11
-3	14.9	-	36	8	7	23	9	1	16
-4	4.3	-	46	-	2	32	9	5	6
ELM-1	25.6	2	-	-	-	*	97	*	-
-2	22.4	2	2	-	-	*	95	-	1
-3	25.4	2	3	-	-	*	61	7	27
-4	31.5	4	6	-	1	1	79	3	6

Table E-2. METROPOLITAN AREA WATERSHEDS LAND USE (1980) (Cont.)

Tertiary Watersheds	Total Area (miles^2)	Percent in Single Family Housing: Low Density	Percent in Single Family Housing: Medium Density	Percent in Single Family Housing: High Density	Percent in Multifamily Housing	Percent Commercial and Industrial	Percent in Agriculture and Vacant Land	Percent in Lakes and Open Water	Percent in Open Space
GRA	3.7	1	2	-	-	11	63	23	-
LML	18.1	-	28	-	4	34	16	12	6
LMN	8.3	*	34	-	2	10	34	7	13
MIN-1	22.7	11	4	-	*	2	55	12	16
-2	40.2	5	3	-	*	1	56	21	14
-3	2.4	16	-	-	-	2	64	18	-
-4	29.2	29	6	-	*	3	15	43	4
-5	21.3	10	4	-	-	2	58	22	4
-6	9.8	10	39	-	2	9	20	16	4
-7	58.0	3	30	17	6	20	8	5	11
NIN-1	14.8	12	20	-	1	9	46	3	9
-2	12.0	-	45	-	6	22	19	-	8
-3	2.2	-	12	-	-	5	18	31	34
-4	1.9	-	22	-	-	-	27	14	37
-5	12.7	-	46	-	5	21	11	1	16
PUR-1	21.1	3	26	-	1	7	56	3	5
-2	5.5	7	13	-	2	8	60	7	3
-3	1.6	-	38	-	11	-	43	-	8
-4	0.6	-	40	-	7	-	33	-	20
-5	1.8	-	22	-	3	4	31	7	33
SHI-1	2.6	2	-	-	-	56	42	-	-
-2	5.8	6	15	-	3	15	46	14	1
-3	7.9	5	9	-	*	3	74	4	5
-4	4.1	-	10	-	*	34	46	-	10
-5	3.5	-	34	-	11	14	37	-	4
-6	11.9	-	49	5	5	27	5	5	4
-7	4.4	-	42	-	2	13	30	2	11
-8	2.8	-	57	-	4	23	9	-	7
-9	2.4	-	6	39	3	28	1	1	22
UMS-1	10.5	12	3	-	*	12	62	4	7
-2	6.0	1	7	-	1	1	77	10	3
-3	33.7	2	26	1	2	13	52	2	3
-4	8.8	*	34	-	1	15	32	3	15
-5	1.1	-	49	-	-	15	20	15	1
-6	21.7	-	3	17	10	61	2	1	5
-7	12.3	-	1	24	24	36	3	6	6
-8	2.7	-	-	29	-	64	-	7	*
Ramsey Co.									
RWM-1	3.2	*	34	-	8	18	40	-	-
-2	10.9	-	38	-	2	16	37	-	7
-3	10.3	-	33	7	2	14	22	10	12
-4	9.0	-	19	24	7	11	33	1	5

Table E-2. METROPOLITAN AREA WATERSHEDS LAND USE (1980) (Cont.)

Tertiary Watersheds	Total Area (miles^2)	Percent in Single Family Housing			Percent in Multifamily Housing	Percent Commercial and Industrial	Percent in Agriculture and Vacant Land	Percent in Lakes and Open Water	Percent in Open Space
		Low Density	Medium Density	High Density					
-5	10.0	-	25	1	5	8	47	3	11
-6	5.5	-	5	-	1	33	27	33	1
-7	2.9	-	24	-	8	7	41	-	20
-8	4.3	-	10	-	-	5	74	2	9
RIC-1	26.1	-	39	-	3	26	20	6	6
-2	16.6	1	24	-	2	22	30	5	16
-3	43.6	5	3	-	-	6	64	11	11
-4	28.5	1	3	-	-	3	80	9	4
-5	27.4	1	1	-	-	1	91	2	4
-6	0.8	4	-	-	-	-	96	-	-
-7	42.5	1	11	-	*	3	65	17	3
-8	4.6	6	-	-	-	-	88	6	-
STP-1	40.0	-	10	38	8	22	4	7	10
-2	33.6	7	18	-	1	4	48	11	11
Scott Co.									
CLA	21.9	*	-	-	-	*	94	4	2
CRE-1	11.2	5	-	-	-	3	73	4	15
-2	33.3	6	1	-	-	1	73	*	19
-3	3.1	21	-	-	-	1	60	12	6
PRI-1	52.1	2	3	-	*	6	70	7	12
-2	2.6	9	20	-	-	3	38	25	5
-3	5.1	14	8	-	-	*	46	29	3
-4	1.1	10	-	-	-	-	90	-	-
-5	15.9	3	-	-	-	*	89	6	2
-6	2.3	*	-	-	-	-	92	8	-
-7	2.7	6	-	-	-	*	79	15	-
ROB	11.6	-	-	-	-	1	99	-	-
SAN-1	74.2	*	*	-	-	1	96	1	1
-2	35.1	*	-	-	-	*	98	1	*
-3	4.8	2	8	-	-	7	80	-	3
-4	4.4	9	-	-	-	-	53	28	10
-5	23.8	1	-	-	-	-	99	-	-
-6	23.1	*	-	-	-	*	96	4	-
Washington Co.									
BML-1	32.0	3	1	-	-	1	84	10	1
-2	10.2	2	-	-	-	1	95	2	-
BRO	29.0	3	3	-	*	2	90	1	1
CON	11.0	*	2	-	-	-	91	-	7
COT	14.4	2	14	-	*	6	75	*	3
CGR	32.4	1	1	-	*	2	93	1	2
MSC	39.3	3	1	-	-	2	80	5	9

Table E-2. METROPOLITAN AREA WATERSHEDS LANND USE (1980) (Cont.)

Tertiary Watersheds	Total Area (miles^2)	Percent in Single Family Housing: Low Density	Medium Density	High Density	Percent in Multifamily Housing	Percent Commercial and Industrial	Percent in Agriculture and Vacant Land	Percent in Lakes and Open Water	Percent in Open Space
STC-1	21.7	1	14	-	*	11	51	20	3
-2	6.3	5	4	-	-	2	71	13	5
-3	12.7	2	-	-	-	1	81	12	4
TRO	7.0	3	-	-	-	-	85	*	12
VAL-1	8.9	7	5	-	1	7	63	11	6
-2	14.6	5	4	-	*	4	56	5	26
-3	24.0	5	1	-	-	7	82	-	5
-4	4.4	13	-	-	-	5	82	-	-
-5	5.3	6	-	-	-	6	83	5	-
-6	8.7	4	-	-	-	-	96	-	-
TOTAL	2968.0								

* - This means that individual values marked this way are less than 0.50%. If two or more *s add up to 0.5 or more, this has been figured into 100% total.

Rivers - To provide a degree of consistency the areas of the following rivers (open water) have been figured into the areas of bordering watersheds:

Crow River
Minnesota River
Mississippi River
St. Croix River

All other rivers, streams, etc. appear too narrow to be measured.

Sheds - Secondary watersheds very often cross county boundaries. You will find them listed under the county containing the majority of the land area of the watershed.

Single-Family Housing Densities calculated as follows:

Low Density - 2 units or fewer per acre
Medium Density - 3-8 units per acre
High Density - 9 or more units per acre

SA1162

Table E-3. Watersheds

Agricultural

1. No. Vermillion
2. Vermillion
3. Hardwood-Miss. 97 (Ravenna)
4. Lower Cannon
5. Chub Creek
6. Miss. 96 (So. Washington Co.)
7. Basswood Grove
8. Afton
9. Stillwater
10. Brown's Creek
11. Marine-on-St. Croix
12. Big Marine Lake
13. So. Sunrise
14. Rice Creek
15. Coon Creek
16. Cedar Creek
17. Ford Brook
18. Lower Rum R.
19. Crow River
20. Sarah Creek
21. Pioneer Creek
22. Lower So. Fork Crow River
23. Winsted Lake
24. Elm Creek
25. Riley Creek
26. Bluff Creek
27. Hazeltine-Bavaria Creek
28. Chaska Creek
29. Bevens Creek
30. Silver Creek
31. Robert Creek
32. Sand Creek (Scott)
33. Spring Lake
34. Shakopee
35. Credit R.
36. Miss. 92 (Cottage Grove Ravine)
37. Minn. 122 (Scott Co.)
38. Minn. 126 (Carver Co.)
39. Carver Creek
40. Belle Plaine
41. West Sunrise
42. Seelye Brook

Urban

1. Lower Minnehaha Creek
2. Lower Nine Mile Creek
3. Upper Nine Mile Creek
4. Purgatory Creek
5. Upper Shingle Creek
6. Lower Shingle Creek
7. Upper Bassett Creek
8. Lower Bassett Creek
9. Lower Minnesota R. (Hennepin Co.)
10. St. Paul
11. St. Paul North
12. Ramsey-Washington North
13. Ramsey-Washington South
14. Lower Mississippi R. (Dakota Co.)
15. Lower Mississippi R. (Cottage Grove)
16. Black Dog Lake (Minnesota R.)
17. Gun Club Lake (Minnesota R.)
18. Grass Lake (Minnesota R.)
19. Prior Lake
20. Upper Mississippi R. (Anoka)
21. Lower Rum River (Coon Rapids)
22. Sand Creek (Anoka Co.)
23. Osseo
24. Upper Mississippi-Spring Lake Park
25. Upper Mississippi-No. Minneapolis
26. Upper Mississippi-Minneapolis
27. Upper Mississippi-So. Minneapolis
28. North Vermillion*
29. Vermillion*
30. Hardwood-Mississippi 97*
31. Lower Cannon*
32. Cottage Grove Ravine*
33. Basswood Grove*
34. Afton*
35. Stillwater*
36. Brown's Creek*
37. Marine-on-St. Croix*
38. Big Marine Lake*
39. South Sunrise*
40. West Sunrise*
41. Rice Creek
42. Upper Rice Creek*
43. Coon Creek*
44. Cedar Creek*
45. Ford Brook*
46. Seelye Brook*
47. Lower Rum R.*
48. Lower Crow R.*
49. Sarah Creek*
50. Pioneer Creek*
51. Lower So. Fork Crow R.*
52. Elm Creek*
53. Riley Creek*
54. Bluff Creek*
55. Hazeltine-Bavaria Creek*
56. Chaska Creek*
57. Bevens Creek*
58. Sand Creek* (Scott)
59. Spring Lake*
60. Shakopee*
61. Credit River*
62. Carver Creek*
63. Belle Plaine*
64. Upper Minnehaha Creek
65. Middle Minnehaha Creek

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* Urban part of rural watershed.

Table E4a. Ten Percent Duration Load for Rural Subwatersheds

OBS	COD10	TSS10	TN10	NN10	TKN10	TP10	IN10
1	864746	1375616	150743	107989	42754	588.0	2.76000
2	3101929	2249007	439226	337540	101685	26721.0	4.39000
3	1084492	1876541	88749	22349	66400	15021.4	2.03000
4	1410324	2126808	202018	168773	33245	11373.2	7.71000
5	1395421	382671	115807	68923	46884	7976.0	2.66000
6	312756	134800	42354	40412	1942	2855.6	5.53000
7	458349	795714	62447	50383	12064	5865.1	3.07308
8	263933	1183000	169697	140991	28706	5585.0	2.25036
9	1256247	1094966	201467	161270	40197	15279.0	6.12749
10	309018	127341	26731	14562	12169	2709.0	2.68110
11	495998	793115	59943	41022	18921	12783.3	2.50951
12	575230	276772	65466	23365	42101	11460.1	3.69000
13	803101	1517171	87709	50579	37130	10921.0	1.70000
14	2513384	2550986	195210	76183	119027	30346.0	6.85000
15	927919	1174014	62634	8959	53675	11746.0	1.89000
16	763253	194545	68281	40134	28147	6527.0	1.36000
17	493896	275930	61637	20731	40906	6708.0	1.41000
18	992928	688169	116054	70265	45789	4596.7	1.37000
19	812750	726198	181278	142290	38988	9469.0	2.20000
20	45788	127827	21987	17357	4630	561.2	2.98950
21	638185	758923	149607	114684	34923	12709.0	3.52000
22	983002	442430	385220	345215	40005	10390.0	5.31000
23	26986	68061	19836	15962	3874	961.0	2.81000
24	1467462	815215	103015	33106	69909	18869.0	3.87000
25	308406	63717	24805	15656	9150	2882.0	1.56354
26	81294	310382	6737	2588	4149	1412.0	3.69000
27	292292	40615	10338	6307	4031	3014.0	2.09361
28	94596	39563	12214	7965	4249	1689.0	5.72000
29	454412	737810	50267	5306	44961	5123.0	1.01000
30	32285	1337133	29352	1949	27403	2589.0	6.69000
31	178072	255413	10756	3256	7500	1360.0	5.78000
32	1705523	1343867	162186	39853	122333	9964.3	9.58000
33	245909	106651	27983	10509	17474	5982.1	0.26000
34	1134078	1138436	141195	109897	31297	13974.0	3.52000
35	596390	632943	53531	19211	34319	9289.0	4.66000
36	287605	1654500	32214	15401	16813	10956.4	9.98000
37	732838	533418	83793	63562	20231	1707.5	1.16000
38	387578	246916	40862	29795	11067	3118.8	1.45000
39	954344	531378	73595	9879	63716	18830.3	3.48000
40	305005	252146	41413	34499	6914	1978.6	1.13000
41	1193980	720662	174611	156933	17678	5296.0	1.70000
42	253207	153191	38367	21682	16685	2561.0	1.64000

Table E4b. Fifty Percent Duration Load for Rural Subwatersheds

OBS	COD50	TSS50	TN50	NN50	TKN50	TP50	IN50
1	2041011	2700000	369299	318168	51132	10592.1	3.3678
2	7508947	8646513	1045453	810767	234686	43805.7	5.7700
3	1643170	3900000	143145	38326	104819	19540.6	2.4400
4	1744362	3957000	228836	129933	98903	20205.6	8.9362
5	1923262	655853	139876	35169	104709	18330.9	3.6933
6	448045	533930	42921	18087	24834	5550.2	6.4324
7	772187	1655000	89690	56828	32862	8456.4	4.4411
8	447345	1820000	235691	200347	35344	8095.7	4.8800
9	3925390	4256095	551184	456542	94642	24645.7	11.8425
10	604488	200095	46495	28598	17897	5013.5	4.3100
11	1034455	1117064	83254	58357	24896	9950.8	7.3600
12	1554073	420626	90925	41433	49492	15079.1	8.0300
13	3797911	2920015	116325	62513	53812	16803.2	2.0124
14	9876444	6792900	241000	56555	184445	45293.3	9.5200
15	4291038	2795460	128500	63645	64855	14305.7	2.2200
16	1295868	278719	95900	52596	43304	9593.6	1.6600
17	1742100	353000	82180	31869	50311	9723.0	1.8500
18	2239262	1086614	178546	114055	64492	12998.6	1.6500
19	2546382	1192846	262723	196891	65832	13425.1	3.0600
20	507237	175106	30387	22242	8145	3168.6	4.4130
21	3028285	1130623	196203	122293	73910	19550.8	4.6263
22	1335352	660344	566500	504004	62496	16678.1	6.6100
23	372170	71079	28554	23069	5485	1328.4	3.5000
24	5589740	1501550	567449	428869	138580	27596.2	4.9000
25	499148	357421	35552	12551	23001	5311.0	2.0766
26	213744	431087	9986	4231	5755	2522.2	4.5090
27	648020	485744	14359	8836	5523	4477.4	5.3717
28	243156	57164	16072	9890	6182	2317.4	7.5285
29	600409	1135093	73922	25690	48232	8667.3	1.1800
30	51247	1937874	45434	15790	29644	3719.6	8.4710
31	184147	335216	15149	3090	12059	2346.2	6.7249
32	3986363	1919071	201199	66720	134478	35276.2	12.6100
33	776324	148823	40554	18435	22119	7049.3	0.6424
34	3234488	2182753	389277	296603	92675	20251.3	4.0900
35	2976433	1320102	83414	27293	56121	13463.1	6.4721
36	416819	2330000	44743	19646	25096	6762.6	13.3127
37	1564165	729324	174663	116890	57772	11496.6	1.4166
38	767186	342944	73422	42713	30709	6853.9	1.6533
39	2924627	746993	103565	14329	89236	29850.6	4.6300
40	454753	344000	60041	38686	21354	4217.0	1.5000
41	1681662	1292942	254510	230683	23827	7440.2	2.0032
42	788567	423350	57055	38513	18542	3552.3	2.0153

Table E4c. Ninety Percent Duration Load for Rural Subwatersheds

OBS	COD90	TSS90	TN90	NN90	TKN90	TP90	IN90
1	11605484	9963000	632601	221197	411404	101885	11.4265
2	28579626	35631874	1884449	838997	1045452	468183	23.5148
3	7065631	11898446	685833	344085	341748	121148	7.6100
4	12009007	15171000	1002316	464031	538285	225025	14.0900
5	7500722	2098729	637843	128957	508886	132392	9.9300
6	1886613	2098729	157278	61995	95284	25418	17.2300
7	4455075	3580433	280512	87005	193507	51959	13.8500
8	5082794	2293200	938050	781762	156288	6980	14.8500
9	19143991	5277557	624654	209920	414733	169804	16.4700
10	3174971	470223	159338	15406	143932	89591	16.5542
11	5379166	2960219	390460	154161	236299	64177	11.7500
12	17427920	849069	426438	119588	306850	124100	13.0900
13	24351929	16739474	457294	52089	405205	91744	4.2600
14	56748883	24454440	1105922	294936	610936	295763	16.6600
15	45651005	10542067	362373	1621	360753	67090	6.3900
16	27873176	666138	466074	396944	69130	51035	5.1400
17	29111523	1263740	385419	76528	306891	39864	5.9200
18	30670367	3542361	889400	674750	214650	46793	4.0400
19	5565805	2210205	1092927	869694	223233	47737	7.3100
20	1281785	471035	112128	57090	55038	5957	14.0934
21	16958396	3041375	888799	406167	482632	8521	14.7600
22	8145647	2080083	2831009	2466657	364352	60605	18.8200
23	6782667	250196	124693	86036	38657	4249	8.3600
24	9272323	3183285	2637245	2289868	347377	129931	12.0500
25	3482323	750584	77099	10789	66310	16992	8.6597
26	2713272	1082028	48935	2828	46107	7566	15.4786
27	4166932	1306651	131419	92095	39324	11461	14.8600
28	4254627	112041	72806	41098	31708	6233	13.0200
29	3782576	3473364	527168	89603	437565	122602	2.8700
30	293645	4960957	195366	14538	180828	11082	14.6500
31	907168	610162	135221	58774	76447	5841	12.7000
32	14749144	4413863	828939	199582	629357	114902	16.9500
33	3974779	316992	161405	11681	149524	22274	2.9100
34	6989344	4714746	461467	151354	310113	96394	10.6300
35	6741960	1767879	257972	16644	241327	55467	14.3997
36	5615856	4403700	338596	57551	281045	26777	17.4400
37	4434039	1553460	324709	153336	171374	64722	3.6700
38	6427370	771684	156179	68376	87803	31866	3.7600
39	10788949	1516395	440151	122474	317677	123260	12.0100
40	2005470	706840	163813	65625	98188	16843	3.8900
41	10950049	4045192	1191107	1002864	188243	31463	4.2400
42	12513964	638233	243054	164128	78926	15486	6.1900

Table E5a. Ten Percent Duration Flow-Weighted Mean Concentration for Rural Subwatersheds

OBS	FWCOD10	FWTSS10	FWTN10	FWNN10	FWTKN10	FWTP10
1	40.17	63.895	7.002	5.016	1.9858	0.02731
2	20.14	20.400	3.984	3.062	0.9224	0.24238
3	47.12	81.529	3.856	0.971	2.8849	0.65263
4	15.91	23.992	2.279	1.904	0.3750	0.12830
5	48.96	13.426	4.063	2.418	1.6450	0.27985
6	36.45	15.712	4.937	4.710	0.2263	0.33285
7	44.53	77.309	6.067	4.895	1.1721	0.56983
8	31.85	142.744	20.476	17.012	3.4637	0.67390
9	23.80	20.749	3.818	3.056	0.7617	0.28952
10	29.77	12.269	2.575	1.403	1.1724	0.26100
11	36.94	59.072	4.465	3.055	1.4093	0.95211
12	26.68	12.837	3.036	1.084	1.9526	0.53152
13	54.03	102.077	5.901	3.403	2.4981	0.73478
14	20.31	20.614	1.577	0.616	0.9618	0.24522
15	50.64	64.327	3.432	0.491	2.9410	0.64360
16	77.88	19.851	6.967	4.095	2.8721	0.66600
17	56.71	31.683	7.077	2.380	4.6970	0.77024
18	101.19	70.130	11.827	7.161	4.6663	0.46844
19	63.54	56.930	14.172	11.124	3.0481	0.74028
20	13.04	36.408	6.262	4.944	1.3187	0.15983
21	23.91	28.432	5.605	4.297	1.3084	0.47613
22	11.76	6.643	5.784	5.184	0.6007	0.15601
23	7.70	19.420	5.661	4.556	1.1062	0.27430
24	26.63	14.795	1.870	0.601	1.2687	0.34244
25	154.59	31.939	12.434	7.848	4.5864	1.44464
26	18.53	70.748	1.536	0.590	0.9457	0.32185
27	84.34	12.275	3.124	1.906	1.2183	0.91092
28	9.35	3.910	1.207	0.787	0.4199	0.16693
29	61.32	99.571	6.784	0.716	6.0677	0.69137
30	1.77	44.325	0.973	0.065	0.9084	0.08582
31	14.48	26.502	1.116	0.338	0.7782	0.14111
32	7.57	5.969	0.720	0.177	0.5433	0.04425
33	309.16	136.596	35.180	13.212	21.9683	7.52063
34	47.89	48.074	5.962	4.641	1.3216	-0.59009
35	29.34	21.585	1.826	0.655	1.1704	0.31678
36	6.12	35.177	0.685	0.327	0.3575	0.23298
37	132.44	96.399	15.143	11.487	3.6562	0.30858
38	95.58	62.806	10.394	7.579	2.8151	0.79330
39	21.74	12.105	1.677	0.225	1.4515	0.42896
40	157.70	130.442	21.422	17.851	3.5802	1.02411
41	181.43	109.513	26.530	23.854	2.6863	0.80472
42	78.80	47.722	11.947	6.749	5.1968	0.79802

Table E5b. Fifty Percent Duration Flow-Weighted Mean Concentration for Rural Subwatersheds

OBS	FWCOD50	FWTKN50	FWTSS50	FWTN50	FWNN50	FWTP50
1	77.69	1.9463	102.78	14.057	12.111	0.40319
2	51.82	1.6197	59.69	7.215	5.595	0.30232
3	59.39	3.7888	140.97	5.174	1.385	0.70632
4	16.98	0.9626	38.51	2.227	1.265	0.19666
5	48.60	2.6459	16.57	3.535	0.889	0.46321
6	44.90	2.4885	53.50	4.301	1.812	0.55618
7	51.91	2.2093	111.26	6.030	3.820	0.56851
8	24.89	1.9666	101.27	13.114	11.148	0.45047
9	38.49	0.9279	41.73	5.404	4.476	0.24164
10	36.23	1.0726	11.99	2.787	1.714	0.30048
11	26.27	0.6323	28.37	2.114	1.482	0.25270
12	33.12	1.0548	8.96	1.938	0.883	0.32138
13	215.85	3.0584	165.96	6.611	3.553	0.95501
14	57.43	1.0724	39.50	1.401	0.329	0.26335
15	200.17	3.0254	130.40	5.994	2.969	0.66733
16	108.33	3.6201	23.30	8.017	4.397	0.80200
17	169.96	4.4029	30.89	7.192	2.789	0.65090
18	189.48	5.4570	91.94	15.108	9.651	1.09988
19	143.13	3.7003	67.05	14.767	11.067	0.75459
20	97.87	1.5716	33.79	5.863	4.291	0.61137
21	86.32	2.1068	32.23	5.593	3.486	0.55730
22	16.11	0.7539	7.97	6.833	6.080	0.20118
23	84.39	1.2412	16.09	6.468	5.220	0.30081
24	80.12	1.9563	21.52	8.134	6.147	0.39555
25	188.37	8.6604	134.89	13.417	4.736	2.00429
26	39.87	1.0735	60.41	1.863	0.789	0.47048
27	76.33	0.6506	57.22	1.691	1.041	0.52741
28	18.26	0.4642	4.29	1.207	0.743	0.17402
29	69.35	5.5714	131.12	8.539	2.967	1.00117
30	1.34	0.7761	50.73	1.189	0.413	0.09738
31	16.42	1.0754	29.90	1.351	0.276	0.20924
32	13.45	0.4537	6.46	0.679	0.225	0.11903
33	395.04	11.2554	75.73	20.636	9.381	3.58706
34	117.55	3.3681	79.33	14.147	10.779	0.73599
35	73.08	1.3780	32.41	2.048	0.670	0.33057
36	6.64	0.4001	37.14	0.713	0.313	0.10780
37	231.48	8.5497	107.93	25.848	17.299	1.70137
38	171.15	6.6509	76.51	16.380	9.529	1.52903
39	50.08	1.5279	12.79	1.773	0.245	0.51111
40	177.22	8.3711	134.04	23.432	15.082	1.64317
41	188.91	2.6698	145.24	28.588	25.910	0.83580
42	198.48	4.6573	106.49	14.359	9.654	0.89403

Table E5c. Ninety Percent Duration Flow-Weighted Mean Concentration for Rural Subwatersheds

OBS	FWCOD90	FWTSS90	FWTN90	FWNN90	FWTKN90	FWTP90
1	130.20	111.78	7.097	2.482	4.6157	1.1431
2	48.40	60.34	3.191	1.421	1.7704	0.7928
3	81.89	137.90	7.949	3.988	3.9607	1.4041
4	74.13	93.65	6.187	2.864	3.3227	1.3890
5	70.50	19.73	5.995	1.212	4.7828	1.2443
6	70.58	78.51	5.884	2.319	3.5646	0.9509
7	96.04	77.18	6.047	1.676	4.1715	1.1201
8	92.94	41.93	17.152	14.295	2.8577	0.1276
9	134.96	37.21	4.404	1.480	2.9238	1.1971
10	49.54	7.34	2.486	0.240	2.2459	1.3980
11	65.57	47.09	6.211	2.452	3.7589	1.0209
12	227.86	11.10	5.575	1.564	4.0118	1.6225
13	653.83	449.44	12.278	1.399	10.8795	2.4633
14	186.55	81.25	3.674	0.980	2.6943	0.9827
15	739.83	170.85	5.873	0.026	5.8465	1.0873
16	752.53	17.98	12.583	10.717	1.8664	1.3779
17	796.15	34.56	10.540	2.148	8.3929	1.0902
18	1059.91	122.42	30.736	23.318	7.4179	1.6171
19	130.96	52.00	25.715	20.463	5.2524	1.1232
20	77.44	28.46	6.774	3.449	3.3252	0.3599
21	151.52	27.17	7.941	3.629	4.3121	0.0761
22	34.51	6.81	11.994	10.450	1.5436	0.2568
23	650.67	24.01	11.958	8.252	3.7084	0.4081
24	54.04	18.55	15.371	13.347	2.0247	0.7573
25	306.05	66.40	6.820	0.954	5.8659	1.5032
26	147.44	58.80	2.659	0.154	2.5054	0.4111
27	176.58	55.64	5.596	3.921	1.6744	0.4880
28	184.74	4.86	3.161	1.784	1.3768	0.2706
29	179.64	164.96	25.037	4.255	20.7811	5.8227
30	4.45	75.10	2.957	0.220	2.7373	0.1678
31	42.84	36.26	6.386	2.776	3.6101	0.2758
32	37.62	11.08	2.081	0.501	1.5798	0.2884
33	446.47	35.61	18.130	1.335	16.7956	2.5020
34	97.73	65.93	6.453	2.116	4.3364	1.3479
35	74.41	19.51	2.847	0.184	2.6633	0.6121
36	70.77	53.59	4.120	0.700	3.4198	0.3258
37	255.26	88.74	18.548	8.759	9.7891	3.6970
38	630.47	75.70	15.320	6.707	8.6127	3.1258
39	71.22	10.61	2.905	0.808	2.0969	0.8137
40	301.43	106.21	24.614	9.859	14.7512	2.5279
41	667.36	246.42	72.557	61.132	11.4738	1.9180
42	1033.33	69.18	20.063	13.539	6.5149	1.2773

Table E6a. Ten Percent Duration Load for Urban Subwatersheds

OBS	COD10	TSS10	TN10	NN10	TKN10	TP10	IN10	CL10	PB10
1	1880010	1609286	102915	31444.4	71470.6	12823.2	5.09248	4891882	478.50
2	711565	558918	59167	25806.1	33361.3	4799.4	5.06073	2 6300	1513.24
3	146579	84086	4080	2820.8	1263.0	1366.3	1.14424	133964	42.00
4	601662	102833	23619	12583.4	11035.6	252.4	5.09000	89868	381.00
5	67374	230063	10545	510.8	10034.6	1380.1	3.62075	225207	146.00
6	654500	615630	35079	3133.2	31945.7	5194.1	3.34000	1891929	871.84
7	368987	462808	19328	936.7	18391.3	3163.3	3.51674	858634	174.00
8	767397	522979	32303	5948.2	26354.3	4561.4	3.68000	785773	828.06
9	706415	866836	36010	3216.4	32793.6	6110.4	3.75182	1602528	155.00
10	1560000	1443680	76240	19680.0	56560.0	11520.0	5.17000	3778400	1960.00
11	831128	109233	22171	18169.3	4001.7	3082.0	2.31000	994510	307.00
12	650718	714391	38245	5836.6	32408.4	5874.4	3.70000	451606	887.00
13	851780	1509540	36899	11828.3	25070.5	3677.4	4.79387	459843	185.00
14	2104176	3116445	102625	45980.0	56645.0	14651.0	5.33000	997557	239.00
15	1086177	522805	65991	41782.7	24208.0	7666.0	5.35000	408119	681.00
16	511151	36951	23828	15305.9	8522.2	91.6	6.60000	61124	739.26
17	484587	157459	43017	27632.0	15385.0	8605.0	5.54846	1014535	267.00
18	102752	0	0	0.0	0.0	0.0	0.00000	0	0.00
19	304848	155656	9291	3443.1	5848.0	1822.0	2.86000	278418	94.00
20	96446	148636	19034	6839.3	12195.0	3312.5	2.66000	539124	418.00
21	199973	223843	9863	880.2	8982.8	1728.1	2.18000	115233	218.00
22	187016	111783	10466	934.0	9532.0	496.0	1.57000	135711	169.00
23	976019	981850	50483	6673.0	56144.0	8459.0	2.25000	2089400	1011.00
24	83564	168158	8755	61.9	8693.1	1267.3	2.35909	75862	139.54
25	662523	593780	32810	4970.0	27841.0	5295.0	2.17000	2910500	831.00
26	161991	440439	19777	2419.3	17357.5	3538.3	4.06463	1124411	801.00
27	58618	171584	7010	857.0	6153.0	866.0	3.44000	269209	114.00
28	165052	123397	7498	1398.0	6100.5	1131.9	3.24000	319635	245.00
29	170310	373096	18176	1182.9	16993.3	3261.9	2.35000	1261198	458.11
30	97895	76099	4570	826.8	3743.7	696.0	3.33000	428483	147.49
31	60910	82931	4418	397.1	4021.1	752.0	2.67000	362550	149.31
[illegible]	37236	42345	2315	290.7	2024.5	380.8	3.45000	181471	70.65
3.	15378	15769	881	124.0	757.4	142.2	3.90000	50006	26.99
34	79552	49936	3153	754.5	2398.6	450.3	5.17800	179357	85.48
35	65598	398951	23667	5660.3	18006.7	3127.9	1.94611	1418542	46.01
36	333188	57921	3367	503.7	2863.5	531.3	3.37000	233828	115.00
37	58436	67914	3636	529.7	3106.3	595.2	3.31000	185302	85.93
38	60014	81611	3395	495.0	2900.0	623.2	3.15000	191395	58.00
39	499012	316934	11998	1037.9	10960.0	2313.0	2.37000	780336	59.00
40	267663	136017	5285	1983.8	3301.0	1130.0	3.29000	487414	32.00
41	1212663	1068207	58686	10951.9	47734.0	8211.8	4.47074	1923185	138.35
42	1019575	895716	33125	655.0	32470.0	11989.5	2.45000	2596933	145.00
43	311671	312435	14457	285.6	14171.1	2725.0	2.17000	811021	372.07
44	76467	66769	3015	11.7	3003.6	579.6	2.93000	195661	74.67
45	23787	44991	2275	123.9	2151.0	404.6	2.91000	168699	75.06
46	2445	5037	256	6.7	249.0	46.2	1.78600	24103	10.00
47	200386	267416	11638	634.0	11004.0	2208.0	2.77000	722247	99.40
48	33420	45659	2445	199.3	2246.2	417.6	2.93000	143101	88.50
49	18392	16256	669	9.0	680.5	135.5	3.45000	26484	8.30
50	129490	59088	5124	66.6	5057.4	1149.0	3.13000	281934	48.00
51	49035	91084	3136	255.4	2880.6	656.2	2.89800	142168	20.00
52	266190	230098	10138	825.0	9313.0	1882.7	3.68000	340675	231.00
53	31721	36220	1734	240.4	1494.0	277.2	2.42000	85431	60.00
54	6893	10399	393	51.2	341.8	78.2	2.48000	17151	2.00
55	70414	78988	3447	81.2	3366.3	665.0	2.96000	198383	51.94
56	12565	12592	715	92.5	622.5	115.5	2.57000	34064	25.00
57	16719	25183	1331	86.40	1245	231.0	2.380	68280	50.00
58	105371	141142	9424	4396.78	5027	1079.1	3.000	210282	90.00
59	72627	29738	1316	614.07	702	298.0	3.560	101657	6.00
60	121361	214551	10041	1820.01	8221	1704.3	4.670	392577	116.00
61	167741	144241	8755	2916.90	5838	1180.2	6.194	190411	34.65
62	71759	132137	4136	266.96	3869	917.7	3.170	198714	9.00
63	31189	34509	1494	270.64	1223	263.2	2.560	38328	8.00
64	2410223	778494	14847	297.98	14549	702.0	2.540	390675	278.00
65	2866299	1349737	476324	9560.00	466764	11667.0	2.900	3614522	415.00

Table E6b. Fifty Percent Duration Load for Urban Subwatersheds

OBS	COD50	TSS50	TN50	NN50	TKN50	TP50	IN50	CL50	PB50
1	2764721	3697604	197966	34317.4	126537	35128.3	7.74310	4928633	2786.32
2	1094715	2127563	139146	15486.4	70151	27603.0	6.97888	308908	1619.30
3	187923	148874	14398	117.1	3500	3111.7	3.27524	171749	67.00
4	884797	365246	42277	1891.7	29938	6196.5	6.13070	112336	502.08
5	415100	281434	21650	2680.0	15944	3004.6	3.80500	285072	205.18
6	1124849	1662877	85204	15347.9	59135	14513.9	4.12404	2280260	1514.19
7	625402	611807	33597	5925.2	24519	4908.2	3.92990	1060043	232.04
8	930166	1272791	71796	9164.3	44257	13243.4	4.43166	946715	1095.81
9	1077281	1417697	71341	11348.3	44821	11990.1	4.81198	2136777	227.99
10	2255880	3458000	231920	124520.0	107400	23040.0	7.44000	4543520	2792.00
11	1204533	247535	41832	0.0	20869	5928.7	3.61450	1407505	490.00
12	914876	1598394	103936	16044.3	55166	20313.4	4.35752	571653	1504.38
13	1120763	831895	59987	5643.2	37660	9710.7	6.73942	656411	306.79
14	2697662	2219912	155493	24077.8	85093	27577.5	6.89158	1385496	385.39
15	1277855	746865	67348	16166.0	41032	11111.8	6.27142	536999	801.95
16	594361	405370	32487	1975.8	24231	4740.8	7.76520	81499	484.85
17	654847	258129	58091	0.0	24422	11474.5	5.90360	1470340	330.99
18	142711	0	0	0.0	0	0.0	3.84860	0	0.00
19	429363	216189	17408	3658.3	8476	2893.2	3.81654	356946	126.00
20	374204	215414	26448	4337.9	16261	4581.2	3.52502	691185	603.88
21	285675	381275	20435	4163.2	13663	3500.5	3.10430	527528	307.95
22	256186	155254	11143	0.0	12881	716.3	2.59780	178568	233.86
23	1215222	1208040	106290	50145.0	56144	14625.0	3.75000	2697685	2490.00
24	313716	375168	24887	2299.8	14447	4466.6	3.33510	103920	178.33
25	824882	1841569	84196	28644.0	62474	10590.0	3.77000	3769270	3580.00
26	728012	1039070	47210	10989.8	31982	8302.6	4.91030	1874019	1014.50
27	84954	281286	10191	2737.5	7503	1701.2	4.10750	507941	155.76
28	221265	364071	17071	4080.5	13136	2870.4	4.56866	591918	442.64
29	568760	1071019	47006	11900.6	35966	7861.4	3.52882	1854703	1125.37
30	104334	282359	11373	3060.7	8808	1903.7	4.32346	498237	281.62
31	139612	271587	12101	3248.3	9351	2025.5	3.71514	489932	321.29
32	58509	148416	6036	1615.9	4654	1010.2	3.81928	263002	147.26
33	32534	42395	2209	576.0	1705	369.6	4.73770	76933	63.20
34	90863	147961	7001	1827.3	5405	1171.4	5.74802	263761	189.02
35	640746	1054759	42406	9032.3	33186	6536.3	4.16462	2086092	532.33
36	105334	187451	8705	2338.6	6747	1457.0	4.43724	338882	240.06
37	104977	190831	8484	2110.1	6498	1418.6	4.40136	325091	202.82
38	115374	140862	7209	1941.7	5185	1206.7	4.54478	277375	139.88
39	818053	511184	28868	6287.4	13701	4819.1	3.49418	1130922	147.00
40	456608	256636	14390	3654.4	4784	2406.8	3.83636	706397	65.00
41	1513018	2213427	118311	17938.3	74971	20594.2	5.56262	2530507	1215.33
42	1654509	1690030	60472	20240.9	47752	13286,2	3.58352	3657652	374.00
43	519453	750429	36051	8214.7	27587	6021.3	3.12498	1192678	850.22
44	131840	155317	8362	2160.6	6397	1402.2	3.71160	283567	229.41
45	82232	136823	6471	1749.0	4989	1083.3	3.65576	251790	177.56
46	5923	20889	751	199.9	582	125.6	2.13026	35977	16.77
47	435625	591996	29530	7721.6	22116	4940.8	3.64260	1094314	702.32
48	78308	130412	5948	1353.5	4622	993.4	3.18856	204431	148.32
49	28738	33893	1799	456.8	1352	300.8	4.08040	61593	44.58
50	187668	221077	11017	2864.6	7551	1843.3	3.86598	433745	134.51
51	75436	166193	6477	1752.0	4444	1084.2	2.97592	315929	54.40
52	397298	437704	23769	5936.7	17722	3974.6	3.99672	792269	564.10
53	55624	96695	4508	1199.5	3492	753.8	4.28870	174351	124.60
54	9991	17783	736	193.0	503	123.5	3.24420	33632	6.02
55	103050	235372	9384	2499.0	7084	1570.5	3.25704	431269	207.16
56	23575	40542	1900	512.7	1473	318.1	4.25036	74055	53.15
57	40540	88453	3800	1025.4	2945.2	636.1	3.25928	158792	100.13
58	154958	293923	12500	3361.1	8997.4	2092.3	3.94678	551414	201.18
59	105257	60690	3395	908.9	1152.2	568.2	4.99842	171898	15.00
60	217859	512819	19617	4717.3	14395.7	3278.6	5.47786	872395	296.30
61	243103	251970	13773	3100.3	10256.7	2300.1	8.66558	413938	302.55
62	113903	190066	7948	2135.3	5217.1	1330.3	3.61072	374933	34.62
63	45168	57213	2404	469.4	1703.8	400.8	3.38820	95849	30.44
64	3544446	1197684	38415	0.0	23851.5	1413.1	2.95110	930180	1071.00
65	4154057	1901031	126919	25453.8	67774.8	18520.5	3.87232	5293866	989.00

Table E6c. Ninety Percent Duration Load for Urban Subwatersheds.

OBS	COD90	SS90	TN90	NN90	TKN90	TP90	IN90	CL90	PB90
1	3062320	4226647	221722	76513.2	145209	38289.0	13.700	5188005	3804.2
2	1079160	2341620	161409	79391.2	82018	29535.0	13.000	466360	2554.4
3	270609	163852	15693	11620.0	4073	3391.0	6.790	215380	315.0
4	964429	648924	48196	10714.1	37482	8964.2	12.070	1752657	793.9
5	468791	313204	25114	6367.4	18747	3304.0	6.468	358858	584.0
6	1522737	1030181	92019	23185.9	68833	15528.0	5.921	2445007	4560.0
7	853403	687629	37313	8729.4	28584	5399.1	8.920	987801	726.0
8	1339439	1305560	76330	26012.8	50321	14170.0	8.820	2067783	2803.0
9	1328640	1082149	76350	24774.8	51559	13309.0	7.790	3083451	1050.0
10	2413680	4382200	287440	154320.0	133120	25560.0	10.330	6539200	11200.0
11	1722482	516911	45179	15409.4	29770	6521.0	5.320	2031084	1318.0
12	1317421	1667493	114329	52252.3	62077	29047.0	5.052	824917	4452.0
13	1221632	1050114	65384	20363.7	45020	12180.0	15.090	947226	1231.6
14	3884633	2770106	163268	76768.2	86500	35299.0	13.860	1999324	1112.0
15	1940062	1241736	74083	32373.0	41710	11620.3	9.952	774910	2883.0
16	648330	491906	34456	3822.2	30614	5946.5	16.670	1042589	1442.0
17	713783	270285	63899	33972.7	29926	14916.0	12.290	2121757	874.0
18	205504	0	0	0.0	0	0.0	8.340	0	0.0
19	579640	311603	18799	9587.0	9212	3124.0	8.630	515087	435.0
20	538854	330414	28627	12056.4	16771	4993.0	4.500	940012	2110.0
21	433717	393980	22069	6756.5	15312	4655.0	7.660	230535	927.0
22	639229	162565	25515	7811.6	17703	1998.3	4.165	221424	687.0
23	1753175	1674216	131430	62008.0	69422	16075.0	5.970	3400000	7414.0
24	453241	592228	26877	9707.4	17170	4913.0	7.720	139253	868.4
25	1598422	2457960	110952	28644.0	82308	4970.0	9.120	4732990	10741.0
26	829616	1087402	49097	13714.8	35382	9633.0	11.000	2417484	2484.0
27	233094	342321	11297	2976.8	8320	2007.0	8.115	654228	366.0
28	341175	423631	17162	2426.2	14736	3415.0	9.780	775412	1162.0
29	984495	1190090	49499	9265.9	40233	9119.0	5.692	2351763	2990.0
30	247005	292001	11607	1678.7	9928	2179.0	6.568	667637	753.0
31	262411	310509	12782	2250.8	10531	2409.0	8.035	636862	719.0
32	130675	154776	6269	1032.6	5236	1202.0	6.899	336348	419.0
33	47080	56304	2333	416.1	1917	439.0	8.261	104629	138.0
34	149298	178487	7395	1319.6	6075	1276.0	7:330	340251	523.0
35	1267593	1060767	48758	9989.0	38769	7059.0	6.769	2753641	1271.0
36	188862	223408	8987	1381.2	7606	1588.0	8.108	437154	696.0
37	175858	213360	8961	1696.4	7265	1560.0	4.825	435622	341.0
38	156646	185123	7613	1921.9	5691	1352.0	9.940	363361	364.0
39	876424	708039	30492	16588.0	13904	5301.0	7.450	1493948	564.0
40	790368	364580	15064	10210.0	4854	2648.0	8.180	918316	114.8
41	1696027	2372800	124967	38277.5	86690	22653.0	11.540	3177944	2367.6
42	1799185	2056742	87221	38762.1	48459	14349.0	8.160	4608641	740.0
43	710762	892324	38079	7385.7	30693	6443.0	6.650	1574335	1436.0
44	177425	215079	8654	1697.1	7157	1570.0	8.572	379979	460.0
45	140909	166515	6635	1219.1	5616	1223.0	9.194	322291	352.0
46	13782	25390	778	122.6	656	132.0	4.706	46770	22.0
47	630392	753120	31190	6594.0	24596	5484.0	9.415	1389779	1411.0
48	117175	147177	6262	1111.5	5170	1112.0	7.250	257583	207.7
49	57742	45573	1699	395.5	1504	333.0	8.400	79455	73.0
50	230408	280624	11637	3523.2	8114	2009.0	8.030	559531	269.0
51	141097	174503	6973	2182.2	4790	1192.0	6.150	417026	102.0
52	493897	599960	23950	4324.0	19626	4411.0	8.210	1053771	1128.0
53	97211	115363	4756	823.2	3935	813.0	7.970	226670	232.0
54	15760	17628	751	211.9	539	137.0	6.870	42737	10.0
55	202523	240340	10051	2142.5	7909	1743.0	9.407	539086	405.0
56	41333	48817	2008	347.6	1661	350.0	8.741	100713	107.0
57	82667	97633	4092	771.1	3321.0	700.0	7.733	208017	162
58	271341	320872	12993	3115.8	9876.9	2301.0	10.903	727866	371
59	235083	87061	3597	2428.2	1169.0	615.0	11.840	230343	25
60	398766	625639	20485	4669.8	15815.2	3671.0	9.990	1081769	497
61	269695	340059	14548	3256.7	11291.3	2645.0	16.370	459431	510
62	172439	203981	8435	2918.3	5517.1	1662.0	7.440	472415	67
63	69676	69799	2466	639.6	1826.9	406.5	4.946	125562	49
64	3863446	1254086	51282	22158.2	29123.8	20075.0	6.490	1209234	2688
65	4527922	3246735	141479	72700.5	68779.0	1554.0	8.000	6723210	1967

Table E7a. Ten Percent Duration Flow-Weighted Mean Concentration for Urban Subwatersheds

OBS	FWCOD10	FWTSS10	FWTN10	FWNN10	FWTKN10	FWTP10	FWPB10	FWCL10
1	43.900	37.578	2.40315	0.73425	1.66889	0.29943	0.011173	114.229
2	24.551	19.284	2.04141	0.89037	1.15104	0.16559	0.052210	8.843
3	215.491	123.618	6.00372	4.14695	1.85678	2.00862	0.061746	196.945
4	26.642	4.554	1.04588	0.55721	0.48867	0.01117	0.016871	3.979
5	7.874	26.886	1.23236	0.05970	1.17267	0.16128	0.017062	26.318
6	46.444	43.686	2.48923	0.22234	2.26690	0.36858	0.061866	134.253
7	39.981	50.147	2.09424	0.10149	1.99275	0.34275	0.018853	93.035
8	63.639	43.370	2.67879	0.49328	2.18551	0.37827	0.068670	65.163
9	58.760	60.360	2.50747	0.22397	2.28351	0.42548	0.010793	111.588
10	52.000	48.000	2.54000	0.66000	1.89000	0.38000	0.060000	126.000
11	73.854	9.706	1.97012	1.61453	0.35559	0.27387	0.027280	88.372
12	42.710	46.889	2.51023	0.38309	2.12714	0.38557	0.058219	29.641
13	38.658	68.511	1.67466	0.53683	1.13783	0.16690	0.008396	20.870
14	40.518	60.010	1.97613	0.88538	1.09075	0.28212	0.004602	19.209
15	37.743	18.166	2.29305	1.45187	0.84118	0.26638	0.023663	14.181
16	24.061	1.739	1.12163	0.72048	0.40116	0.00431	0.034798	2.877
17	17.161	5.576	1.52342	0.97857	0.54485	0.30474	0.009456	35.929
18	.	.	.	.	.	.	.	.
19	95.474	48.749	2.90985	1.07833	1.83151	0.57062	0.029439	87.197
20	15.156	23.357	2.99110	1.07475	1.91635	0.52053	0.065686	84.719
21	91.691	102.635	4.52233	0.40360	4.11873	0.79236	0.099956	52.836
22	57.053	31.191	3.19284	0.28493	2.90791	0.15131	0.051557	41.401
23	88.000	89.000	4.59000	0.61000	3.98000	0.77000	0.099990	190.000
24	24.677	49.659	2.58544	0.01828	2.56716	0.37424	0.041208	22.403
25	97.000	87.000	4.81000	0.73000	4.08000	0.78000	0.120000	426.000
26	22.347	60.760	2.72828	0.33376	2.39453	0.48812	0.110501	155.116
27	43.528	127.413	5.20541	0.63638	4.56903	0.64306	0.084653	199.906
28	71.703	53.607	3.25755	0.60732	2.65023	0.49173	0.106435	138.858
29	38.156	83.587	4.07215	0.26502	3.80713	0.73079	0.102633	282.555
30	67.585	52.538	3.15542	0.57081	2.58461	0.48051	0.101829	295.820
31	49.168	66.944	3.56654	0.32057	3.24597	0.60704	0.120529	292.662
32	46.524	52.908	2.89273	0.36324	2.52949	0.47579	0.088271	226.739
33	45.325	46.479	2.59804	0.36554	2.23250	0.41912	0.079563	147.389
34	55.769	55.007	2.21042	0.52893	1.68149	0.31568	0.059926	125.737
35	16.372	59.569	5.90671	1.41269	4.49403	0.78065	0.011482	354.034
36	296.477	51.539	2.99620	0.44820	2.54799	0.47276	0.102329	208.064
37	50.734	58.963	3.15677	0.45987	2.69691	0.51675	0.074606	160.879
38	69.159	94.047	3.91232	0.57046	3.34186	0.71816	0.066838	220.559
39	161.354	102.479	3.87948	0.33560	3.54388	0.74790	0.019077	252.319
40	150.760	71.285	2.76969	1.03968	1.73001	0.59222	0.016771	255.447
41	43.612	38.593	2.12024	0.39568	1.72456	0.29668	0.004998	69.482
42	125.886	110.593	4.08991	0.08087	4.00904	1.48034	0.017903	320.641
43	90.880	91.103	4.21542	0.08327	4.13215	0.79458	0.108492	236.486
44	78.260	68.335	3.08599	0.01200	3.07398	0.59319	0.076420	200.248
45	33.163	62.726	3.17166	0.17278	2.99888	0.56408	0.104652	235.196
46	47.205	97.249	4.93794	0.13014	4.80781	0.89205	0.193085	465.392
47	62.367	83.229	3.62216	0.19732	3.42484	0.68721	0.030937	224.789
48	43.704	59.710	3.19803	0.26058	2.93745	0.54611	0.115730	187.138
49	73.536	64.994	2.75679	0.03598	2.72081	0.54176	0.033185	105.890
50	95.111	116.851	3.76359	0.04892	3.71467	0.84394	0.035256	207.081
51	68.646	127.513	4.39023	0.35748	4.03276	0.91865	0.027999	199.028
52	74.461	64.365	2.83589	0.23078	2.60511	0.52664	0.064617	95.296
53	75.337	71.771	4.11909	0.57085	3.54924	0.69835	0.142500	202.898
54	95.849	151.553	5.46474	0.71195	4.75280	1.08739	0.027810	238.488
55	65.628	73.618	3.21315	0.07573	3.13743	0.61980	0.048407	184.898
56	67.437	67.582	3.83762	0.49648	3.34114	0.61992	0.134162	182.832
57	48.450	72.978	3.8583	0.25038	3.6079	0.669413	0.144895	197.868
58	73.408	98.328	6.5654	3.06308	3.5023	0.751771	0.062700	146.496
59	156.338	64.014	2.8330	1.32186	1.5111	0.641479	0.012916	219.259
60	31.429	55.590	2.6015	0.47156	2.1299	0.441584	0.030056	101.717
61	48.471	38.241	2.3211	0.77332	1.5478	0.312892	0.009186	50.481
62	74.346	136.900	4.2851	0.27658	4.0085	0.950782	0.009324	205.877
63	105.034	116.216	5.0313	0.91143	4.1199	0.886370	0.026941	129.076
64	100.223	32.372	0.6174	0.01239	0.6050	0.029191	0.011560	16.245
65	113.049	53.234	18.7865	0.37705	18.4095	0.460154	0.016368	150.447

Table E7b. Fifty Percent Duration Flow-Weighted Mean Concentration for Urban Subwatersheds

OBS	FWCOD50	FWTKN50	FWTSS50	FWTN50	FWNN50	FWTP50	FWCL50	FWPB50
1	42.459	1.94328	56.785	3.0402	0.52702	0.53948	75.691	0.042790
2	27.389	1.75514	53.230	3.4813	0.38746	0.69061	7.729	0.040514
3	96.519	1.79755	76.463	7.3947	0.06014	1.59821	88.212	0.034412
4	32.529	1.10067	13.428	1.5543	0.06955	0.22781	4.130	0.018459
5	46.160	1.77306	31.296	2.4076	0.29803	0.33412	31.701	0.022817
6	64.645	3.39849	95.566	4.8967	0.88205	0.83412	131.047	0.087021
7	60.640	2.37743	59.322	3.2576	0.57452	0.47590	102.783	0.022499
8	64.054	3.04767	87.648	4.9440	0.63108	0.91197	65.193	0.075460
9	58.487	2.43339	76.969	3.8732	0.61612	0.65096	116.009	0.012378
10	52.000	2.49000	80.000	5.3700	2.89000	0.53000	105.000	0.060000
11	68.405	1.18515	14.057	2.3756	0.00000	0.33669	79.932	0.027827
12	50.987	3.07448	69.081	5.7925	0.89417	1.13210	31.859	0.083841
13	36.182	1.21579	26.856	1.9366	0.18218	0.31349	21.191	0.009904
14	40.175	1.26725	33.060	2.3157	0.35858	0.41070	20.634	0.005739
15	37.879	1.21630	22.139	1.9964	0.47920	0.32939	15.918	0.023772
16	23.780	0.96946	16.218	1.2998	0.07905	0.18967	3.261	0.019398
17	21.796	0.81286	8.592	1.9335	0.00000	0.38192	48.939	0.011017
18	69.121	0.00000	0.000	0.0000	0.00000	0.00000	0.000	0.000000
19	100.768	1.98936	50.738	4.0854	0.85857	0.67901	83.772	0.029571
20	44.373	1.92829	25.544	3.1362	0.51438	0.54324	81.961	0.071609
21	91.985	4.39942	122.768	6.5799	1.34052	1.12714	169.860	0.099157
22	47.233	2.37489	28.624	2.0544	0.00000	0.13206	32.923	0.043116
23	66.000	3.06000	66.000	5.8000	2.74000	0.80000	147.000	0.140000
24	65.532	3.01783	78.368	5.1985	0.48040	0.93302	21.708	0.037251
25	70.000	5.27000	155.000	7.1000	1.83000	0.89000	318.000	0.300000
26	83.135	3.65220	118.656	5.3911	1.25498	0.94812	214.003	0.115851
27	52.833	4.66624	174.930	6.3380	1.70242	1.05795	315.886	0.096868
28	68.169	4.04713	112.166	5.2593	1.25716	0.88433	182.362	0.136371
29	84.857	5.36596	159.792	7.0131	1.77552	1.17290	276.715	0.167901
30	55.479	4.68354	150.144	6.0476	1.62753	1.01228	264.937	0.149754
31	80.995	5.42515	157.559	7.0205	1.88445	1.17508	284.230	0.186393
32	66.036	5.25262	167.509	6.8122	1.82375	1.14017	296.835	0.166200
33	78.936	4.13793	102.862	5.3599	1.39759	0.89677	186.662	0.153345
34	57.382	3.41344	93.441	4.4215	1.15400	0.73978	166.570	0.119370
35	74.728	3.87035	123.012	4.9456	1.05340	0.76230	243.292	0.062083
36	71.185	4.55950	126.679	5.8829	1.58045	0.98467	229.016	0.162236
37	68.542	4.24275	128.597	5.5397	1.37772	0.92626	212.259	0.132423
38	92.151	4.14145	112.509	5.7579	1.55089	0.96379	221.544	0.111721
39	179.412	3.00487	112.111	6.3313	1.37893	1.05690	248.030	0.032240
40	205.221	2.15023	115.344	6.4677	1.64246	1.08173	317.489	0.029214
41	43.934	2.17693	64.271	3.4354	0.52087	0.59799	73.478	0.035289
42	139.664	4.03092	142.662	6.7930	1.70862	1.12154	308.757	0.031571
43	105.186	5.58582	151.948	7.2997	1.66332	1.21920	241.495	0.172154
44	106.516	5.16850	125.484	6.7721	1.74561	1.13287	229.100	0.185343
45	91.259	5.53655	151.842	7.1816	1.94102	1.20216	279.428	0.197048
46	81.317	9.42044	338.148	12.1527	3.23633	2.03388	582.395	0.271436
47	103.103	5.23437	160.112	6.9890	1.82753	1.16938	259.000	0.166224
48	94.097	5.55421	156.715	7.1474	1.62643	1.19374	245.663	0.178239
49	97.152	4.57151	114.575	6.0809	1.54423	1.01704	208.218	0.150705
50	111.601	4.49052	131.469	6.5518	1.70352	1.09614	257.936	0.079988
51	102.642	6.05908	226.569	8.8295	2.38842	1.47802	430.704	0.074168
52	102.329	4.56464	112.736	6.1221	1.52907	1.02370	204.058	0.145290
53	74.812	4.67947	129.586	6.0364	1.60753	1.01026	233.656	0.166977
54	106.199	5.34419	189.027	7.8473	2.05196	1.31298	357.495	0.063991
55	87.266	6.00011	199.366	7.9485	2.11671	1.33025	365.295	0.175472
56	76.509	4.77912	151.573	6.1666	1.66390	1.03227	240.334	0.172504
57	85.786	6.23235	187.177	8.04205	2.16985	1.34616	336.020	0.211894
58	82.057	4.76451	155.645	6.61937	1.77986	1.10796	291.998	0.106534
59	161.374	1.76652	93.047	5.20517	1.39352	0.87120	263.544	0.022997
60	48.123	3.17984	113.276	4.33320	1.04200	0.72421	192.702	0.065450
61	46.068	1.94366	47.749	2.61006	0.58751	0.43587	78.442	0.057333
62	103.605	4.74540	172.863	7.22950	1.94223	1.21007	341.036	0.031494
63	114.980	4.33531	145.578	6.11654	1.19448	1.01983	243.886	0.077456
64	126.856	0.85364	42.865	1.37486	0.00000	0.05057	33.291	0.038331
65	122.700	2.00168	56.151	3.74885	0.75184	0.54705	156.366	0.029212

Table E7c. Ninety Percent Duration Flow-Weighted Mean Concentration for Urban Subwatersheds

OBS	FWCOD90	FWTSS90	FWTN90	FWNN90	FWTKN90	FWTP90	FWPB90	FWCL90
1	26.580	36.687	1.92451	0.66412	1.26039	0.33234	0.033020	45.031
2	14.495	31.451	2.16793	1.06633	1.10161	0.39669	0.034309	6.264
3	67.042	40.594	3.88787	2.87880	1.00907	0.84010	0.078040	53.359
4	18.009	12.118	0.90000	0.20007	0.69993	0.16739	0.014825	32.729
5	30.668	20.489	1.64292	0.41654	1.22638	0.21614	0.038204	23.476
6	60.953	73.260	3.68340	0.92810	2.75530	0.62156	0.182531	97.870
7	36.456	29.374	1.59395	0.37291	1.22104	0.23064	0.031014	42.197
8	46.345	45.174	2.64119	0.90006	1.74114	0.49029	0.096985	71.546
9	44.565	49.706	2.55997	0.83086	1.72911	0.44634	0.035214	103.408
10	40.000	73.000	4.80000	2.58000	2.22000	0.43000	0.190000	109.000
11	66.460	19.945	1.74319	0.59456	1.14863	0.25161	0.050854	78.367
12	63.329	81.118	5.49583	2.51179	2.98405	1.39630	0.214009	39.654
13	17.614	15.141	0.94272	0.29361	0.64911	0.17561	0.017758	13.657
14	28.766	20.513	1.20900	0.56847	0.64053	0.26139	0.008234	14.805
15	36.240	23.196	1.38386	0.60472	0.77914	0.21707	0.053854	14.475
16	12.063	9.168	0.64178	0.07123	0.57054	0.11082	0.026874	19.430
17	11.412	4.321	1.02163	0.54316	0.47847	0.23848	0.013974	33.923
18	45.932	0.000	0.00000	0.00000	0.00000	0.00000	0.000000	0.000
19	60.161	32.341	1.95116	0.99504	0.95612	0.32424	0.045149	53.461
20	50.053	30.692	2.67770	1.11990	1.55780	0.46379	0.195995	87.316
21	56.596	51.411	2.07981	0.08167	1.99814	0.60744	0.120965	30.083
22	73.509	18.694	2.93411	0.89830	2.03581	0.22979	0.079002	25.463
23	60.000	57.000	4.50000	2.13000	2.38000	0.55000	0.250000	116.000
24	40.901	55.395	2.42542	0.87601	1.54941	0.44336	0.078366	12.566
25	56.000	86.000	3.87000	1.00000	2.87000	0.41000	0.370000	165.000
26	42.290	55.431	2.50274	0.69912	1.80362	0.49105	0.126623	123.232
27	73.373	107.756	3.55610	0.93704	2.61907	0.63176	0.115209	205.938
28	49.102	60.969	2.47004	0.34918	2.12086	0.49149	0.167236	111.598
29	91.062	110.079	4.57842	0.85706	3.72136	0.84347	0.276563	217.529
30	66.459	102.209	4.06267	0.58761	3.47506	0.76271	0.263572	233.693
31	70.389	63.291	3.42864	0.60375	2.82489	0.64619	0.192864	170.832
32	81.648	96.706	3.91691	0.64517	3.27174	0.75103	0.261798	210.156
33	65.511	78.346	3.24631	0.57902	2.66729	0.61086	0.192023	145.589
34	73.936	88.391	3.66218	0.65348	3.00670	0.63191	0.259002	168.500
35	90.955	76.114	3.49857	0.71675	2.78182	0.50651	0.091199	197.585
36	69.849	82.626	3.32389	0.51083	2.81306	0.58731	0.257411	161.678
37	104.748	127.433	5.33712	1.01039	4.32673	0.92913	0.203098	259.454
38	57.206	67.605	2.78019	0.70187	2.07832	0.49374	0.140233	132.696
39	90.152	72.831	3.13651	1.70630	1.43021	0.54528	0.058015	153.672
40	166.600	76.850	3.17531	2.15214	1.02316	0.55817	0.024207	193.570
41	23.739	33.211	1.74912	0.53576	1.21337	0.31707	0.033139	44.481
42	66.698	76.245	3.23337	1.43695	1.79643	0.53193	0.027433	170.847
43	67.629	84.905	3.62323	0.70275	2.92048	0.61305	0.136636	149.799
44	62.068	74.540	3.09734	0.59368	2.50366	0.54922	0.160919	132.926
45	62.179	73.390	3.01609	0.53793	2.47816	0.53967	0.155327	142.218
46	100.993	186.054	5.70398	0.89837	4.80561	0.96728	0.161213	342.724
47	57.724	68.962	2.85604	0.60381	2.25223	0.50216	0.129204	127.261
48	61.927	77.763	3.32006	0.58743	2.73263	0.58770	0.109760	136.134
49	61.978	74.837	3.11842	0.64947	2.46895	0.54683	0.119876	130.476
50	67.111	80.343	3.33168	1.00869	2.32299	0.57518	0.077015	160.194
51	93.079	115.117	4.59975	1.43958	3.16016	0.78634	0.067288	275.105
52	61.927	75.228	3.00289	0.54216	2.46073	0.55307	0.141433	132.126
53	70.103	83.193	3.43118	0.59364	2.83754	0.58629	0.167304	163.461
54	79.108	94.510	3.76914	1.06356	2.70558	0.68769	0.050196	214.524
55	59.394	70.485	2.94772	0.62832	2.31940	0.51117	0.118774	156.098
56	65.227	77.036	3.16886	0.54847	2.62039	0.55233	0.168854	158.933
57	73.729	87.078	3.64968	0.68772	2.96196	0.624322	0.144486	185.528
58	52.013	61.508	2.49057	0.59727	1.89330	0.441078	0.071117	139.524
59	152.155	56.349	2.32824	1.57161	0.75662	0.398052	0.016181	149.087
60	48.299	75.778	2.48117	0.56561	1.91555	0.444634	0.060197	131.025
61	27.054	34.113	1.45937	0.32669	1.13267	0.265330	0.051160	46.087
62	76.121	90.045	3.72368	1.28823	2.43545	0.733665	0.029576	208.540
63	121.450	121.665	4.29922	1.11484	3.18438	0.708523	0.085410	218.863
64	62.875	20.409	0.83458	0.36061	0.47397	0.326706	0.043745	19.679
65	64.737	46.419	2.02276	1.03941	0.98335	0.022218	0.028409	96.123

Figure E-1. FLOW-WEIGHTED MEAN CONCENTRATION, TP

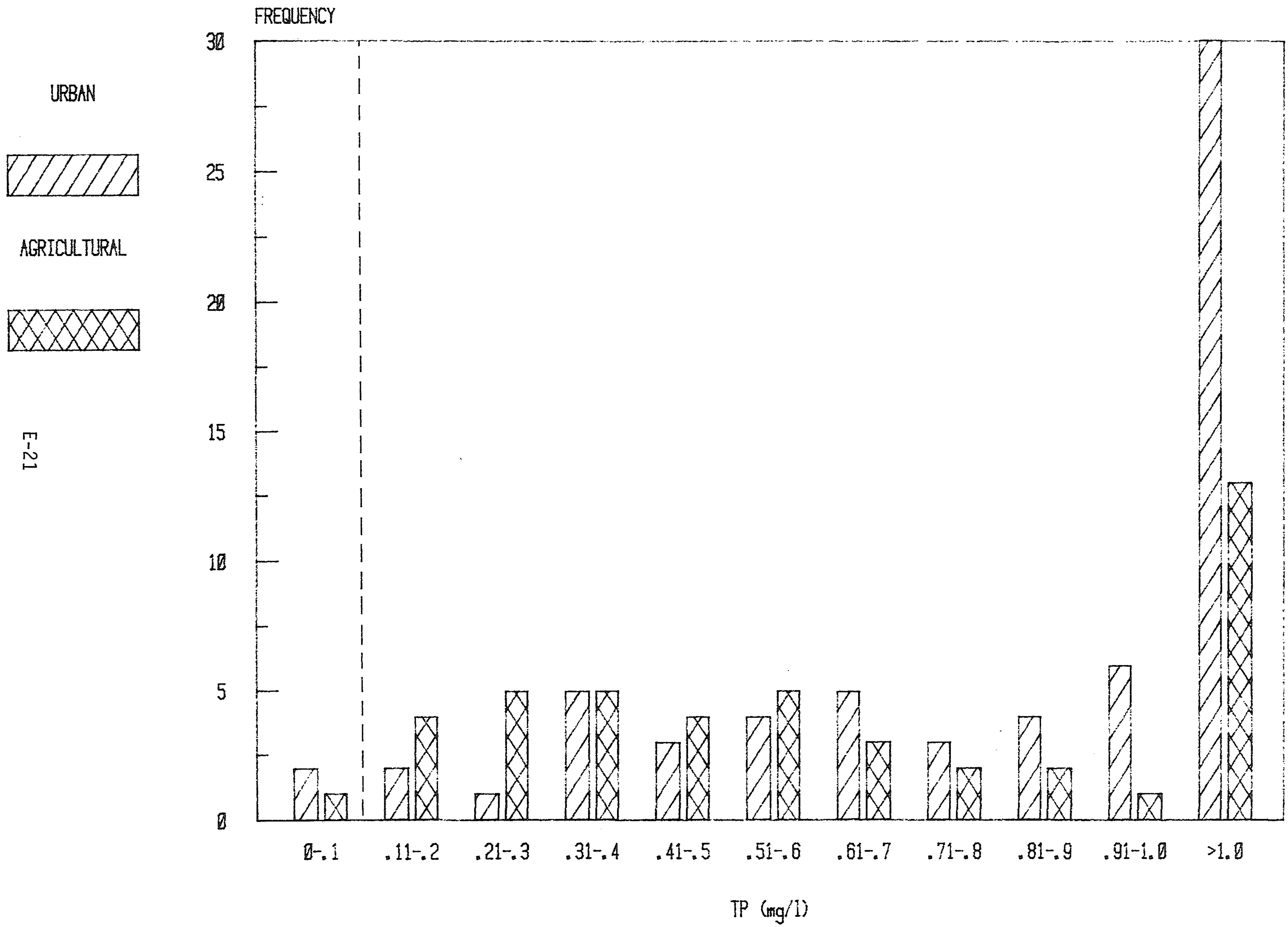


Figure E-2. FLOW-WEIGHTED MEAN CONCENTRATION, TN

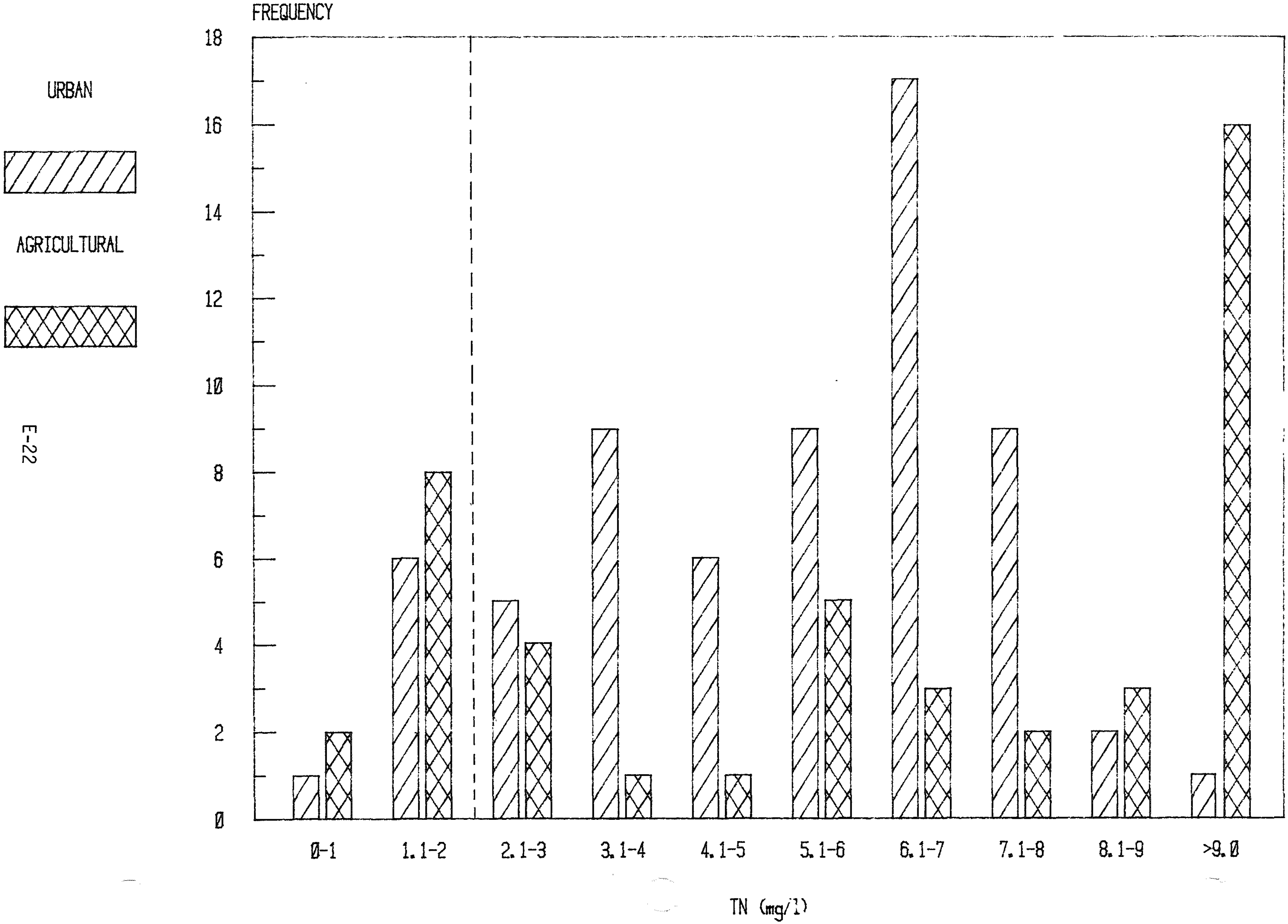


Figure E-3. FLOW-WEIGHTED MEAN CONCENTRATION, TSS

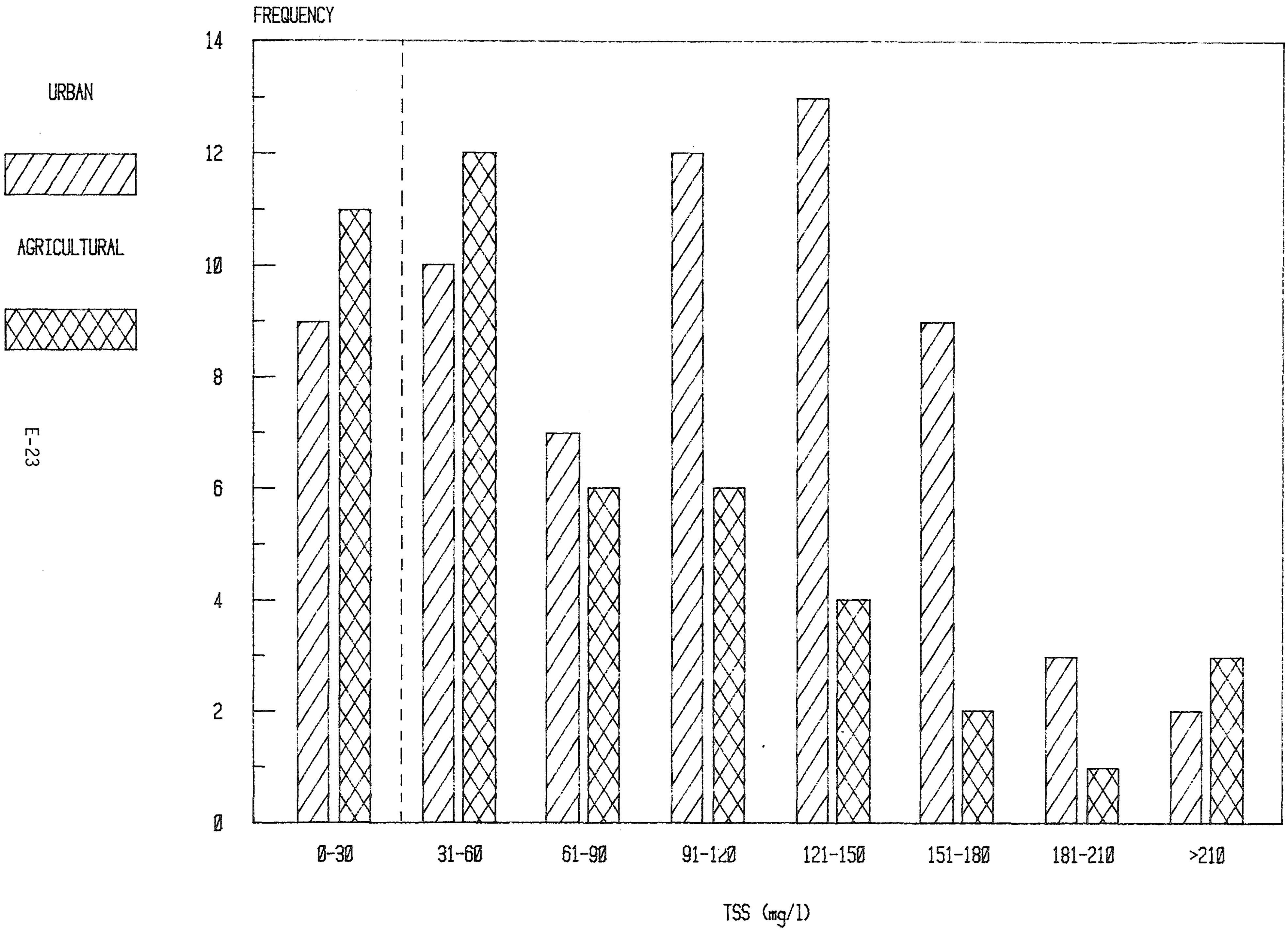


Figure E-4. FLOW-WEIGHTED MEAN CONCENTRATION, COD

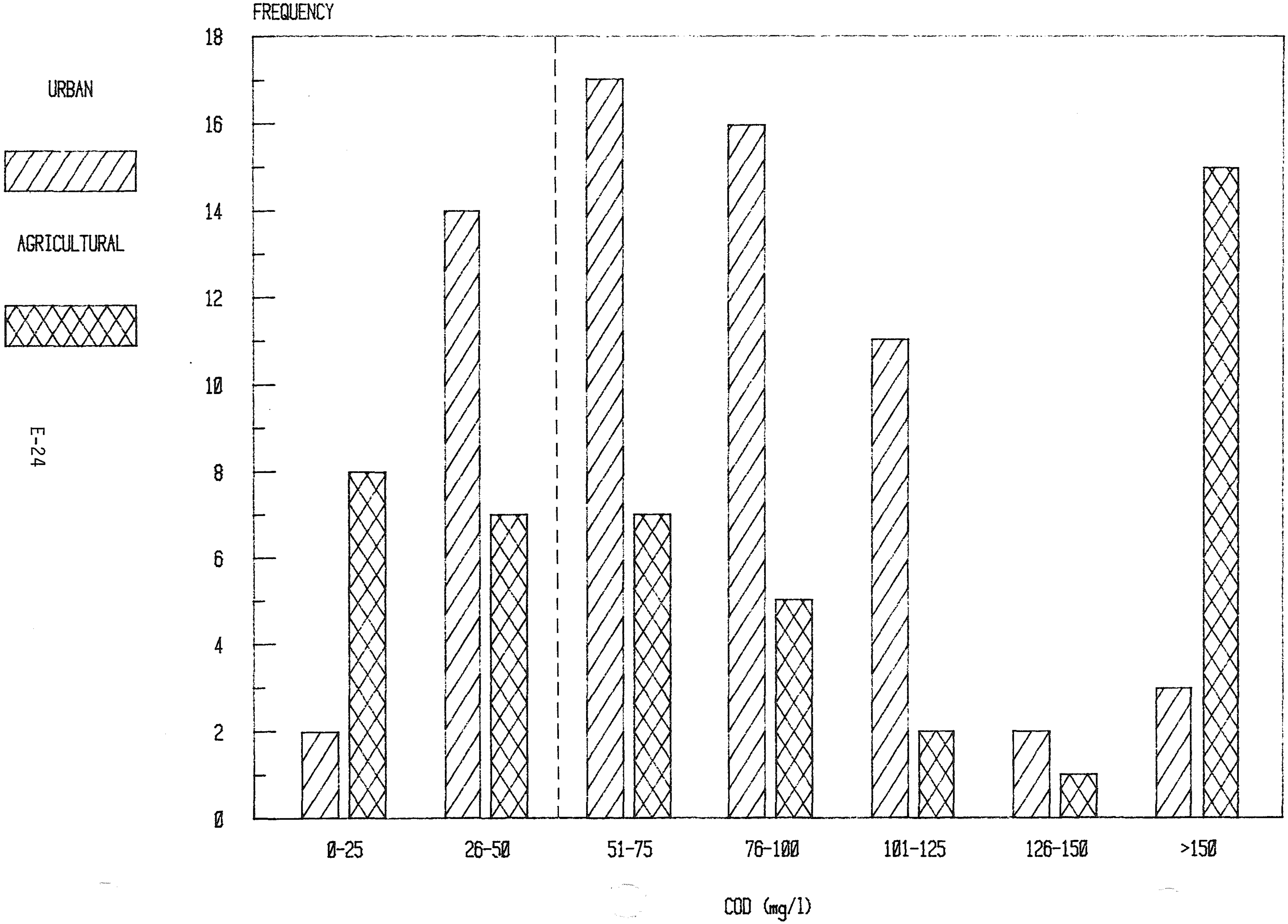
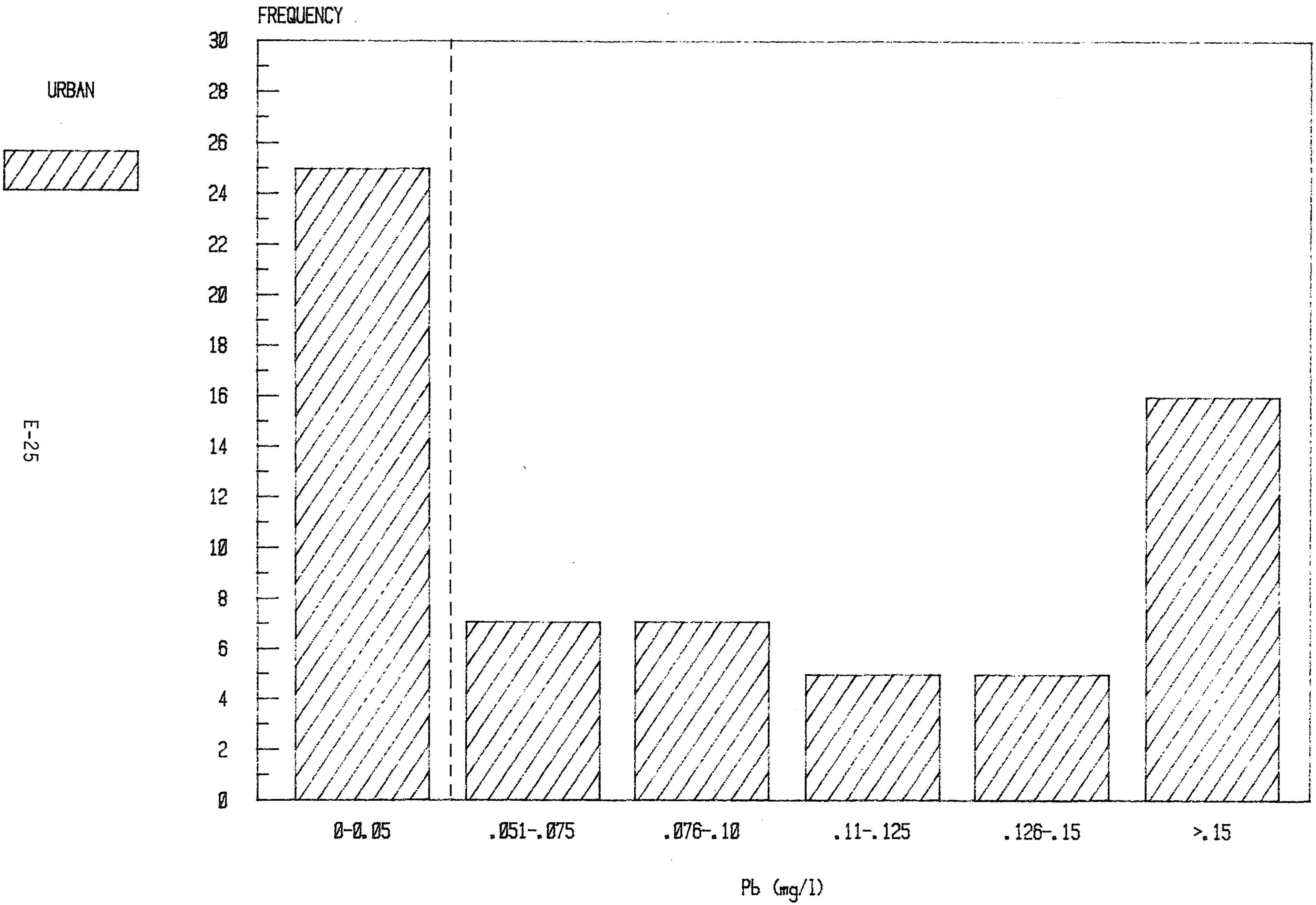


Figure E-5. FLOW-WEIGHTED MEAN CONCENTRATION, Pb



Appendix F

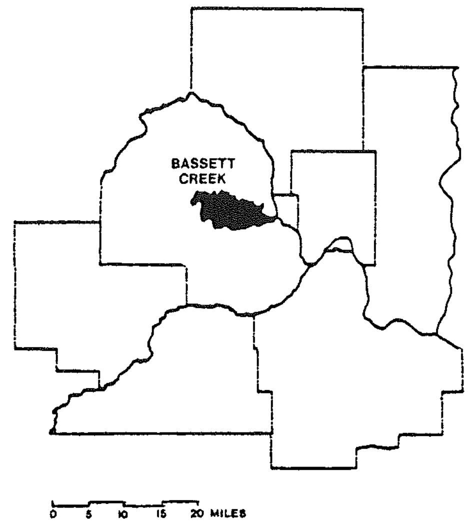
44 WATERSHED ANALYSES FOR REGION

WATERSHED ANALYSES

This section defines the major identified problems for each secondary watershed in the Metropolitan Area. Subsequent implementation efforts should focus attention on these problems and develop programs for addressing these concerns. Subwatersheds (Table 5) and priority lakes will be discussed in the same section that evaluates their corresponding secondary watershed.

The evaluations that follow describe each secondary watershed's problems and include a table containing watershed or subwatershed listing of flow-weighted mean values for several water quality constituents, including the priority pollutant. All pollutant values are given in milligrams per liter (mg/l). Severity of the problem is evident by comparing this table with the recommended water quality guidelines discussed earlier.

1. Bassett Creek. This watershed is recommended for critical priority because of its poor overall water quality. Bassett Creek Flood Control Commision is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Upper Bassett	18.1	53	54	0.42	2.9	0.05
Lower Bassett	22.6	88	64	0.92	4.9	0.08

Upper Bassett Evaluation: Upper Bassett subwatershed generally lies upstream of Medicine Lake. The basin is currently developing at low- to medium-density urban uses. For this reason attention must be placed on control of storm water runoff through a comprehensive program. Water quality guidelines are equalled or exceeded for all five of the constituents noted above. The "regionally important" Medicine Lake is located at the lower end of this subwatershed, and has an overall TP inflow equal to 0.29 mg/l. Large parts of this watershed are undergoing development, again stressing the importance of good storm water planning.

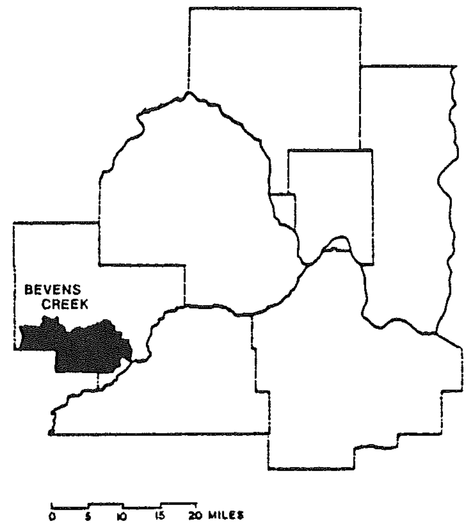
Suggested management needs:

- 700 acre-feet of water quality storage.
- Comprehensive storm water management for whole subwatershed urbanizing area.
- Medicine Lake:
  - Information program for lakeshore homeowners.
  - Intensive housekeeping for the urbanized area (1,160 curb-miles per year priority sweeping; leaf/litter program).
  - 600 acre-feet of water quality storage, possibly retrofitted into existing storage.

Lower Bassett Evaluation: The Lower Bassett Creek subwatershed is highly urbanized with parts of the basin draining into the combined sewer in Minneapolis. Again, because of the combined sewer problem, the priority pollutant is COD. The COD level in the basin needs a reduction of 22 percent; TSS for comparison needs a reduction of 66 percent. Because of the dense urban development, management approaches are limited and usually quite expensive. Recommendations for this subwatershed are limited to intensive housekeeping (street sweeping, catch basin cleaning). Storage options, although effective, are precluded because of lack of space and high cost of subterranean storage.

Suggested management needs: Intensive housekeeping in the urbanized area (3,000 curb-miles per year priority sweeping; cleaning of 5,000 catch basins per year).

2. Bevens Creek. This watershed is recommended for secondary priority because even though it has water quality problems, the frequency of such problems is low.



	Area (sq. mi.)	TSS	COD	TP	TN
Mainstem	51.6	131	69	1.0	8.5
Silver Creek	31.1	50	130	0.11	0.2

Mainstem Evaluation: The mainstem subwatershed begins in the outstate area and flows through essentially an agricultural basin within the Region. Water quality exceeds recommended guidelines for the priority TSS pollutant and for the nutrients because of intensive agricultural activity. The basin agriculture is predominantly dairy and supporting crops. Management attention should focus on this subwatershed. The county has identified upgrading of the Young America-Norwood sewage treatment plant as a high-priority need for cleaning up the stream.

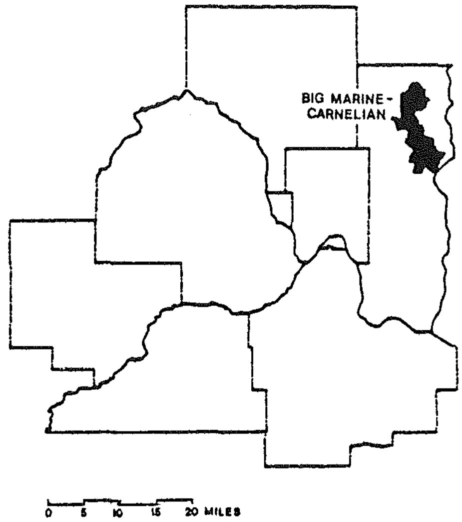
Suggested management needs:

- 2,600 acres in cropland conservation practices.
- 3,000 acres in noncropland critical area treatment.
- Limiting animal access to stream channel.

Silver Creek Evaluation: The Silver Creek subwatershed, although similar to the mainstem in character, has much less of a water quality problem. Limited management is needed for TSS reduction.

Suggested management needs: 900 acres cropland conservation practices.

3. Big Marine-Carnelian. This watershed is a high-priority lake basin because of Big Marine and Big Carnelian Lakes. Carnelian-Marine Watershed District is the existing watershed management organization.



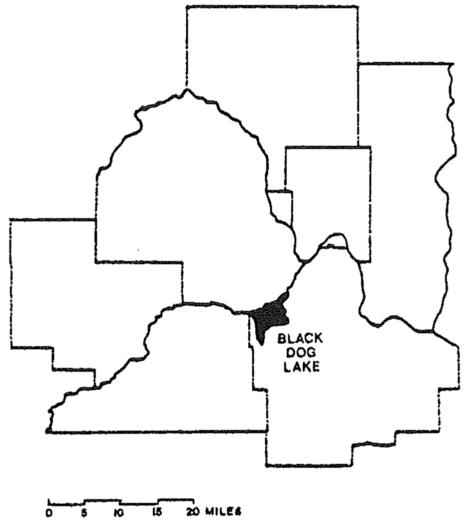
	Area (sq. mi.)	TSS	COD	TP	TN
Big Marine-Carnelian	42.2	12	34	0.31	2.5

Evaluation: The presence of two priority lakes on the mainstem of this watershed requires that priority attention be placed on the nutrient quality of the runoff. Nutrients in this watershed came from agricultural runoff and undoubtedly from septic tank leakage (although the Council's surface water planning program did not gather data to document this). This watershed has undergone several high-water problems in the past several years, largely due to development within the zone of water fluctuation of the watershed's lakes. These flooding events are the major watershed problem. The watershed portion of the recommendations focuses on nutrient reduction through agricultural runoff management. The two priority lakes experience runoff loading that is about 0.48 mg/l TP, not including an added unknown load from flooded septic tanks. As with the watershed, attention will focus on reducing external nutrient loading through agricultural runoff management. Elimination of the water level fluctuation problems on the watershed's lakes can only be solved by home relocation or installation of a lake level control outlet, possibly creating more problems for downstream locations. A newly created watershed district will address this and the septic tank problem.

Suggested management needs:

- 4,350 acres in cropland conservation practices.
- 1,075 acres in noncropland critical area treatment.
- Big Marine Lake:
  - 800 acres in cropland conservation practices.
  - Reduction of flooded septic tanks.
- Big Carnelian Lake:
  - 720 acres in cropland conservation practices.
  - 50 acre-feet of wetland storage.
  - Reduction of flooded septic tanks.

4. Black Dog Lake (BLA). This watershed is recommended for secondary priority. It is located partially within Lower Minnesota River Watershed District.

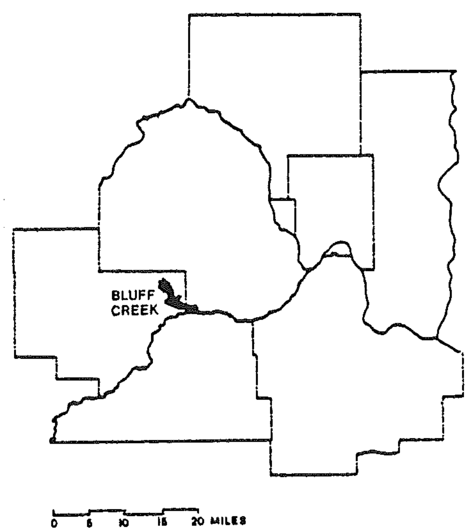


	Area (sq. mi.)	TSS	COD	TP	TN	Pb
BLA	22.2	13	24	0.19	1.3	0.02

Evaluation: This watershed covers some of the Region's most rapidly urbanizing area (Burnsville, Apple Valley, Eagan). Major water quality problems do not exist currently (it meets TSS guidelines) but attention must be paid to comprehensive storm water management as the area urbanizes. A low remedial priority is given to this watershed, but a high priority for storm water management is warranted. For this reason the watershed is given a secondary priority.

Suggested management needs: No additional management practices, but a comprehensive storm water management program is essential while the area urbanizes.

5. Bluff Creek. This watershed is recommended for secondary priority. The mouth is located in the Lower Minnesota River Watershed District.



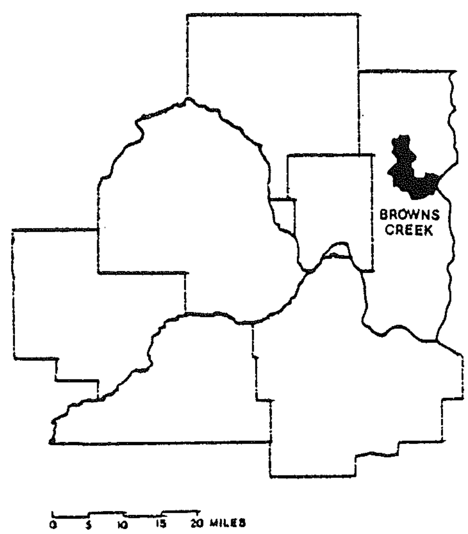
	Area (sq. mi.)	TSS	COD	TP	TN
Bluff Creek	8.4	80	40	0.5	1.9

Evaluation: As the watershed name suggests, the creek flows from croplands over the Minnesota River bluff, where it creates a channel erosion problem. The watershed is predominantly rural, but should develop slowly within the next 20 years. Although the TSS level needs a 62-percent reduction, this watershed was not recommended as critical because of its small size and the nature of its major problem; that is, it is not yet determined what portion of the bluff erosion is natural and what portion is due to human activity. The suggested management needs that can be made, however, will involve attempts to control runoff from uplands in hopes of reducing channel impact.

Suggested management needs:

- 1,400 acres in cropland conservation practices.
- 900 feet of channel stabilization along bluff.

6. Brown's Creek. This watershed is recommended for secondary priority. MPCA's recommended 20 mg/l TSS guideline for DNR trout streams is slightly exceeded.

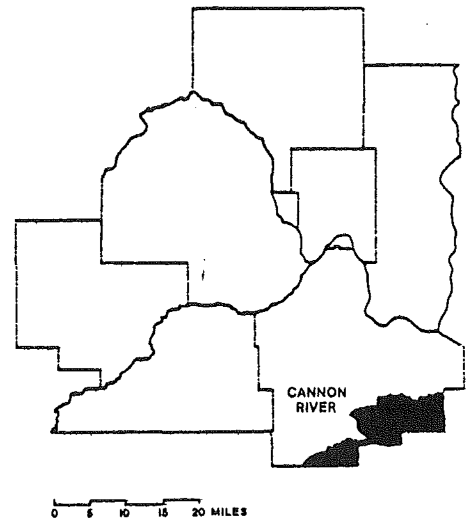


	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Brown's Creek	29.0	21	39	0.236	3.0	0.01

Evaluation: This small watershed does exceed the recommended priority trout stream guidelines; care should be taken in the future to protect its trout fishery status.

Suggested management needs: No additional management practices at this time.

7. Cannon River. This watershed is recommended for secondary priority.

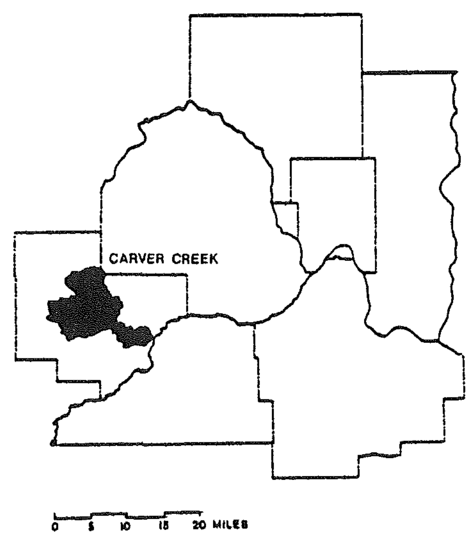


	Area (sq. mi.)	TSS	COD	TP	TN
Cannon River	81.3	39	49	0.20	2.2

Evaluation: With only a portion of the watershed located in the Region, the Cannon River receives much of its total load, including point source discharges, from outstate areas. The TSS level that exceeds the guidelines is the result of agricultural activity and stream bank erosion on steep slopes that drop to the river valley. Cropland tributary to areas experiencing severe channel erosion in southeast Dakota County should receive priority attention.

Suggested management needs: 4,400 acres in cropland conservation practices.

8. Carver Creek. This watershed is recommended for secondary priority; attention should focus on the priority lakes.



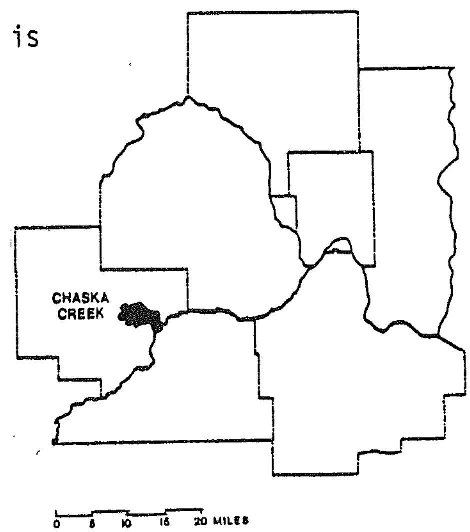
	Area (sq. mi.)	TSS	COD	TP	TN
Carver Creek	89.1	13	50	0.51	1.8

Evaluation: The Carver Creek watershed is predominantly rural except for the northern portion around Lake Waconia. The watershed itself meets the suggested TSS and COD guidelines and needs no additional management recommendations. There are, however, three priority lakes--Burandt, Hydes and Miller--and one "regionally important" lake--Waconia--in the watershed. Lakes Waconia and Burandt have watersheds that contribute TP values of 1.52 mg/l, while the similar value for Lakes Hydes and Miller is 0.55 mg/l. The lakes' evaluations have been combined for management evaluation purposes.

Suggested management needs:

- No additional watershed management practices.
- Lakes Waconia, Burandt, Hydes and Miller:
  - 2,600 acres in cropland conservation practices.
  - 1,760 acres in noncropland critical area treatment.
  - Comprehensive storm water management in the urban/urbanizing area surrounding Lakes Waconia and Burandt.

9. Chaska Creek. This watershed is recommended for secondary priority. Its mouth is located in the Lower Minnesota River Watershed District.

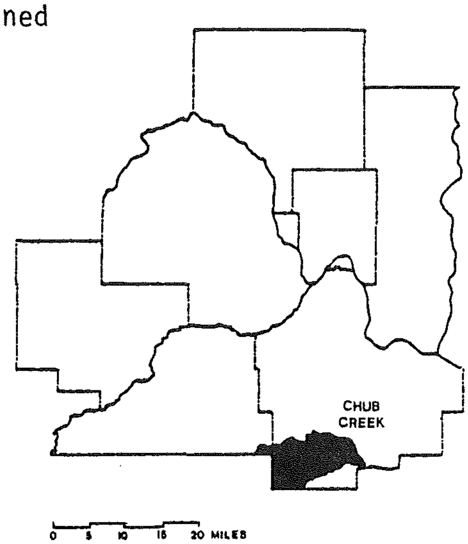


	Area (sq. mi.)	TSS	COD	TP	TN
Chaska Creek	12.7	7	20	0.19	1.3

Evaluation: The Chaska Creek watershed is very similar to the previous two. The Chaska basin apparently needs no additional attention to reach the TSS or COD recommended guidelines.

Suggested management needs: No additional management practices.

10. Chub Creek. A secondary priority is assigned to this watershed because it does not currently exceed priority pollutant guidelines.

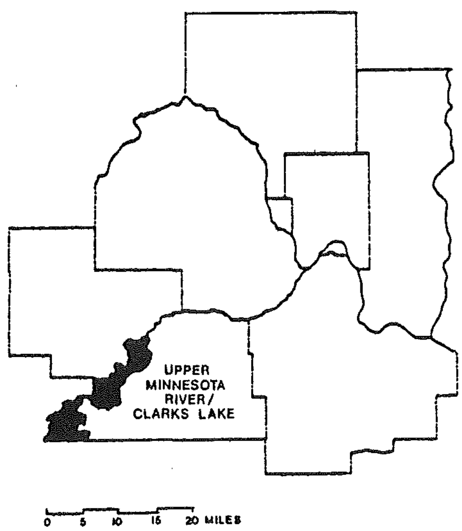


	Area (sq. mi.)	TSS	COD	TP	TN
Chub Creek	75.1	17	49	0.46	3.5

Evaluation: Land uses in the Chub Creek watershed are predominantly agricultural uses that do not appear to cause a water quality problem. The local soil and water conservation district has pointed out the need for programs on feedlots and erosion-prone land.

Suggested management needs: No additional management practices besides specific attention to feedlots and erosion-prone land.

11. & 12. Clark's Lake and Upper Minnesota River (UMN). These two watersheds are recommended for secondary priority because of the numerous small streams involved and because of the bluff line erosion, which might be due significantly to natural causes.



	Area (sq. mi.)	TSS	COD	TP	TN
Minn. 8-122	33.2	108	230	1.70	25
Minn. 8-126	19.1	77	170	1.53	16
Belle Plaine	12.6	135	168	1.56	21

Minn. 8-122 Evaluation: The Clark's Lake subwatershed (Minn. 8-122) is the farthest regional basin to the southwest. The basin is dominated by agricultural uses. Watershed flow contains a TSS level that needs reduction by 72 percent to meet the guideline, with a fair amount of this violation likely due to bluff erosion. Management recommendations focus on reduction of flow to the bluff area. Much of the water quality problem of the watershed is natural erosion of the bluff, a condition that should not be given top priority considering limited financial resources.

Suggested management needs:

- 1,350 acres in cropland conservation practices.
- 160 feet of channel stabilization along bluff.

Minn. 8-126 Evaluation: The Minn. 8-126 subwatershed is similar to the previous subwatershed in problem type and management approach.

Suggested management needs:

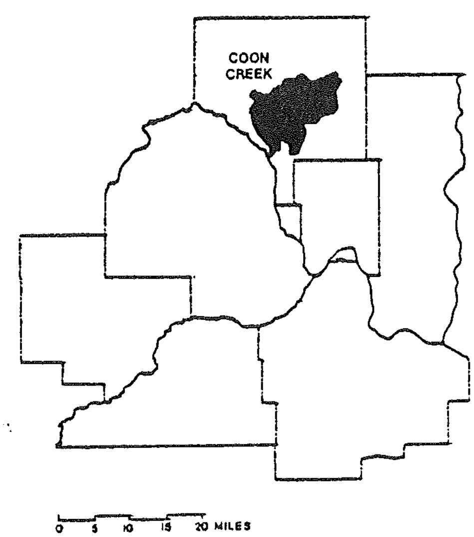
- 725 acres in cropland conservation practices.
- Evaluation of severe bluff erosion areas for future emphasis.

Belle Plaine Evaluation: The Belle Plaine subwatershed is largely comprised of the city of Belle Plaine and the surrounding rural area. The channel erosion problem along the bluff also exists in this watershed, as do many small streams draining the watershed.

Suggested management needs.

- 1,800 acres in cropland conservation practices.
- 215 feet of channel stabilization along bluff.

13. Coon Creek. This watershed is recommended for critical priority because it discharges poor quality water upstream of the Fridley water supply intakes. Coon Creek Watershed District is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Mainstem urban	10.9	152	105	1.22	7.3	0.17
Mainstem rural	66.9	131	201	0.67	6.2	--
Sand Creek	14.4	29	47	0.13	2.0	0.04

Mainstem Evaluation: The Mainstem Coon Creek subwatershed presents some water quality problems to the downstream Mississippi River water intake at Fridley. Because of the health-related impacts of this watershed, the urban portion is evaluated for lead (Pb) contribution and the rural portion for TP. The urban part of the basin is comprised mainly of the developed portions of Coon Rapids in the lower subwatershed. The urban uses in this area contribute high Pb values from transportation vehicles, as well as several other high-priority pollutants, as evidenced in the figures above. The rural portion of the subwatershed presents an equally serious problem from the standpoint of elevated TP levels. These high phosphorus concentrations come from upper basin agricultural cash-cropping and sod farming. The rural portion of the watershed contains three high-priority lakes--Ham, Crooked and Netta--combined here for management need evaluation. Significant TP reductions are needed for these lakes.

Suggested management needs:

Urban area:
- 800 acre-feet of water quality storage.
- Leaf/litter program for Coon Rapids.
- Intensive housekeeping for Coon Rapids (2,400 curb-miles per year of priority sweeping).

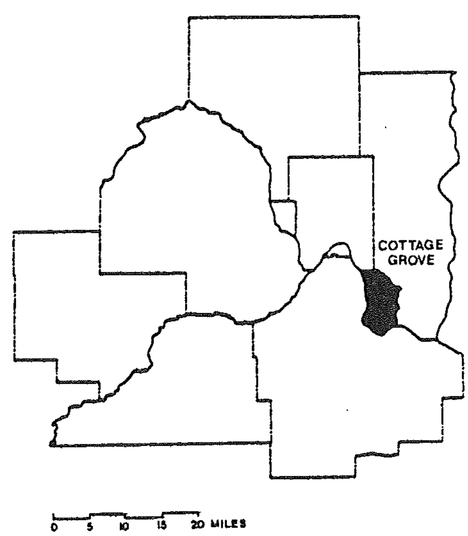
Rural area:
- 1,200 acres cropland conservation practices.
- 5,280 acres noncropland critical area treatment.
- Intensive information and education program on phosphorus fertilizer overuse.

Ham, Crooked and Netta Lakes: 1,360 acres in agricultural area treatment.

Sand Creek Evaluation: The Sand Creek subwatershed has a low priority because it falls below the priority pollutant guidelines.

Suggested management needs: No additional management practices.

14. Cottage Grove. A secondary priority is recommended for this watershed because it does not currently exceed priority pollutant guidelines.



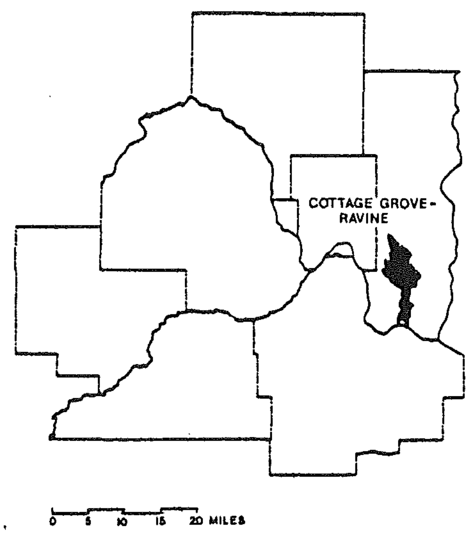
	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Cottage Grove	37.1	22	38	0.33	2.0	0.02

Evaluation: The Cottage Grove watershed currently does not appear to have a water quality problem, but the likelihood of increased urbanization in the next 20 years points to the importance of preparing a good storm water plan.

Suggested management needs:

- No additional management practices at this time.
- Comprehensive storm water management for developing area.

15. Cottage Grove Ravine. A secondary priority is recommended for this watershed.



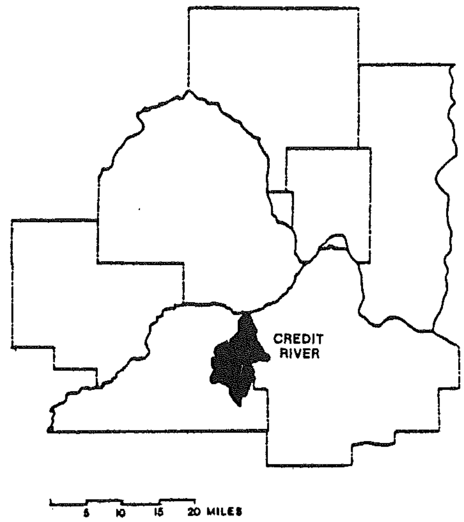
	Area (sq. mi.)	TSS	COD	TP	TN
Cottage Grove Ravine	33.1	37	7	0.1	0.7

Evaluation: This watershed is variable in land use, with the northern part undergoing urbanization and the southern part largely rural. Channel erosion in the lower end of this basin appears to be a problem caused by upstream runoff from agriculture and new development. Reduction of runoff from the urban and rural portions of the watershed could help mitigate the channel erosion problem.

Suggested management needs:

- 4,400 acres in cropland conservation practices.
- Control of runoff from future development.

16. Credit River. This watershed is recommended for secondary priority because of existing water quality problems and future urbanization. The mouth is located in the Lower Minnesota River Watershed District.



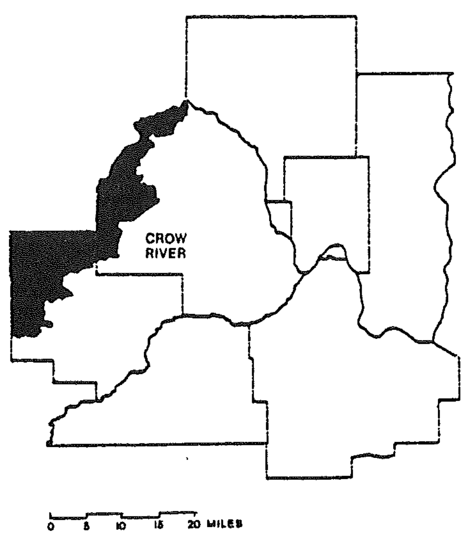
	Area (sq. mi.)	TSS	COD	TP	TN
Credit River	47.6	34	70	0.34	2.1

Evaluation: Credit River is a watershed in the beginning stages of transition from rural in the upper portions to urban at the river's mouth. Water quality problems are not currently severe, with the TSS level needing only a 12-percent reduction to reach the guideline. Management should focus on upper watershed agricultural activity and lower watershed urbanization. Priority Orchard Lake is located in the watershed, with an inflow TP concentration of 0.45 mg/l.

Suggested management needs:

- 2,925 acres in cropland conservation practices.
- Comprehensive storm water management in the developing lower basin area.
- Orchard Lake: - 25 acres in cropland conservation practices.
  - 225 acre-feet of water storage.

17. Crow River. The water quality problems of this watershed lead to a secondary-priority recommendation.



	Area (sq. mi.)	TSS	COD	TP	TN
Mainstem	41.9	71	141	0.77	14.9
Sarah Creek	8.6	98	38	0.63	5.9
Pioneer Creek	55.3	37	87	0.58	6.3
Lower South Fork	88.2	10	17	0.21	6.8
Winsted	8.7	16	84	0.30	6.5

Mainstem Evaluation: The mainstem of the Crow River covers a very small area in the Region. The water quality data is quite inadequate, but the quality of the river is determined more by outstate contributions than by Metropolitan Area sources. Within the Region, pollutant contributions come mostly from agricultural uses, particularly dairy operations with a large number of animals. Row crops are raised to support the dairy animals. Priority Lake Rebecca is located within this subwatershed; the Hennepin Co. Park Reserve has noted that Lake Rebecca has poor water quality. Specific recommendations are not made at this time, but attention in the watershed plan should be placed on Rebecca.

Suggested management needs:

- 4,000 acres in cropland conservation practices.
- Lake Rebecca: No additional management practices, but watershed attention should focus here.

Sarah Creek Evaluation: The Sarah Creek subwatershed is similar in land use to the mainstem basin, with similar problems. Basin attention should focus on TP because of high-priority Lake Sarah midway in the watershed. Suggested management needs for the subwatershed combine the watershed and the lake drainage basin.

Suggested management needs:

- 160 acres in cropland conservation practices.
- 930 acres in noncropland critical area treatment.

Pioneer Creek Evaluation: The Pioneer Creek subwatershed is again quite similar in use to the previous two subwatersheds, but its problems are reduced for TSS. Two "regionally important" lakes--Independence and Whaletail--and one other priority lake--Little Long--are located in the basin. Little Long needs no additional management, but the inflow to Independence and Whaletail has a concentration of 0.6 mg/l TP, mostly from agricultural activity. The Pioneer Creek Conservation Management District is a joint-powers agreement operating in this basin.

Suggested management needs:

- 1,400 acres in cropland conservation practices.
- Little Long Lake: No additional management practices.
- Independence and Whaletail Lakes:
  - 280 acres in cropland conservation practices.
  - 150 acres in noncropland critical area treatment.

Lower South Fork Evaluation: The Lower South Fork Crow subwatershed is essentially all agriculture (dairy and support) and generally under adequate protection. The water quality levels of the basin for the priority pollutants are currently below the recommended guidelines.

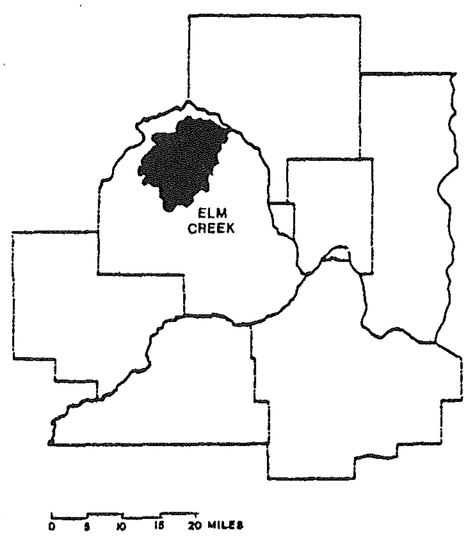
Suggested management needs: No further management practices.

Winsted Evaluation: The Winsted subwatershed was difficult to model because of its small size, but indications seem to be that the TSS guideline is not exceeded, but the COD guideline is exceeded. Management attention to address this reduction need should focus on critical cropland management and animal access to streams.

Suggested management needs:

- 1,500 acres in cropland conservation practices.
- Fencing along erosive channels to keep animals out.

18. Elm Creek. This watershed is recommended for critical priority because of its poor quality discharge upstream from Fridley and its likely future development problems. Elm Creek Conservation Commission is the existing watershed management unit.



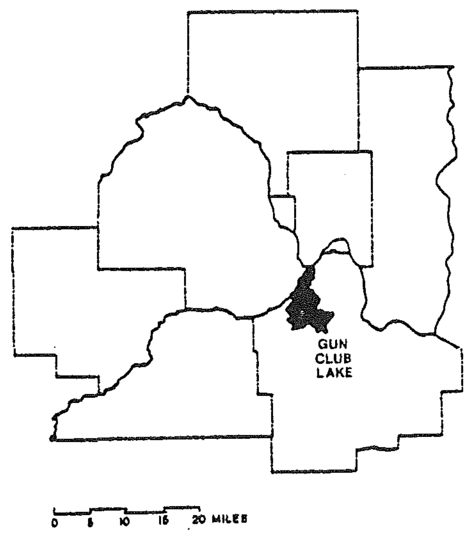
	Area (sq. mi.)	TSS	COD	TP	TN
Elm Creek	104.9	26	81	0.43	8.0

Evaluation: The Elm Creek watershed is partially in transition from rural to urban uses. The eastern part of the watershed (Maple Grove, Champlin) is expected to undergo urbanization during the next 20 years. Because of the potential threat to water quality from urbanization, specific attention must be paid to minimizing runoff impacts from development; comprehensive storm water management is essential. Problems in the western watershed result from agricultural activity. The priority pollutant for the watershed is TP because of the basin location upstream of Fridley. Priority Lakes Fish and Weaver are located in the watershed. The Fish basin is rapidly developing and appears to contribute a TP concentration of 1.1 mg/l to the lake; again, comprehensive storm water management is essential. The Weaver Lake basin flow has an inflow concentration of 0.43 mg/l, predominantly from agricultural activity. The Weaver Lake basin is beginning to urbanize and in need of storm water control also.

Suggested management needs:

- Comprehensive storm water management for all urbanizing areas of the watershed.
- 10,000 acres in cropland conservation practices, including 5,000 acres of intensive treatment.
- Fish Lake:
  - Information program for homeowners.
  - 160 acre-feet of water storage.
  - Intensive housekeeping for area surrounding lake (leaf/litter program; 80 curb-miles per year of priority sweeping).
- Weaver Lake:
  - 90 acres in cropland conservation practices.
  - Information program for homeowners.

19. Gun Club Lake (GUN). This watershed is recommended for secondary priority. It is located partially within the Lower Minnesota Watershed District.

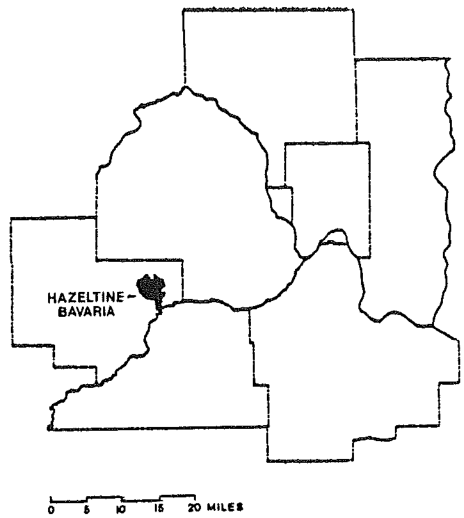


	Area (sq. mi.)	TSS	COD	TP	TN	Pb
GUN	35.1	9	22	0.38	1.1	0.01

Evaluation: This watershed is very similar to BLA in that it drains an area undergoing rapid urbanization (Eagan, Apple Valley, Rosemount). Like BLA, severe water quality problems do not currently exist, but caution must be taken to plan properly for storm water management. An existing runoff quantity problem occurs between several northern watershed communities and should be addressed.

Suggested management needs: - No additional management practices, but a comprehensive storm water management program is essential while the area urbanizes; the northern watershed problem should be addressed by all affected communities.

20. Hazeltine-Bavaria. This watershed is recommended for secondary priority. Its mouth is located in the Lower Minnesota River Watershed District.



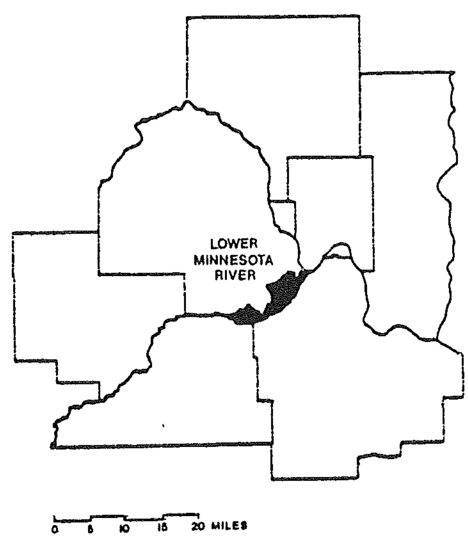
	Area (sq. mi)	TSS	COD	TP	TN
Hazeltine-Bavaria	13.4	76	77	0.63	2.7

Evaluation: This watershed is a small basin that is slowly urbanizing at quite low densities. Like Bluff Creek, it discharges from an upland area over the Minnesota River bluff, where channel erosion has occurred. Management practices should focus on reduction of storm water from the uplands to the bluff area to minimize erosion. Priority Lake Bavaria is located in the far upper end of the basin. The TP inflow to Bavaria is 0.56 mg/l, and management should focus on rural area runoff control.

Suggested management needs:

- 2,100 acres in cropland conservation practices.
- 900 acre-feet wetland and closed basin storage.
- Lake Bavaria: - 200 acres in cropland conservation practices.
  - 35 acres in noncropland critical area treatment.

21. Lower Minnesota River (LMN). This watershed is recommended for secondary priority. It is located partially within the Lower Minnesota River Watershed District.



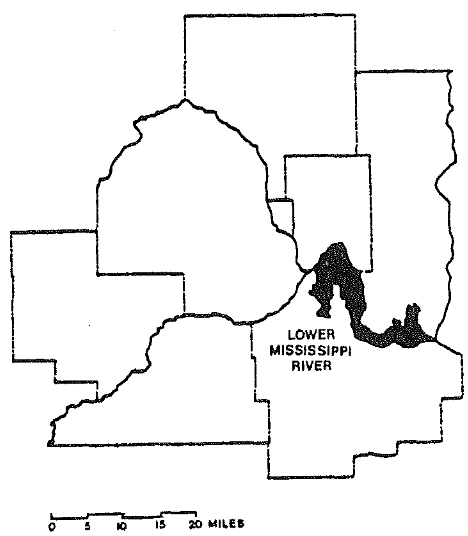
	Area (sq. mi.)	TSS	COD	TP	TN	Pb
LMN	26.4	77	58	0.65	3.9	0.01

Evaluation: Land use within the watershed varies from open space to highly developed commercial (I-494 strip). Two subwatersheds--LML and LMN--are combined for management analysis. Both subwatersheds contain portions of the Minnesota river valley bluff, which is easily eroded. Major problems in the watershed result from runoff from developed residential and long, contiguous commercial strips. Particular attention is placed on the need to redevelop the stadium site so storm water detention is provided to minimize (perhaps reduce from current levels) off-site impacts.

Suggested management needs:

- Intensive housekeeping along the I-494 corridor and in residential areas.
- 2,100 feet of channel stabilization along bluff lines.
- 240 acre-feet of water quality storage.
- Careful attention to minimizing storm water impacts as the area develops and redevelops (stadium site).

22. Lower Mississippi River (LMS). This watershed is recommended for secondary priority.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Major LMS	67.2	33	40	0.41	2.3	0.01
Southern	11.0	54	45	0.56	4.3	

Major LMS Evaluation: The Major LMS subwatershed covers most of the total watershed. Land use varies from open space to highly urbanized and commercial. About seven percent of the subwatershed drains to the South St. Paul combined sewer system, but the basin COD level appears acceptable. The TSS level needs only a slight reduction, and the nutrients are over the guidelines. A runoff quantity problem exists between communities in the northern portion of the watershed.

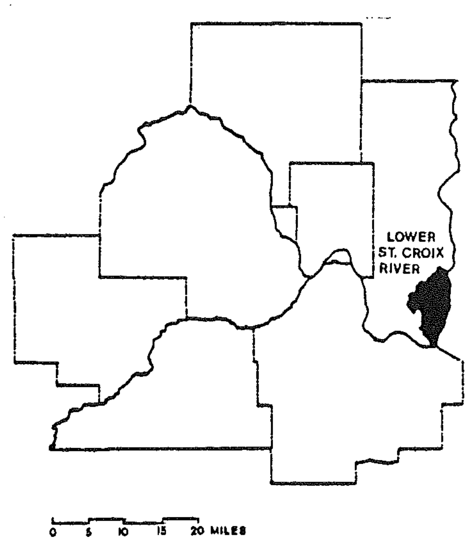
Suggested management needs:

- Intensive housekeeping in urbanized part of watershed (600 curb-miles per year of priority sweeping; cleaning of 200 catch basins per year).
- Comprehensive storm water management in urbanizing area; specific attention should be devoted to the quantity problem among several northern watershed communities.

Southern Evaluation: The Southern subwatershed consists of two small basins, both predominantly rural. This subwatershed is in a fairly erosive area, however, so water quality values are quite high for TSS and the nutrients.

Suggested management needs: 2,760 acres in cropland conservation practices.

23. Lower St. Croix River. A secondary priority is recommended because of the numerous small channels involved in the water quality problem.



	Area (sq. mi.)	TSS	COD	TP	TN
Afton	27.3	101	25	0.45	13.0
Basswood Grove	23.7	111	52	0.57	6.0

Afton Evaluation: The Afton subwatershed is generally rural, with its major problem being channel erosion along the bluff descending to the St. Croix River. This erosion results in a high overall watershed TSS concentration. The recommended approach for this basin is to reduce discharges to the erosive channels by instituting cropland control.

Suggested management needs:

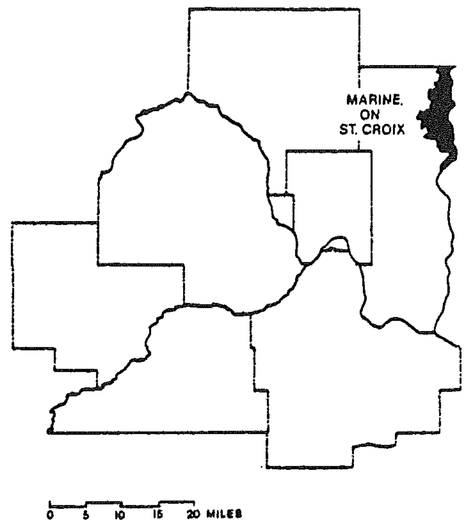
- 2,250 acres in cropland conservation practices.
- 275 feet of channel stabilization.

Basswood Grove Evaluation: The Basswood Grove subwatershed is very similar to the Afton subwatershed in the nature and extent of the problem, and in the management approach required.

Suggested management needs:

- 4,800 acres in cropland conservation practices.
- 675 feet of channel stabilization.

24. Marine on St. Croix (MSC) This watershed is recommended for secondary priority status.

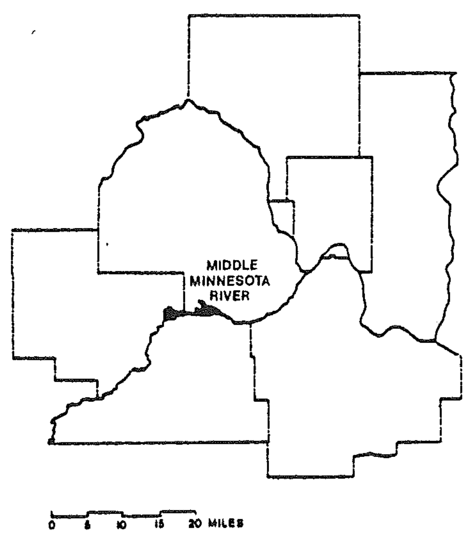


	Area (sq. mi.)	TSS	COD	TP	TN
MSC	39.3	32	28	0.28	2.2

Evaluation: The MSC watershed is comprised of many small streams that discharge from the uplands into the St. Croix Valley. Serious water quality problems do not exist and no priority lakes occur in the watershed; therefore, a lot of attention is not required to meet quality guidelines.

Suggested management needs: 880 acres in cropland conservation practices.

25. Middle Minnesota River (MMN). This watershed is recommended for secondary priority. It is located partially within the Lower Minnesota River Watershed District.

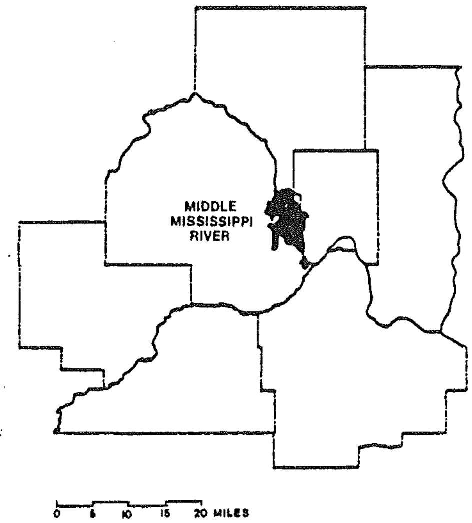


	Area (sq. mi.)	TSS	COD	TP	TN
GRA	3.7				
MMN	2.0	(see evaluation)			

Evaluation: The MMN watershed is located almost entirely in the undeveloped Minnesota River floodplain and, as such, creates no water quality problem.

Suggested management needs: No additional management practices.

26. Middle Mississippi River (MMS). This series of three basins is recommended for critical priority because of its water quality problems. The watershed is located almost totally within Minneapolis.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Northern	21.7	155	70	0.89	7.1	0.30
Middle	12.3	119	83	0.95	5.4	0.12
Southeastern	2.7	175	53	1.06	6.3	0.10

Northern Evaluation: The Northern subwatershed (MMS-6) covers northwest and north Minneapolis and is densely developed, with a portion of the surface draining to the Minneapolis combined sewer system. All of the water quality constituents indicated above exceed recommended guidelines substantially.

Suggested management needs: Intensive housekeeping, particularly in combined sewer areas (1,000 curb-miles per year of priority sweeping; cleaning of 225 catch basins per year).

Middle Evaluation: The Middle subwatershed (MMS-7) is in central Minneapolis and covers a substantial portion of the downtown area. About one-quarter of the basin drains to the combined sewer system. The COD level is in need of a 40-percent reduction, while the TSS level needs 75 percent; Pb is particularly high, at 0.12 mg/l. Management possibilities are severely limited because of the built-up nature of the subwatershed.

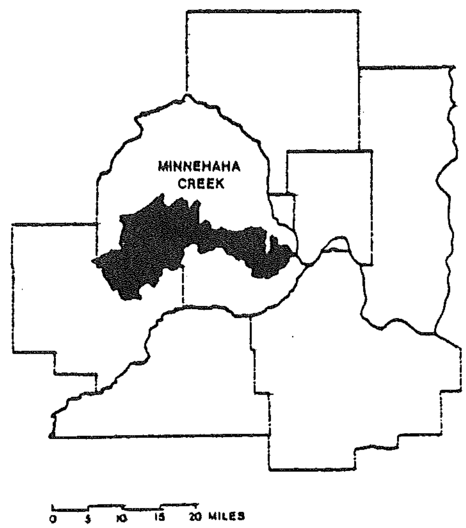
Suggested management needs:

- Intensive housekeeping, particularly in combined sewer area (300 curb-miles per year of priority sweeping; cleaning of 100 catch basins per year).
- 420 acre-feet of water storage with emphasis on infiltration.

Southeastern Evaluation: The final subwatershed is the Southeastern basin (MMS-8) located in southeast Minneapolis and covering a portion of the Minneapolis-St. Paul International Airport. This subwatershed drains in part to the lower Minnesota River. The watershed drains only about four percent to the combined sewer system, and needs only a six-percent COD reduction; the TSS level needs an 83-percent reduction for comparison. The nutrients and Pb are similarly high.

Suggested management needs: Intensive housekeeping in urbanized residential/commercial Minneapolis (30 curb-miles per year of priority sweeping; cleaning of 25 catch basins per year).

27. Minnehaha Creek. This watershed is recommended for critical priority because of its many (20) high-priority lakes and its poor water quality. Minnehaha Creek Watershed District is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Upper	125.6	50	124	0.32	2.7	0.03
Lower	58.0	56	42	0.53	3.0	0.06

Upper Evaluation: The Upper Minnehaha subwatershed (Minn. 1-6) essentially includes the entire drainage basin emptying to Lake Minnetonka. A substantial part of the subwatershed is composed of standing water. There exists within the basin seven "regionally important" lakes--Minnetonka, Auburn, Minnewashta, Zumbro, Stiegar, Parley and Schutz--and seven priority lakes--Pierson, Christmas, Long, Langdon, Dutch, Waterman and Virginia. Because so much of this subwatershed consists of priority lakes, the priority pollutant is TP; the needed TP reduction is 69 percent determined for the entire subwatershed. An existing watershed district has guided growth in the past, and continued storm water management is essential as the basin develops.

Suggested management needs:

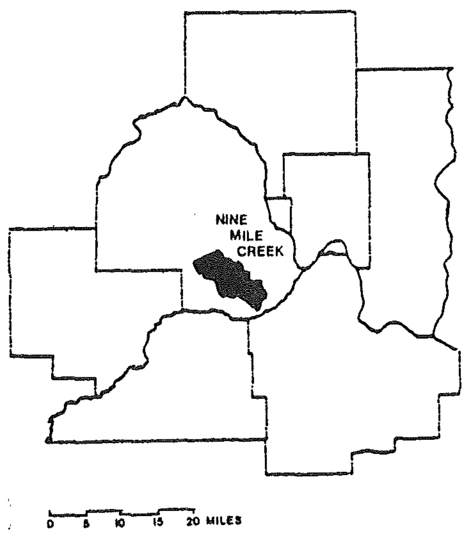
- Comprehensive storm water management for urbanizing area.
- 25 square miles in cropland conservation practices in western part of basin.
- 4,600 acre-feet of water quality storage, emphasizing wetlands and possibly retrofitted into existing storage.

Lower Evaluation: The Lower subwatershed has mixed land uses from urbanizing to fully developed, dense urban. Almost 850 acres of combined sewer area are located within the basin in Minneapolis, but the COD level appears acceptable. The TSS level, however, needs a 46-percent reduction. Small areas in the central and western part of the subwatershed are being developed and the previous storm water control comments are appropriate. The lower watershed also contains the "regionally important" Chain of Lakes (Cedar, Isles, Calhoun and Harriet) and Lake Nokomis. The TP inflow into these lakes appears to be 0.56 mg/l. The watershed's suggested management needs will undoubtedly be expensive so innovative storage and infiltration techniques will need to replace usual surface storage techniques. In light of the recently ordered cutback in street sweeping in Minneapolis, the plan's suggested management needs encourage priority street sweeping for lake tributary areas.

Suggested management needs:

- Comprehensive storm water management in urbanizing area.
- Intensive housekeeping with priority on lake watersheds (2,700 curb-miles per year of priority sweeping; cleaning of 4,500 catch basins per year).
- 1,900 acre-feet of water storage, with emphasis on infiltration.
- Chain of Lakes:
  - Priority intensive housekeeping (2,640 curb-miles per year of priority sweeping; cleaning of 5,000 catch basins per year).
  - 1,300 acre-feet of water storage with emphasis on infiltration.
- Lake Nokomis:
  - Priority intensive housekeeping.
  - 125 acre-feet of water storage, with emphasis on infiltration (1,560 curb-miles per year priority sweeping; cleaning of 3,000 catch basins per year).

28. Nine Mile Creek. This watershed is recommended for secondary priority. Nine Mile Creek Watershed District is the existing watershed management organization.



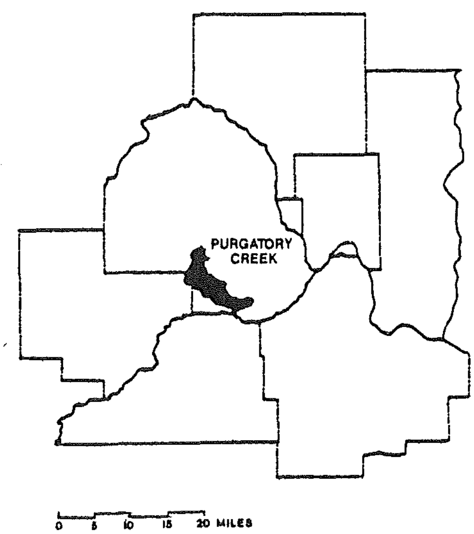
	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Nine Mile Creek	39.6	53	32	0.76	3.8	0.05

Evaluation: The Nine Mile Creek watershed is an urban-urbanizing basin that has had much of its growth guided by a watershed district, and as such, has few serious problems. The existing problems in the basin are the result of normal urban activities, and suggested management needs are oriented toward these. Additionally, the watershed has three priority lakes--Bryant, Bush and Glen. These lakes' watersheds are in varying stages of urban development, but all can be categorized as urban area lakes. The inflow into Bryant has a TP concentration of 0.71 mg/l; Bush's, 2.0 mg/l; and Glen's, 0.71 mg/l TP.

Suggested management needs:

- 2,650 acre-feet of water quality storage, possibly retrofitted into existing storage.
- Intensive housekeeping for the urban part of the watershed (800 curb-miles per year of priority sweeping; cleaning of 2,000 catch basins per year; leaf/litter program).
- Bryant Lake: - 700 acre-feet of predominantly wetland storage.
  - Comprehensive storm water management for urbanizing area.
- Bush Lake: - Information program for lakeshore owners.
  - 40 acre-feet of wetland storage.
- Glen Lake: - Information program for lakeshore owners.
  - 60 acre-feet of water quality storage.

29. Purgatory Creek. This watershed is recommended for secondary priority; it contains three priority lakes within the watershed. Riley-Purgatory Creek Watershed District is the existing watershed management organization.



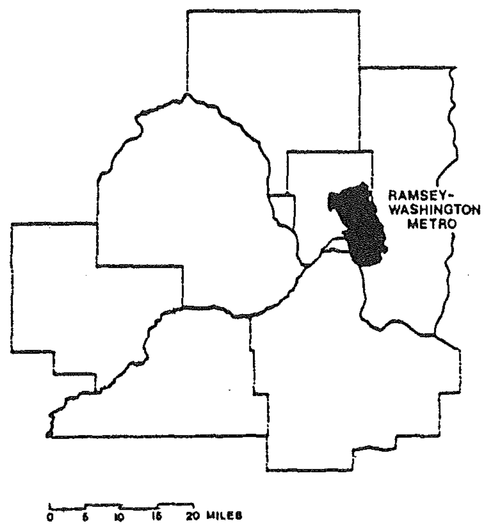
	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Purgatory Creek	30.6	13	32	0.22	1.5	0.03

Evaluation: As with Nine Mile Creek, much of the development has occurred under the guidance of a watershed district, and, as such, major problems do not exist. The mainstem watershed TSS level is below the recommended guideline so further management strategies are not suggested. However, there are three priority lakes in the watershed--Lotus, Staring and Mitchell--all exceeding the TP guideline with an inflow value of 0.24 mg/l.

Suggested management needs:

- No additional watershed management practices beyond those used by the watershed district.
- Lotus Lake: - 270 acre-feet of water storage.
  - Comprehensive storm water management for urbanizing area.
- Staring Lake: 1,300 acre-feet of water quality storage, possibly from retrofitting existing storage.
- Mitchell Lake: - 500 acres of vacant/agricultural land treatment.
  - Comprehensive storm water management for urbanizing area.

30. Ramsey-Washington Metro (RWM). This watershed is recommended for critical priority because of its water quality problems. Ramsey-Washington Metro Watershed District is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Northern	28.4	88	50	1.13	5.8	0.01
Southern	31.7	27	36	0.31	1.9	0.01

Northern Evaluation: About 85 percent of the northern subwatershed discharges to the combined sewer system through Phalen Lake in St. Paul. The COD level of this subwatershed appears acceptable at 50 mg/l, but the TSS level needs reduction by 66 percent. The nutrient and Pb levels are also quite high. "Regionally important" Phalen and Gervais Lakes occur in the basin. The TP level discharging to the lakes is at 1.1 mg/l, a very high concentration. Several communities are currently involved in discussions on how to manage and pay for inflows into the combined sewer system via Phalen Lake.

Suggested management needs:

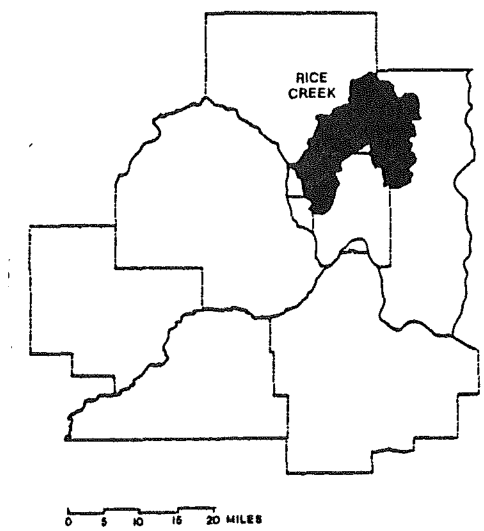
- Intensive housekeeping in the urbanized area (600 curb-miles per year of priority sweeping; cleaning of 100 catch basins).
- 400 acre-feet of wetland storage.
- 1,650 acre-feet of urban area storage, emphasizing infiltration.

- Phalen and Gervais Lakes:
  - Priority housekeeping in areas immediately tributary to lakes (600 curb-miles per year of priority sweeping; cleaning of 50 catch basins).
  - Information program for homeowners in same area.
  - 350 acre-feet of water quality storage.
  - Development of solution to Phalen Lake overflow problem.

Southern Evaluation: A small part of the southern subwatershed drains to Beaver Lake, which outlets into the St. Paul combined sewer system. The dominant stream in this subwatershed is Battle Creek, which has been identified as the cause of the worst erosion problem in the Region. Because a multi-million dollar project is under way on Battle Creek by the watershed district and discussions between the communities discharging to Beaver Lake are under way, no further management recommendations are made for this basin. The watershed district has identified Fish Creek (south of Battle Creek) as a problem area. Because of the conditions stated above, the immediate priority should remain with Battle Creek, with Fish Creek to be addressed later. Several communities are currently involved in discussion on how to manage and pay for inflows into the combined sewer system via Beaver Lake.

Suggested management needs: No additional management practices beyond those used by the watershed district; Battle Creek project should be completed and a solution to Beaver Lake overflow problem should be pursued.

31. Rice Creek. This watershed is recommended for critical priority because of its many priority lakes and problems meeting TP guidelines. Rice Creek Watershed District is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Upper Rice	147.4	46	63	0.32	1.7	0.002
Lower Rice	42.7	64	44	0.60	3.4	0.040

Upper Rice Evaluation: The Upper Rice Creek subwatershed contains eight of the 13 lakes used to store and supply water to the St. Paul water supply system. Additionally, three multiple-recreation priority lakes are located in the far upstream portion of the basin. Because essentially all of the watershed drains into a priority lake, or drains downstream into a lower Rice Creek priority lake, individual lake evaluations are bypassed in favor of a whole-watershed approach, designed to reduce the TP concentration of 0.32 mg/l. The lakes within the subwatershed are Clear, Howard, Columbus, Randeau, Peltier, Centerville, Otter, Bald Eagle (all eight are for water supply), Sunset, Pine Tree and White Bear. Problems in this subwatershed result from nutrients contained in runoff from agricultural activities and from urban areas close to the priority lakes.

Suggested management needs:

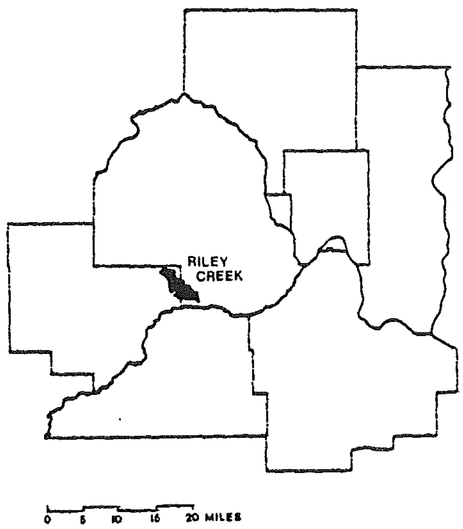
- Intensive housekeeping for Centerville, Mahtomedi, Willernie, Birchwood, White Bear Lake and Dellwood (leaf/litter program; 200 curb-miles per year of priority sweeping).
- 6,100 acres in cropland conservation practices.
- 4,300 acre-feet of wetland and artificial storage.
- 8,700 acres in noncropland rural critical area treatment.

Lower Rice Evaluation: The Lower Rice Creek subwatershed is a unique situation. A multimillion-dollar Clean Lake (Section 314) grant has been under way for several years on the area directly tributary to Long Lake. This remedial program addresses most of the identified problems on the main creek channel and three of the four priority lakes within the subwatershed. As such, no further suggested management needs will be made for the subwatershed or the three lakes (Long, Johanna, Josephine). Turtle Lake is not directly addressed in the project, and therefore is addressed in the suggested management need for reducing its inflow TP level of 0.62 mg/l.

Suggested management needs:

- Lower subwatershed should have no additional management practices beyond those associated with the Long Lake project and those used by the watershed district.
- Turtle Lake: - Information program for homeowners.
  - Intensive housekeeping in urban area.
  - 90 acre-feet of water storage.

32. Riley Creek. This watershed is recommended for high-priority lake attention because it contains three priority lakes; almost the entire watershed is covered by the priority lakes. Riley-Purgatory Creek Watershed District is the existing watershed management organization.



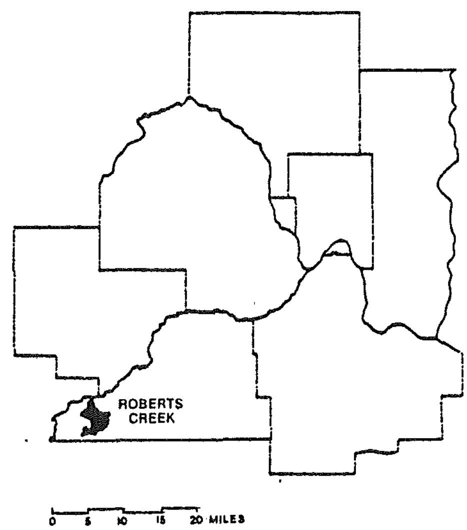
	Area (sq. mi.)	TSS	COD	TP	TN
Riley Creek	10.0	134	163	1.8	11.8

Evaluation: The Riley Creek watershed is another watershed undergoing development, but in a somewhat reduced manner. This watershed was not recommended for critical status because the problems of the watershed related to the priority lakes are to receive accelerated efforts. The focus of management, then, will be on reducing the TP concentration from agricultural and developing areas. The three priority lakes in the watershed are Riley, Ann and Lucy.

Suggested management needs:

- 1,100 acres in cropland conservation practices.
- 200 acre-feet of water storage.
- 340 acres in noncropland critical area treatment.
- Comprehensive storm water management in the urbanizing areas.

33. Robert's Creek. This watershed is recommended for secondary priority.

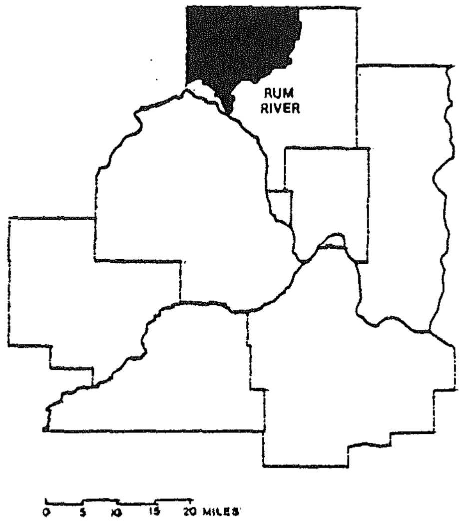


	Area (sq. mi.)	TSS	COD	TP	TN
Robert's Creek	11.6	30	16	0.20	1.4

Evaluation: Effective agricultural management in the watershed has eliminated the need for further efforts to meet the TSS and COD recommended guidelines.

Suggested management needs: No additional management practices.

34. Rum River. This watershed is recommended for critical priority because large parts of it discharge poor quality water upstream of the Minneapolis and St. Paul water supply intakes. Specific attention should be placed on this lower portion.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Cedar Creek	52.0	33	108	0.83	7.9	0.02
Ford Brook	45.3	39	164	0.88	7.3	0.01
Lower Rum urban	8.0	140	103	1.17	7.0	0.17
Lower Rum rural	49.4	92	189	1.10	15.1	
Seelye Brook	13.7	106	198	0.89	14.0	

Cedar Creek Evaluation: The Cedar Creek subwatershed is a predominantly rural basin, with flows going through the Anoka sand plain. The low TSS value and high solubles (COD, TP, TN) indicate low-erosion, high-infiltration/subsurface flow typical of agriculture from this area. Management to minimize this type of nonpoint pollution is difficult. Good agricultural management is the only feasible treatment method.

Suggested management needs:

- 560 acres in cropland conservation practices.
- Careful attention to chemical application practices.

Ford Brook Evaluation: The Ford Brook subwatershed is similar to Cedar Creek in its character and problems, as well as management approach. East Twin Lake is a priority lake with a watershed TP inflow value of 1.0 mg/l.

Suggested management needs:

- 2,900 Acres in cropland conservation practices.
- Careful attention to chemical application practices.
- East Twin Lake: - 40 acres in cropland conservation practices.
  - 24 acres in noncropland critical area treatment.

Lower Rum Evaluation: The priority problems of the watershed largely result from the Lower Rum subwatershed and management should focus here. Attention in the lower basin area will focus on Pb for the urbanized area of Anoka and on TSS from the rapidly urbanizing areas of Andover and Ramsey. Particular attention should be paid to minimize the runoff impact of the rapidly developing area. The rural portion of the basin is extensive; emphasis here should be on TP because of the discharge upstream of Fridley. The high-priority Lake George is located in the rural area, but suggested management needs are not made because of no apparent problems and the 1982 Clean Lakes study to be undertaken.

Suggested management needs:

Urban area:
- Intensive housekeeping for city of Anoka (leaf/litter program; 400 curb-miles per year priority sweeping).
- 375 acre-feet of water storage.
- Minimization of storm water impact from developing area.

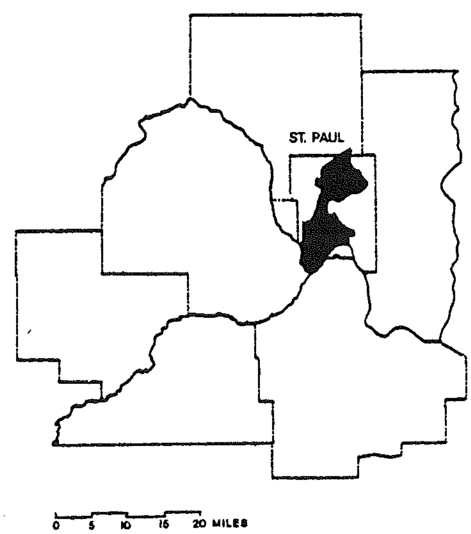
Rural area:
- 950 acres in cropland conservation practices.
- 1,570 acres in noncropland critical area treatment.
- 1,220 acre-feet of water storage.

Lake George: No additional management practices until completion of Section 314 study.

Seelye Brook Evaluation: The Seelye Brook subwatershed is a very small basin located only partially within the Region. The water quality modeling results attribute very high pollution levels to this basin. Suggested management needs focus on the critical cropland of the subwatershed.

Suggested management needs: 300 acres in cropland conservation practices.

35. St. Paul-Ramsey. This watershed is recommended for critical priority because of health-related lakes and generally poor water quality.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Northern	33.6	14	68	.34	2.4	0.03
Southern	40.0	80	52	.53	5.4	0.06

Northern Evaluation: The priority pollutant in this subwatershed is TP because of the high number of priority lakes within it. The St. Paul water supply lakes are Deep, Charley, Pleasant, Sucker and Vadnais; Wabasso Lake is a high-priority lake because it has been identified as a lake of exceptional quality; finally, Owasso and Snail are "regionally important," multiple-recreation lakes. Management of this basin is complicated by the fact that water diverted from the Mississippi River at Fridley is discharged into Charley Lake for the St. Paul water supply system, and watershed discharge occurs through the Vadnais Lake conduit to the McCarron's supply system treatment plant. Management of the watershed coincides with management of the lakes because of the number of priority lakes. The suggested management needs include those made for the Mississippi River upstream from Fridley.

Suggested management needs:

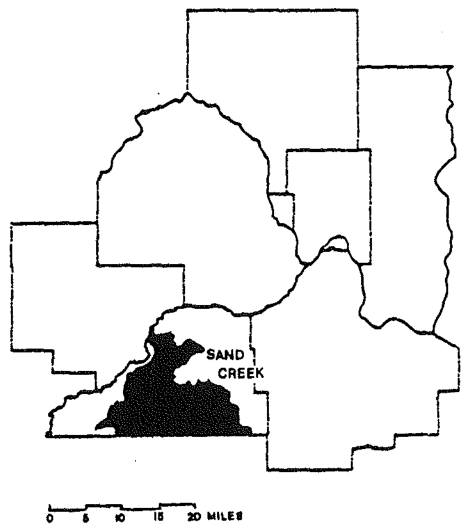
- Information program for homeowners around priority lakes.
- 1,575 acre-feet of water storage in developing southwest portion of basin.
- 1,060 acre-feet of storage in agricultural/vacant part of basin.
- 950 acre-feet of storage from the urbanized part of the basin.
- Comprehensive storm water management in urbanizing part of basin.

Southern Evaluation: The Southern subwatershed is quite densely developed and does include discharge into the combined sewer systems of St. Paul and Minneapolis. The COD level of this watershed appears to be acceptable, but the TSS level needs reduction by 64 percent. Management practice options are fairly limited because of the dense development. Several communities are currently involved in discussions on how to manage and pay for inflows into the combined sewer system via Como and McCarron's Lakes.

Suggested management needs:

- Intensive housekeeping in urban area (3,900 curb-miles per year priority sweeping; cleaning of 650 catch basins per year).
- 1,625 acre-feet of storage with emphasis on infiltration.
- Development of solution to lakes overflow problem.

36. Sand Creek. This watershed is recommended for secondary priority.



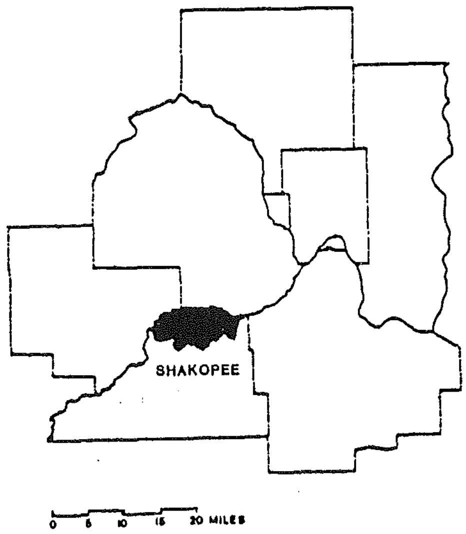
	Area (sq. mi.)	TSS	COD	TP	TN
Sand Creek	165.4	7	14	0.13	0.7

Evaluation: The Sand Creek watershed is essentially all rural and apparently has quite good quality. The TSS and COD levels need no reduction to meet the recommended guidelines. The numerous subwatersheds in this large watershed should be individually addressed in the watershed planning stage. The local soil and water conservation district has pointed out the need for programs for feedlots and erosion-prone lands. There are, however, two priority lakes--Cedar and McMahon--in the watershed. Cedar Lake is "regionally important," but is unfortunately of quite poor quality because of its shallowness. Both McMahon and Cedar Lakes have watersheds that contribute a level of 0.12 mg/l TP, only slightly above the guideline.

Suggested management needs:

- Existing watershed management practices, plus specific attention on feedlots and erosion-prone land.
- Cedar Lake: 260 acres in cropland conservation practices.
- McMahon Lake: 55 acres in cropland conservation practices.

37. Shakopee. This watershed is recommended for critical priority because of the water quality problems and priority lakes.



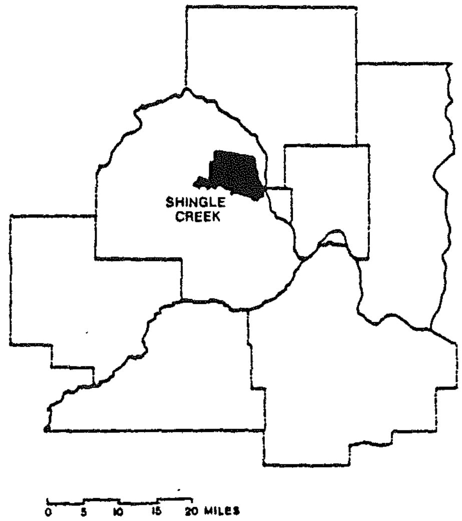
	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Shakopee	52.1	84	107	0.73	13	0.01

Shakopee Evaluation: The Shakopee watershed is a wide basin discharging to the Minnesota River from many small streams. Land use within the basin varies from rural to fully urbanized to open space with a fair amount of urbanization under way. Two priority lakes--O'Dowd and Thole--are in the watershed. Each of these lakes has an inflow TP value of 0.8 mg/l. This watershed might at times be impacted by high water discharges from Prior Lake.

Suggested management needs:

- 5,900 acres in cropland conservation practices.
- Intensive housekeeping for Shakopee and Savage Hwy. 13 commercial corridor.
- 775 acre-feet of water storage.
- 3,400 acres in noncropland critical area treatment.
- Comprehensive storm water management in developing area.
- O'Dowd and Thole Lakes: 350 acres each of cropland conservation practices and noncropland critical area treatment.

38. Shingle Creek. This watershed is recommended for critical priority because of the water quality problems specifically in the Lower Shingle subwatershed.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Upper Shingle	16.3	30	45	0.32	2.3	0.03
Lower Shingle	29.1	96	92	0.83	4.9	0.09

Upper Shingle Evaluation: The Upper Shingle Creek subwatershed is an area where severe water quality problems currently do not exist, but where potential degradation is high because of urbanization. The TSS level is currently at the recommended guideline and, consequently, no additional management practices are recommended at this time. It is emphasized, however, that strict attention be paid to storm water management as this area continues its urbanization to largely residential uses. Additionally, one "regionally important" and one priority lake, Eagle and Bass, respectively, are located in this subwatershed. Both lakes are in an area undergoing urbanization and therefore need good storm water management to guide development. Both Eagle and Bass have inflow at 0.36 mg/l TP.

Suggested management needs:

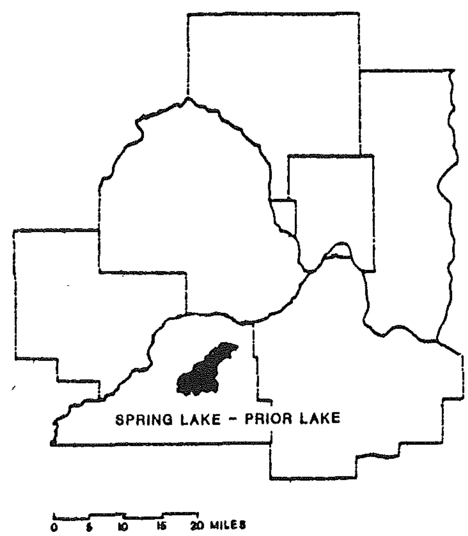
- Comprehensive storm water management for the entire subwatershed as it develops further.
- Eagle Lake: 200 acre-feet of wetland storage.
- Bass Lake: 330 acre-feet of wetland storage.

Lower Shingle Evaluation: The Lower Shingle Creek subwatershed differs markedly from the upper portion. This subwatershed is fully urbanized, with parts of the extreme lower portion (Minneapolis) discharging to the combined sewer system. Because of this combined sewer discharge, the priority pollutant for the subwatershed is chemical oxygen demand (COD). The COD level in the basin needs a 45-percent reduction. For comparison purposes, the TSS level would have to be reduced by 69 percent. Management recommendations focus on housekeeping because of the large amount of impervious surface, and storage that emphasizes infiltration. The infiltration recommendation could include infiltration swales in parking areas, ponds with pervious bottoms and perforated outlet piping, seepage areas or numerous other possibilities that would minimize runoff. This subwatershed also includes the priority Twin Lakes basin, which has an inflow of 0.17 mg/l TP.

Suggested management needs:

- Intensive housekeeping for urban area (2,700 curb-miles per year priority sweeping; cleaning of 4,500 catch basins per year).
- 860 acre-feet of water storage, with emphasis on infiltration.
- Twin Lakes:
  - Information program for watershed homeowners.
  - Intensive housekeeping for areas directly tributary to the lake (360 curb-miles per year of priority sweeping).

39. Spring Lake-Prior lake. This watershed is recommended for critical priority because of its poor water quality and two "regionally important" lakes. Prior Lake-Spring Lake Watershed District is the existing watershed management organization.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Spring Lake	22.0	80	338	2.90	17.0	
Prior Lake	7.7	51	101	0.94	4.1	0.03

Spring Lake Evaluation: The Spring Lake subwatershed drains agricultural land, except for the residential land immediately surrounding the lake itself. The focus for the watershed is reduction of TP because the entire watershed drains to the lake. There appears to be a need for a 97-percent TP reduction, a very high reduction figure. Management should focus on agricultural activities and on the lakeshore owners. The watershed and the priority Spring Lake basin are addressed together because the lake is at the terminus of the subwatershed.

Suggested management needs:

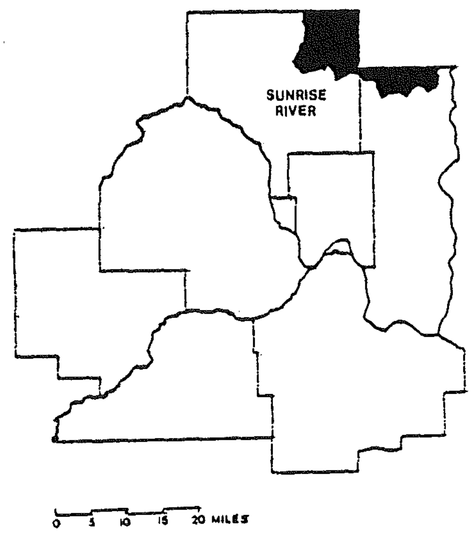
- 1,640 acres in cropland conservation practices.
- 5,900 acres in noncropland critical area treatment.
- Information program for lakeshore owners.
- Adapting the watershed district's detention pond to meet water quality needs to a greater extent.

Prior Lake Evaluation: The Prior Lake subwatershed receives direct runoff from the urbanizing area surrounding the lake, as well as the discharge from the Spring Lake subwatershed. As with the Spring Lake subwatershed, the management recommendations for the Prior Lake watershed and the regionally important Prior Lake are the same because Prior Lake is at the terminus of the subwatershed. Management focuses on the urban and urbanizing activities occurring in the basin. Problems have been minimized to a degree in the recent past by the activities of a watershed district for both Spring and Prior Lakes. An additional note: A new Prior Lake outfall is being installed by the watershed district to discharge high water from the lake northwestward through Shakopee to the Minnesota River. For this reason, the Shakopee watershed might at times be impacted by discharges from the Prior Lake watershed.

Suggested management needs:

- Intensive housekeeping in urbanized area (112 curb-miles per year of priority sweeping; 1,100 catch basins cleaned per year; leaf/litter program).
- Information program for watershed residents.
- 375 acre-feet of water quality storage, possibly retrofitted on existing storage.
- Comprehensive storm water management for developing area.

40. Sunrise River. This watershed is recommended for secondary priority because its greatest problems will be addressed through the priority lakes.



	Area (sq. mi.)	TSS	COD	TP	TN
South Branch	69.3	161	205	0.97	8.5
West Branch	30.7	145	189	0.84	28 0

South Branch Evaluation: The South Branch subwatershed is a predominantly rural watershed with some areas urbanized around lakes, particularly Forest Lake. The most serious problems of the watershed relate to the three high-priority lakes--Forest, Coon and Bone. The watershed concentrations are surprisingly high and are suspected to have been artificially skewed by the water quality model.

Suggested management needs:

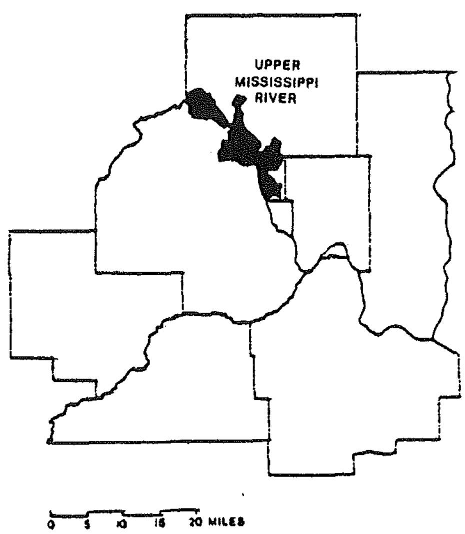
- 5,000 acres in cropland conservation practices.
- 2,160 acres in noncropland critical area treatment.
- 4,050 acre-feet of wetland storage.
- Forest Lake:
  - Intensive housekeeping in city of Forest Lake (800 residential curb-miles per year; 520 commercial/industrial curb-miles per year).
  - 245 acres in cropland conservation practices.
  - 200 acre-feet of wetland storage.
- Coon Lake:
  - Information program for homeowners.
  - Leaf/litter program.
  - 260 acre-feet of wetland storage.
- Bone Lake:
  - 475 acres in cropland conservation practices.
  - 450 acre-feet of wetland storage.

West Branch Evaluation: Water quality values of the West Branch subwatershed were very high, possibly due to model skewing because of the three priority lakes (Linwood, Martin and Island) in a chain. As with the South Branch, the major water quality problem is with the priority lakes because of their location within the basin.

Suggested management needs:

- 1,160 acres in cropland tillage treatment.
- Linwood, Martin, Island chain:
  - 210 acres in cropland conservation practices.
  - 490 acres noncropland critical area treatment.

41. Upper Mississippi River (UMS). This series of four basins is recommended for critical priority because of its water quality problems occurring upstream of the Fridley intakes.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Anoka	6.9	123	92	1.13	6.6	0.10
Coon Rapids	9 9	78	66	0.93	5.2	0.04
Osseo	33.7	66	66	0.80	5.8	0.14
Upper	16.5	26	44	0.54	3.1	0.04

Anoka Evaluation: The Anoka (Rum 7) is predominantly developed, and as such, is analyzed for lead (Pb) as a priority pollutant. The Pb level for this basin needs a 50-percent reduction to meet the guidelines for a health-related watershed. The other four pollutants used for the evaluation also greatly exceed the recommended guidelines.

Suggested management needs: Intensive housekeeping for Anoka and Coon Rapids (covered in Coon Creek and Rum River sections).

Coon Rapids Evaluation: The Coon Rapids subwatershed (UMS 4-5) covers parts of Blaine, Coon Rapids, Spring Lake Park and Fridley. The area is urbanized and above the water intakes, but the Pb level appears acceptable. The secondary pollutant (TP), however, is in need of an 89-percent reduction.

Suggested management needs:

- Intensive housekeeping in urbanized area (300 curb-miles per year of priority sweeping; leaf/litter program).
- 900 acre-feet of water quality storage.

Osseo Evaluation: The Osseo subwatershed (UMS 3) is the largest subwatershed, draining an area that is not yet urbanized but should be within the next 20 years, as well as several urbanized communities in southern Anoka County. Comprehensive storm water management is essential as the area urbanizes. The Pb value of 0.14 mg/l is quite high and is likely a reflection of urbanization and the transportation corridor adjacent to the river.

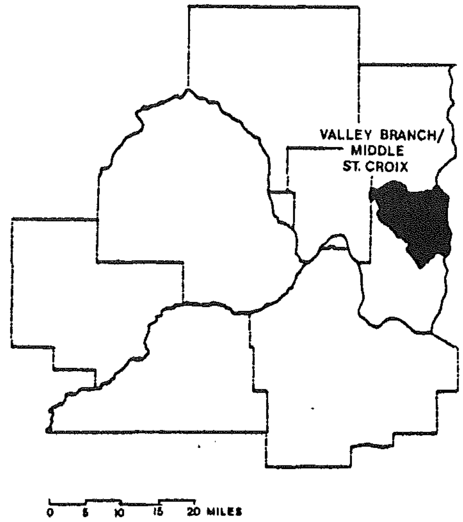
Suggested management needs:

- Intensive housekeeping (776 curb-miles per year; leaf/litter program; cleaning of 100 catch basins).
- 725 acre-feet of wetland storage.

Upper Evaluation: The Upper subwatershed (UMS 1-2) consists principally of the transportation corridor along both sides of the river. Pb, TP and TN all exceed the guidelines, with priority attention going to Pb.

Suggested management needs: 1,100 acre-feet of wetland storage along transportation corridors.

42.& 43. Valley Branch and Middle St. Croix River. The water quality levels of these combined watersheds lead to a recommendation for secondary priority. Valley Branch Watershed District is the existing watershed management unit for Valley Branch portion.



	Area (sq. mi.)	TSS	COD	TP	TN	Pb
Valley and Mid-St. Croix	73.6	48	41	0.25	2.2	0.01

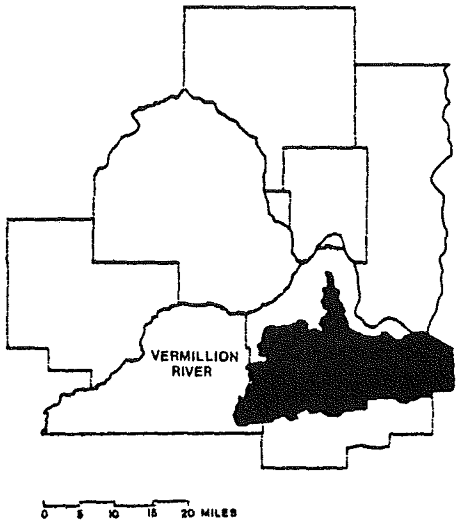
Evaluation: These two secondary watersheds are combined for evaluation because data was collected for one larger watershed, the Stillwater basin. This watershed is quite diverse in nature, with several urbanizing areas, a stable, fully developed area, and large tracts of agricultural land. The watershed is typified by several internally drained subbasins, drainage difficulties and small streams discharging directly to the St. Croix River. The high TSS value results from agricultural activity and new construction. The Valley Branch Watershed District has identified in its mainstem plan several large-scale runoff control projects costing several million dollars over many years. The water quality improvements recommended could be possible from these projects. The Valley Branch watershed also contains four priority lakes--DeMontreville, Elmo, Jane and Olson--one of which (Elmo) is a "regionally important" lake; all four lakes have an inflow TP concentration of 0.83 mg/l. The Tri-Lakes (DeMontreville, Jane and Olson) watershed is combined to evaluate TP reduction needs. Major attention in the combined Valley Branch-Middle St. Croix watershed must be directed at minimizing storm water impact as the area develops.

Suggested management needs:

- Storm water management in urbanizing area.
- 4,700 acres in cropland conservation practices.
- Intensive housekeeping in urban area along St. Croix River.
- 860 acre-feet of wetland and closed-basin storage.
- Tri-Lakes:
  - Storm water management in urbanizing area.
  - 75 acres in cropland conservation practices.
  - 150 acre-feet of water quality storage.*
- Elmo:
  - Storm water management in urbanizing areas.
  - 50 acres in cropland conservation practices.
  - 92 acre-feet of water quality storage.

*Possibly obtained by retrofitting existing quantity-oriented storage areas.

44. Vermillion River. The Vermillion River is one of the Region's critical watersheds because it greatly exceeds the TSS recommended quality guideline of 30 mg/l for all three subwatersheds. Attention should be focused on the North Branch.



	Area (sq. mi.)	TSS	COD	TP	TN
North Branch	58.7	104	77	0.46	13.1
Mainstem	186.3	64	53	0.34	7.3
Hardwood Creek	81.2	142	59	0.76	5.2

North Branch Evaluation: Rural land uses currently predominate in the North Branch subwatershed, but the north and west portions of the basin are urbanizing. Agriculture and new urban development have led to a high TSS, COD and nutrient load. Suggested management needs focus on reducing agricultural runoff and providing storage of urban runoff so this water can be slowed down and infiltrated. This subwatershed should be the focus of management attention because of the rapid urbanization.

Suggested management needs:

- 6,000 acres in cropland conservation practices.
- 3,000 acres in noncropland critical area treatment.
- 500 acre-feet of urban-area storage in closed basins or wetlands.

Mainstem Evaluation: The Mainstem Vermillion is a primarily agricultural subwatershed, undergoing urbanization principally in the far northwestern part of the basin. It is experiencing periodic flooding problems in urban Hastings. Wetlands and standing water are very scarce, and irrigation is commonly used to supplement soil moisture. Cash-cropping is the dominant agricultural activity. Such activity leads to sediment generation as a priority problem, along with the solubles and fine particulate problems associated with agricultural runoff, as discussed previously. The Mainstem subwatershed also contains two of the 100 priority lakes--Marion and Crystal--that have inflow concentrations of 1.25 mg/l TP. Marion Lake's problems result from rural and urban runoff. Crystal's result from its urbanized watershed.

Suggested management needs:

- 18,000 acres in cropland conservation practices.
- 7,100 acres in noncropland critical area treatment.
- Marion Lake: - 325 acres in conservation practices.
  - 230 acres in noncropland critical area treatment.
- Crystal Lake: - Information program for homeowners.
  - 115 acre-feet of wetland detention storage.

Hardwood Creek Evaluation: Hardwood Creek subwatershed is similar to the Mainstem subwatershed in agricultural activity and associated problems. The major individual problem in the basin occurs at Etter, where extreme channel erosion has occurred from upstream runoff. There are no suggested management needs beyond the housing relocations currently under way.

Suggested management needs: 5,200 acres in cropland conservation practices.

Appendix G
ROAD SALT/ANTI-SKID ANALYSIS FROM SEVERAL APPLICATORS

ROAD SALT/ANTI-SKID AGENT SAMPLES

A substudy was done in the 208 program to see what kind of pollutants were introduced to runoff as a result of road salt/anti-skid agents that are applied during the winter. The data are quite rough and should be used only in an evaluative sense.

Method. A five-pound sample of road salt mixed with sand was randomly collected from the storage facilities of five communities, Hennepin County and the Minnesota Department of Transportation (MnDOT). In addition, a straight sand and a straight salt sample were collected from the Hennepin County stockpile. The sand-to-salt ratios for the mixes were:

Brooklyn Park 2:1
Golden Valley 5:1
Eden Prairie 10:1
Crystal 10:1
Hennepin County Highway Department 20:1
Cottage Grove 6:1
MnDOT 2:1

Two hundred grams (g) of each of the mixtures and the straight sand and 40g of the straight salt were each placed in two liters of distilled water and agitated for approximately two minutes. The 200g sample was composed mostly of very coarse-grained sand that settled almost immediately; the 40g of salt dissolved nearly 100 percent after two minutes.

The first sample was taken 10 cm from the surface after 30 seconds, and the second sample was taken 5 cm from the surface at 3:52 minutes. These depths and times at the temperature recorded show the sand split and the silt split, respectively, based on Stokes Law (see Appendix I). Analyses were then run on the split samples for Zn, Pb, TSS, VSS, TP and TKN (see Appendix A).

Results and Discussion. The results of the chemical and physical tests for the sampled road salt/anti-skid agents are listed in Table G-1. The 200g level for solids was chosen to match the concentration actually seen in runoff from highways and road surfaces. The mixtures collected were obviously such a large percentage of coarse sand that it was believed that to properly synthesize field concentrations of suspended solids as actually sampled, a large mass of the mixture would be needed. The 40g of salt was selected to represent the sand:salt mixture of 5:1 without the solids interference. The qualitative scenario that can then be drawn from the data in Table G-1 is that these data represent the fine-grained pollutants that are likely to migrate in snowmelt or early spring runoff from street surfaces. The TSS values in Table G-1 are very close to those actually observed in such runoff events (Table 6 in text).

Table G-1
RESULTS OF ANALYSIS FOR ROAD SALT/ANTI-SKID AGENTS

Sample	Sand:Salt	Time Settled (min.:sec.)	Zn	Pb	TSS	VSS	TP	TKN
Brooklyn Park	2:1	0:30	.08	.31	642	34	.53	.34
		3:52	.07	.32	406	24	.41	.32
Golden Valley	5:1	0:30	.10	.25	895	44	.62	.30
		3:52	.08	.25	582	52	.24	.34
Cottage Grove	6:1	0:30	.13	.03	3036	58	.17	.24
		3:52	.09	.12	992	52	.10	.04
Eden Prairie	10:1	0:30	.08	.10	890	58	.80	.20
		3:52	.06	.12	638	56	.38	.32
Crystal	10:1	0:30	.05	.02	640	36	.43	.20
		3:52	.04	.02	376	32	.30	.26
Hennepin County Highway Dept.	20:1	0:30	.12	.12	1688	98	.15	.20
		3:52	.10	.11	1106	96	.08	.14
Hennepin County Highway Dept.	All sand	0:30	.04	.01	426	32	.24	.16
		3:52	.03	.01	256	22	.23	.30
Mn/DOT	2:1	0:30	.11	.22	1016	58	.07	.12
		3:52	.09	.20	612	58	.04	.08
Hennepin County Highway Dept.	All salt	0:30	.03	.36	--	--	.01	.16
		3:52	--	--	--	--	--	--

Several observations can be made by looking at the data in Table G1. The TSS levels are dependent on the borrow material used rather than on the ratio of sand:salt mixed. Physical observation of clarity after agitation showed quite readily that the Cottage Grove "sand" was very high in silt and clay, and Hennepin County straight sand was low. The Hennepin County sample, however, probably had increased clarity because of lack of colloidal interference from salt. The fines are roughly 60 percent clay and 40 percent silt (as shown in the settling splits), except for Cottage Grove, which is about 70 percent silt. Finally, the suspended solids are primarily inert, with VSS in the 2-9 percent range of TSS. The solids figures clearly show that a very small part of the anti-skid solids applied to a street will likely migrate very far and should readily settle in any nearby detention facility, including a wetland, a lake or a stream channel.

The TKN values in Table G1 generally fall quite low relative to the concentration values seen for TKN in runoff from urban surfaces (Table 6 in the text and USGS Basic Data Report). Typical TKN values of snowmelt and early spring runoff from urban streets are in the 1.0 - 5.0 mg/l range, while the anti-skid agent levels in Table G1 are all less than 0.34 mg/l. The TP concentrations, on the other hand, are very high relative to urban street runoff. Typical TP concentrations at urban storm sewer sites are in the 0.1-1.0 mg/l range. The TP values in Table G1 fall directly in this range and therefore could contribute substantially to the total phosphorus load coming from street surfaces. A key to the source of this TP is in the Hennepin County Highway Department straight sand analysis, which shows a TP concentration of about 0.24 mg/l for the fines portion. Bioavailability of this phosphorus is not known.

Lead and zinc ranges in snowmelt and early spring runoff are generally 0.1-0.5 mg/l and 0.05-0.2 mg/l, respectively. The ranges in areas with high traffic values are 0.5-1.0 mg/l Pb and 0.5-0.7 mg/l Zn (Table 6 in text; and USGS Basic Data Report). Again, it appears that a fair portion of the Pb load and a little less of the Zn load might come from the material added to the street. A possible source of the metals found is seen in the Hennepin County Highway Department straight salt (Table G-1) which contains 0.36 mg/l Pb and 0.03 mg/l Zn.

Although these data do indicate some preliminary findings relative to salt and anti-skid agents, caution should be used in drawing conclusions. The data are fairly limited, representing a one-time effort for evaluative purposes. One must keep in mind that the salt/anti-skid agents are applied usually once or twice during a storm, while automobiles and trucks continually traverse the roadways.

From a management standpoint, however, it seems very apparent that judicious use of these materials is warranted. The data presented do not merit massive curtailments in road salting/sanding operations, but do suggest programs that minimize "precautionary" salting, maximize equipment maintenance, and provide for proper materials storage. The very high pollutant levels seen in runoff during early spring rains also suggests street cleaning as soon as possible after snowmelt, particularly in watersheds immediately tributary to lakes.

Appendix H
IMPACT OF WETLANDS ON WATERSHED WATER QUALITY

Presented by Gary Oberts and Rob Brown
at Midwest Conference on Wetland Values and Management
June 17-19, 1981
St. Paul, Minnesota

IMPACT OF WETLANDS ON WATERSHED WATER QUALITY

G. L. OBERTS[1]

ABSTRACT

A nonpoint source water quality sampling study was conducted on six rural and 11 urban watersheds in the Minneapolis-St. Paul Metropolitan Area (2,968 square miles). Wetland occurrence was one principle watershed selection criterion because wetlands were expected to play a major role in determination of watershed water quality. Regionally, wetlands compose approximately 7.4 percent of the total seven-county area; wetland percentages in the sampled watersheds vary from 4.8 to 16.3 in the rural basins and from 0 to 14.5 in the urban basins. Results of the water quality monitoring show that wetlands occurrence relates to the annual watershed loads for several sampled constituents. Multiple regression statistical modeling of the sampled watersheds yields significant relationships when various combinations of wetland-related watershed factors are evaluated.

INTRODUCTION

A nonpoint source water quality sampling program was undertaken as part of a Section 208 (Public Law 95-217) Water Quality Management Program. Six rural and four urban receiving streams as well as seven subwatersheds within the four urban basins, were monitored during the entire calendar year 1980. The major objective of the program was to sample a sufficient quantity of runoff events to adequately determine the impact of nonpoint sources on receiving streams and lakes in 1980.

It was expected that the degree of wetland occurrence within a watershed would be a major determinant of water quality. Because the Metropolitan Area surface is composed of approximately 7.4 percent wetlands, watersheds with variable wetland content were easy to select, and wetland content was one of the major criteria for watershed selection. If wetlands are found to be a significant factor in improving the quality of runoff, then they would be recommended as nonstructural management practice for treatment or handling of runoff. However, knowledge of wetland behavior and long-term reaction to high loads is needed before widespread use of wetlands for water quality management can be recommended.

METHODS

From 15 to 30 snowmelt and rainfall events, in addition to baseline samples, were collected at each of the 17 sites. The 12 watersheds

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that responded quickly to runoff were equipped with Manning automatic water samplers (model S-4050, adapted for one-liter samples). Each station was equipped with U.S. Geological Survey (USGS) stage recording equipment and set to record every 5 or 15 minutes, depending on watershed response. Finally, each station had on-site or nearby a tipping-bucket rainfall gage (sensitive to 0.01 inch) with recorder, and a bulk precipitation gage for calibration. Sampling sites were maintained and field data were collected by USGS personnel.

Laboratory analysis of up to 35 chemical, biological or physical constituents for each sampling event was done by the Metropolitan Waste Control Commission water quality laboratory. A quality assurance program was concurrently undertaken with the USGS water quality laboratory in Atlanta, Georgia. The data management system was a highly modified version of the system available through the Urban Hydroloogy Program of USGS; the modified system allowed for analysis of over 16,000 pieces of water quality information, plus continuous flow and precipitation data. The system modification was done by project personnel.

Watershed basin characteristics including wetland area were determined for each watershed in the Region from available topographic and land use maps, and from a rural area survey of agricultural use/management done under contract by the Association of Metropolitan Soil and Water Conservation Districts. Approximately 30 characteristics were gathered for each basin. Further details on the nature of the study can be found in Ayers et al., 1980.

RESULTS AND DISCUSSION

1980 Water Quality Loads

The 1980 watershed loads, in pounds per acre, for the 17 watersheds are contained in Table 1. Following are brief descriptions of the sampled watersheds:

Bevens Creek - dairy and support agriculture; wetlands mostly in upper watershed.
Carver Creek - same agriculture as Bevens Creek; wetlands throughout watershed.
Credit River - cash crop agriculture with mixed open space; moderate wetlands.
Elm Creek - in transition from agriculture to low density urban; many wetlands.
Raven Stream - dairy and support activities; moderate wetlands.
So. Branch Vermillion River - cash crop agriculture, highly irrigated; few wetlands.
Bassett Creek - urban tributary; changes from low-density to high-density urban.
Shingle Creek - urban tributary; changes similar to Bassett Creek but slightly less dense.
Purgatory Creek - rapidly urbanizing; site just downstream from small lake.

Table 1
1980 WATERSHED LOADS AND PERCENTAGE WETLAND
IN SAMPLED WATERSHEDS

Site	Area $mi.^2$	Wetland Percent (water)	Load (lb/acre) TSS	COD	TKN	NN	TP	Pb	Runoff, in.
Bevens Creek	82.9	5.2 (0.8)	18.8	31.6	1.44	1.23	0.33	-	1.86
Carver Creek	65.2	9.6 (9.3)	15.6	39.2	1.45	0.29	0.42	-	2.11
Raven Stream	32.4	5.8 (0.2)	24.1	40.8	2.10	1.98	0.38	-	2.30
Credit River	23.2	11.0 (3.0)	24.6	55.4	2.32	0.50	0.56	-	3.42
Elm Creek	14.3	16.3 (0.2)	9.3	59.3	1,89	0.25	0.32	-	4.02
So. Br. Vermillion R.	30.8	4.8 (0.0)	155.1	61.2	2.88	4.63	0.53	-	6.65
Bassett Cr.	31.7	8.1 (6.4)	78.1	55.2	2.20	0.46	0.37	0.037	5.36
Shingle Cr.	22.9	8.2 (4.6)	30.5	36.6	1.71	0.25	0.22	0.034	3.69
Purgatory Cr.	24.0	14.5 (4.9)	14.2	39.3	1.09	0.03	0.07	0.003	3.14
80th St.	1.55	1.5 (0.0)	32.3	53.3	1.85	0.55	0.44	0.048	3.24
Iverson	0.15	0.0 (0.0)	1820	99.7	3.41	0.27	1.70	0.071	2.43
PDQ	0.13	0.0 (0.0)	716	106	7.14	0.90	1.88	0.108	4.96
Wesley	0.33	4.0 (0.0)	347	137	4.20	2.51	0.99	1.049	7.03
Sandburg	0.12	0.0 (0.0)	1350	265	11.4	1.63	0.89	0.380	10.42
Hwy. 100	0.47	0.3 (0.0)	115	168	2.53	0.62	0.42	0.549	6.41
Estates	0.22	0.0 (0.0)	55.1	111	3.76	0.66	0.98	0.276	5.63
Yates	0.35	0.0 (0.0)	159	158	4.98	0.69	0.63	0.107	4.41

Key

TSS - total suspended solids
COD - chemical oxygen demand
TKN - total Kjeldahl nitrogen
NN - nitrite-nitrate-nitrogen
Tb - total phosphorus
Pb - total load

80th Street - site at medium density, new residential; mainstem outlet of detention system.

Estates Drive - medium-density residential storm sewer site in Shingle watershed.

Yates Avenue - multifamily and medium-density residential storm sewer site in Shingle watershed.

Highway 100 - high-density residential storm sewer site with major highway in Bassett watershed.

Wesley Park - medium-density residential storm sewer site in Bassett watershed.

Sandburg Road - light industrial park storm sewer site in Bassett watershed.

PDQ Store - multifamily and medium-density residential storm sewer site in Purgatory watershed.

Iverson Avenue - medium-density residential under construction in 80th Street watershed.

Table 1 shows that a reduction in per-acre loading exists between storm sewer subwatersheds and the mainstems. This load attenuation is due to many physical, chemical and biological factors, including settling, oxidation-reduction, and biological utilization. Nitrite-nitrate-nitrogen (NN) is an exception to the general trends shown elsewhere in the table, due largely to the nitrification-denitrification phenomenon that causes such variability within a watershed.

Analysis of the 1980 seasonal loading data indicates that a large portion of the total annual load for the rural area occurs during snowmelt runoff or as a result of storms that occur prior to establishment of a protective vegetative canopy (Metropolitan Council, 1981). The data indicate that the snowmelt and early storm events accounted for a significant percentage of the annual load: 49 to 82 percent of TSS, 50 to 79 percent of COD, 73 to 89 percent of TKN, and 83 to 86 percent of TP. Wetland retention of runoff and influence on water quality during these periods of the year seems minimal because the ground is frozen and the vegetation largely dormant.

The urban seasonal load analysis, however, showed that the annual load is uniform over the first three seasons, with autumn loading being lower due to decreased rainfall. The urban mainstem and storm sewer sites respond to every measurable rainfall and snowmelt, resulting in numerous load increments composing the total load. The six largest events of the year were responsible for 50 to 75 percent of the flow; 49 to 80 percent of the TSS load; and 50 to 78 percent of the TKN load. Five of these six events occurred between the June and September when wetlands are biologically active and capable of responding to stormwater inputs.

Statistical Analysis

The loading data presented in Table 1 forms the basis for generating loads for every watershed in the Region by regression analysis. Long-term median loads for the 17 study watersheds were determined using the relationship of rainfall-snowmelt-runoff and the resultant water quality. The historic National Oceanic and Atmospheric Administration (NOAA) precipitation records (1952-1980) and USGS flow data from long-term stations (1963-1980) were used to generate 18 years of loading data for the 17 watersheds by applying the relationship above, thus allowing for frequency analysis of nonpoint source loading in the watersheds.

After the particular basin characteristics that influence the loads in a watershed were determined, it was possible to show how these loads related to the occurrence of wetlands. Approximately 30 independent variables were quantified and placed into the modified data management system for multiple regressions using various techniques with loads as the dependent variables. Table 2 lists the final multiple regression models that were chosen to determine the long-term median loads for regional watersheds. Storm sewer subwatersheds were not included in the development of these models because of the size of the watersheds to which projection occurred. The independent variables occurring in the table are defined as follows, with those variables involving wetlands listed first:

LUWET = percentage of watershed area in wetlands.
LUWTR = percentage of watershed area in standing water.
LUWTWR = LUWET + LUWTR.
LUAGI = percentage watershed area in agriculture or vacant land.
USLER = Universal Soil Loss Equation-derived soil loss (tons/acre/yr)
USWET = USLER/LUWET.
RELEF = watershed relief (ft.).
LUURB = percentage of watershed in urban.
LUCI = percentage of watershed in commercial and industrial.
LUOS = percentage of watershed in open space.
LURSF = percentage of watershed in residential single family.
LUURBCO = LUURB - (LUCI + LUOS).
LUWETAGI = LUWET + LUAGI.
LUURBC = LURRB - LUCI.
LUOSAG = LUOS + LUAGI.
LUURBO = LUURB - LUOS.
TAREA = watershed area (square mile).
CSLOPE = slope of main channel (ft/mile).
DRDNS = feet of channel per watershed area (ft/acre).
LUPASG = percentage of watershed in pasture and grass.
LUMEAD = percentage of watershed in meadow.
LUCROP = percentage of watershed in cropland.
NONCRP = LUAGI - LUCROP.
LURSFURB = LURSF/LUURB.

Reference to Table 2 shows that wetland-related variables are part of the final watershed models in the urban area for TN, TSS, TKN, NN, TP and Pb; and in the agricultural area for TSS and TKN. It was an unexpected result to find that the percentage of wetlands (LUWET) alone did not play a more significant role in loading. The LUWET variable appeared only in the urban NN and agricultural TKN models. Table 2 did, however, reveal that wetlands can be quite important when used as a variable in combination with another watershed or management variable.

Table 2
FINAL SELECTED MULTIPLE REGRESSION MODELS
FOR LONG-TERM MEDIAN LOAD DETERMINATION (lbs/mi^2)

Urban Models:	R^2	C.V.[1]	Signif (%)
(2)IN = 1.32+0.012*RELEF+0.025*LUURBCO	.99	1	99
TN = 9296-86*LUWETAGI-54.8*LUURBCO	.99	1	99
COD = 7175-772*LURSF+1297*LUURBC	.99	1	99
TSS = 126,055-1389*LUWETAGI-585*LUURBCO	.99	1	99
TKN = 2957-21.8*LUWTWR-23.6*LUWETAGI	.99	1	98
NN = 1034-38.4*LUWET-8.6*LUOSAG	.99	3	98
TP = 2139-20.3*LUWETAGI-15*LUURBO	.99	7	95
Cl = -41600-84800*LURSFURB+2556*LUURBO	.99	1	99
Pb = 69.6-4.7*LUWTWR-0.8*LURSF+1.3*LUURBCO	.99	1	99
Agricultural Models:			
(3)IN = 0.188-0.002*TAREA+0.01*CSLOPE+ 0.008*DRDNS-0.009*LUPASG	.99	1	99
TN = 1137-90*LUAGI+346*LUURB+113*LUCROP	.98	9	98
COD = 169,000-1924*LUAGI+460*LUCROP-238*LUMEAD	.99	1	99
TSS = 136,000-1676*LUAGI-7025*USLER+83300*USWET	.99	8	99
TKN = 1565+73*LUWTR+10*LUWET-46*LUMEAD	.81	11	73
NN = 174-198*LUWTR+204*LUMEAD+561* LUURB-176*NONCRP	.99	19	88
TP = 254+25.7*LUWTR-4.2*LUMEAD	.99	5	99

(1) Coefficient of variation (C.V.)=100*(standard deviation/mean).
(2) Total inches of runoff.
(3) Inches per square mile of runoff.

The variable LUWETAGI appearing in the urban TN, TSS, TKN and TP models as a negative relationship points to the value of wetlands and nonintensive urban uses as factors in reducing urban area pollution loading. LUWTWR, appearing as a negative relationship in the urban TKN and Pb models, again supports the concept of wetland retention, in conjunction with standing water (storage), as a natural biological pollutant treatment system on a watershed basis. Prior work on the origin and movement of pollutants at the sampled sites (Metropolitan Council, 1981) indicates that much of the material moving from urban surfaces into receiving waters is associated with particulates, which should settle within a reasonable time span. It is for this reason that wetlands are deemed important in reducing loads for the pollutants containing a wetland-related model factor in Table 2.

The agricultural area models in Table 2 are distinctly different from the urban models in terms of independent variables used in the models. Wetland-related variables appear only in the TSS and TKN models. For TSS, the positive relationship with USWET indicates that enhancement of wetlands and/or decreasing the USLE soil loss will result in the reduction of the 83,300 multiplication factor. The TKN model, however, shows a positive LUWET variable, as well as a positive LUWTR. Prior work on the agricultural loadings indicated that a large portion of the agricultural load occurred in the soluble or finely suspended state. This fact, combined with the fact that the rural area runoff and loading are dominated by winter snowmelt and early spring storm events when wetlands are frozen and biologically inactive, indicates that wetlands play less of a critical role in rural area pollution determination compared to the urban pollution determination. In summary, most of the pollutants either wash through the wetlands or solubilize in wetlands during periods of low flow, only to be mobilized in finely suspended or soluble form when a sufficient quantity of flow is available. The majority of sampled rural events verify this hypothesis.

The conclusions drawn from the models in Table 2 indicate that a combination of wetland and other factors would reveal more insight into wetland behavior relative to pollution reduction. This information will also allow for conceptualization of management approaches. Table 3 lists 26 combination variables that were generated based on concepts as to how wetlands might be functioning on a watershed basis in relation to land uses and on-going management. These variables were input to a model development program of the data management system without any other independent variables to model the various long-term median watershed loads. Multiple regression techniques were used to obtain models with an alpha level of 0.05 (95 percent significance level).

Table 4 contains the best one- and two-variable models using the wetland-related independendnent variables. Some interesting observations on wetland behavior can be made from the models in Table 4. Before examining Table 4, however, it should be emphasized that the total number of observations (N) in the urban dependent variables is four, and six for the agricultural dependent variables. While these Ns are low, recall that approximately 10,000 individual pieces of water quality data were collected to determine the 1980 loads for the sample

Table 3
WETLAND FACTORS USED FOR DETERMINATION OF LONG-TERM MEDIAN LOADS

Variable	Explanation
1. LUWETTC	Ratio wetlands/Total contributing area.
2. LUWETDR	Ratio wetlands/Drainage density.
3. LUWETAO	Ratio wetlands/Average overland flow.
4. LUWETMD	Ratio wetlands/Miles of artificial ditch.
5. LUWETCI	Ratio wetlands/Commercial and industrial.
6. LUWETURB	Ratio wetlands/Urbanization.
7. LUWETAG	Ratio wetlands/Agricultural.
8. LUWETSF	Ratio wetlands/Single-family residential.
9. LUWETPO	Ratio wetlands/Population density.
10. LUWETMF	Ratio wetlands/Multifamily residential.
11. LUWETAC	Ratio wetlands/Acreage under construction.
12. LUWETLD	Ratio wetlands/Low-density residential.
13. LUWETRM	Ratio wetlands/Medium-density residential.
14. LUWETBN	Ratio wetlands/Soybean acreage needing treatment.
15. LUWETROW	Ratio wetlands/Acreage in corn and soybeans.
16. LUWETCR	Ratio wetlands/Acreage in cropland.
17. LUWETOAT	Ratio wetlands/Acreage in oats.
18. LUWETWHT	Ratio wetlands/Acreage in wheat.
19. LUWETRF	Ratio wetlands/Unitless crop rotation factor.
20. LUWETUS	Ratio wetlands/Universal soil loss equation.
21. LUWETAU	Ratio wetlands/Number of animal units.
22. LUWETPD	Total of wetlands and acreage of poorly drained soils.
23. LUWETME	Total of wetlands and acreage of meadow.
24. LUWETPG	Total of wetlands and acreage of pasture and grassland.
25. LUWETOS	Total of wetlands and acreage of open space in urban area.
26. LUWETWO	Total of wetlands and acreage of woodland.

Table 4
FIRST AND SECOND VARIABLE REGRESSION MODELS USING WETLAND FACTORS FOR DETERMINATION OF LONG-TERM MEDIAN LOADS

Constituent	Model	R^2	C.V.(1)	Signif. %
Urban Mainstem				
(2) IN	5.46-2.01*LUWETSF	.24	16	50
	8.38-5.93*LUWETSF-51.65*LUWETAC	.99	1	99
TN	2852-7790*LUWETURB	.95	12	98
	2844-9594*LUWETURB+357*LUWETCI	.99	1	99
COD	63,630-83,600*LUWETSF	.88	17	94
	47,640-69340*LUWETSF+18,620*LUWETTC	.99	3	96
TSS	48,300-139,000*LUWETURB	.97	11	99
	52,400-495,000*LUWETURB+20,050*LUWETDR	.99	5	94
TKN	2226-5326*LUWETURB	.92	13	96
	2219-7000*LUWETURB+332*LUWETCI	.99	1	99
NN	626-2465*LUWETURB	.99	5	99
	629-2257*LUWETURB-125*LUWETSF	.99	1	99
TP	450-1594*LUWETURB	.99	8	99
	453-1334*LUWETURB-158*LUWETSF	.99	2	99
Cl	81,000-114,000*LUWETSF	.99	3	97
	68,000-116,000*LUWETSF+33,000*LUWETCI	.99	1	99
Pb	99.4-2.37*LUWETPD	.97	24	99
	100.7-1.61*LUWETPD-151.6*LUWETURB	.99	7	97
Agricultural Mainstem				
(3) IN	0.061+0.184*LUWETTC	.70	45	96
	0.205+0.252*LUWETTC-0.136*LUWETURB	.93	25	98
TN	4876-131.3*LUWETME	.76	25	98
	4878-215.1*LUWETME+550*LUWETDR	.93	16	98
COD	16,700+5292*LUWETDR	.72	14	97
	14,600+1310*LUWETDR+4140*LUWETOAT	.84	12	94
TSS	94,600-1710*LUWETPD	.75	59	98
	110,000-1511*LUWETPD-1334*LUWETPG	.88	47	96
TKN	999+166.9*LUWETOAT	.44	14	85
	858+472*LUWETOAT-99,000*LUWETAO	.75	10	88
NN	3656-134.9*LUWETME	.81	52	99
	4530-127.5*LUWETME-57.0*LUWETPG	.94	34	99
TP	116.6+48.0*LUWETDR	.54	24	91
	96.6+68.4*LUWETDR-2255*LUWETBN	.99	5	99

(1) Coefficient of variation (C.V.)=100*(standard deviation/mean).
(2) Total inches of runoff.
(3) Inches per square mile of runoff.

watersheds. These 10,000 pieces of data then formed the basis for determining the 18-year long-term median loads for all watersheds in the Region. This projection resulted in 26,000 observations for each urban constituent and 39,000 observations for each rural constituent. The purpose again of Table 4 is to indicate general implications of various management approaches.

The most obvious trend in the urban models in Table 4 is the frequent and strong negative correlations between loads and the level of urban development. This relation appears as a first variable in the equations as either LUWETURB or LUWETSF. Therefore the enhancement of urban and single-family residential relative to wetlands will lead to an increased loading of runoff (IN), TN, COD, TSS, TKN, NN, TP and Cl. The second variable relationships generally support this finding, with a few exceptions. The positive variable LUWETCI appears in the second equations for TN, TKN, and Cl. This relationship is not clear, but is suspected of indicating the soluble nature of the nitrogens and Cl; that is, as the area of wetlands becomes larger, there is more solubilization of nitrogen and thus more mobility. In contrast, commercial/industrial areas contribute particulate-associated nitrogen that tends to be less mobile. Further research on this relationship would help determine whether the solubles explanation is reasonable, or whether the relationship is circumstantial.

A different variable appears in the urban models for Pb, where LUWETPD occurs as the first and second models. This variable represents wetlands plus poorly drained soils, indicating a capability to retain Pb and possibly other metals in wetlands and poorly drained soils. This relationship is logical since Pb from urban areas tends to move while adsorbed onto particulates that would settle and/or be attracted to other particulates.

The only other variables appearing in the second variable urban models are LUWETAC, LUWETTC and LUWETDR. The inches of runoff model shows that reduction of wetlands during active construction can lead to increased runoff. The COD model indicates that a large amount of wetlands in a watershed can enhance the COD load; this relationship is viable since the loading work showed that much of the COD moving from both urban and rural areas is dissolved. The TSS model shows a positive LUWETDR relationship. Further consideration of the variable LUWETDR leads to the realization that wetland occurrence and drainage density are actually reverse surrogates, that is, as one increases, the other decreases. This relationship makes explanation of the TSS model difficult because of the intercorrelation of the independent variables in the model.

For the rural models in Table 4, three findings seem most significant. First, the relationships developed, as represented by the R-square, C.V, and significance statistics, are not as strong as in the urban area. This would appear to be a function of the phenomenon discussed previously concerning the dominance of annual loading by snowmelt and early spring storm events when wetlands are less able to play a major role in quality determination.

Another significant finding, perhaps related to the first, is that several of the models seem to indicate that wetlands in rural areas promote loading of soluble constituents. This relationship occurs in the TN, COD, TKN and TP models with the positive LUWETDR and LUWETOAT variables. Again, it is believed that wetlands in rural areas serve as collection points for pollutants during runoff events, and solubiize these pollutants (probably under anaerobic conditions), thus making them more mobile whenever a sufficient quantity of flow again occurs.

The third major finding is that wetlands preservation combined with good agricultural management serves to reduce pollution loads. The negative additive variables LUWETME and LUWETPG, and the negative ratio variable LUWETBN all point to the importance of maintaining a good conservation approach to farming, particularly the inclusion of meadows and grasses into the rotation. The positive LUWETOAT relationship in the second COD model and in both TKN models is not at all clear. Again, it is suspected that this relationship is showing the contribution factor that wetlands in rural areas play in soluble pollutant transport, that is, wetlands tend to promote soluble pollutant migration.

The first rural area inches model shows a positive LUWETTC relationship indicating that wetlands are not important to the runoff situation when most of it occurs in the early spring, and might be positive contributors or recharge points later in the year when smaller runoff events occur. The high variation and low R-square shows substantial variability in these models even though the significance is quite high. Addition of negative LUWETURB improves the R-square showing the effect of impervious surfaces on runoff even in rural areas.

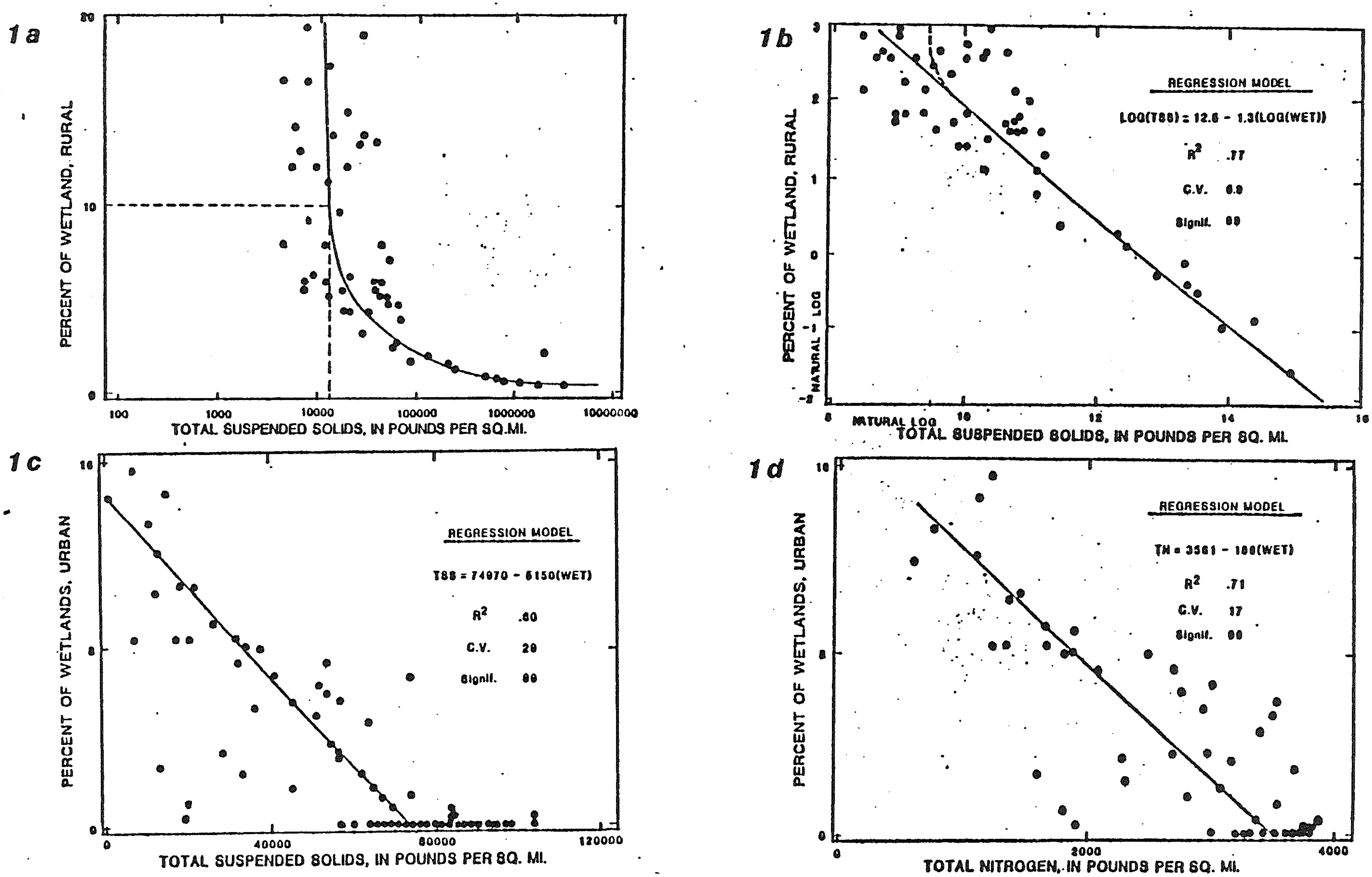
Management Implications

The findings raise questions on the type of management recommendations that can be made relative to wetland preservation. To further evaluate the results for the rural area, the models in Table 2 were applied to 45 rural watersheds, and the resultant loads were plotted against LUWET. The plots that resulted showed random "shotgun" patterns with R-square less than 0.01 for all constituents except TSS. This finding tends to verify the solubilization phenomenon of rural wetlands and the inactivity of wetlands during periods of highest loading. Wetlands did show a relatively good logarithmic correlation with TSS as shown in Figures 1a (semi-log) and 1b (log-log), undoubtedly due to the fact that wetlands generally occur in low-lying areas that promote settling of suspended material.

Figure 1a shows that retention of about 10 percent of watershed wetlands maximizes loading reductions. Retention of wetland area greater than 10 percent of the total probably yields minimal additional improvement in TSS. The same relationship is shown by the dashed line in Figure 1b.

The urban watershed results of the plotting process for 66 watersheds generated far better relationships between load and wetlands, as first evidenced in Table 2. Every constituent except Cl, Pb and COD

Figure 1(a,b,c,d). Plot of percent of wetlands versus load per sq. mi.



showed linear relationships typified by Figures 1c (TSS) and 1d (TN). These relationships all point to the fact that retention of urban wetlands will lead to continued or improved water quality on an annual basis likely because the urban pollutants occur generally in particulate-associated form.

The management implications of these rural and urban findings then are that rural area wetlands, although likely beneficial for solids settling, do not appear to play a significant role in nutrient or oxygen-demanding substance pollution reduction. This indicates that pollution control in the rural area has to focus on the active agricultural practices, particularly as they relate to surface cover during the winter and early spring and focus on increased infiltration and retention of water on the fields becomes extremely important. Wetlands should still, however, be preserved because of their substantial sediment-capturing capabilities and their value as related to other natural resources.

Preservation of urban wetlands has been shown to be of significant importance in pollution reduction. Both particulate-associated and soluble pollutants were shown to be reduced substantially in watersheds where wetland occurrence was large. The findings showed that urban development at the cost of wetland loss would lead to increased pollution loading. It must be emphasized here that no effort was made to study the impact on wetlands from discharging pollutants at rates typical of urban areas. It cannot be stated that continued discharge of pollutants into an urban wetland will not eventually destroy that wetland. Research into this area would certainly enhance and, hopefully, support use of wetlands for stormwater treatment. For now, it is recommended that discharge of highly sediment-laden or suspected toxic stormwater into wetlands be preceeded by a period of adequate settling to reduce the cumulative and shock effect of such loading on a wetland ecosystem.

SUMMARY AND CONCLUSIONS

A study of six rural and 11 urban watersheds has shown that wetland occurrence is a very important factor in urban nonpoint pollution loading, and in rural area particulate loading. Dependence upon wetlands for treatment of soluble or fines-associated pollutants in rural areas does not appear feasible because wetlands are frozen and/or biologically dormant during the period when most of the annual load occurs. From a management standpoint, retention of urban wetlands as treatment systems appears to be a very beneficial practice, as does retention of rural wetlands for particulate controls and related natural resource benefits. Additional study is needed concerning the impact on wetlands from continuous nonpoint loading.

ACKNOWLEDGMENTS

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Appendix I
POLLUTANT ASSOCIATIONS AFTER LABORATORY SETTLING

INTRODUCTION

A substudy was done on several samples collected during three 1980 runoff events (late May-early June, late August, late September). Samples were agitated and allowed to settle for various periods of time to determine pollutant associations with various size fractions under quiescent conditions. Results will bear some relationship to field conditions if quiescent settling is allowed, and outflow is from near the top of the water column, but yield only qualitative information for turbulent conditions.

METHODS

Rainfall runoff samples were collected at selected sites during three events. The samples were either flow composited (May-June, August) or were selected for their location on the runoff hydrograph (September). Approximately four liters of sample were allowed to reach ambient laboratory temperature and then agitated with a plunger for two minutes. Immediately after agitation a subsample was taken at 10 cm depth. Subsequent subsamples were then taken at any or all of the following times: seven minutes; one hour; three hours; and 24 hours.

The subsample times were taken based on the undisturbed settling velocities of sand and silt (seven minutes for 15.5 micrometer particles) and clay (one hour for 4 micrometer particles) at 10 cm based on Stoke's Law, which follows:

$$v = (g/18\mu)\ (S-1)\ d^2$$

Where v = settling velocity
d = particle size
g = acceleration due to gravity
μ = kinematic viscosity of water
s = specific gravity of particle.

The three-hour and 24-hour samples were taken to synthesize typical field detention times likely experienced in association with a runoff event.

Subsamples were extracted from the larger sample by using a peristaltic pump and a silicone hose with a specially designed intake nozzle. A brief purge period preceded every subsample collection. The subsamples were then analyzed according to the methods in Appendix A.

Results and Discussion The results of the laboratory settling study are presented in Tables I-1 to I-3 for three different events. Table I-1 lists the results of analyses from six sites, each site for one of a series of storms that occurred from late May through early June in 1980. Table I-2 similarly lists the results of six sites for an Aug. 30, 1980 event; Table I-2 lists the solids, nutrients and COD, and Table I-2b lists the heavy metals. Finally, Table I-3 shows the results of the analysis for an Oct. 23, 1980 event for four sites at different hydrograph periods; again, the tables are split by analysis type.

Table I-1 was the prototype substudy during which the methodology was tried for the first time. As a result, several samples were destroyed in some manner and data voids exist. This first settling sequence was run only for seven minutes and one hour to see what trends occurred; subsequent addition of settling times was obviously mandated.

Few conclusions can be drawn after examination of Table I-1. It appears for the first five samples that a fair amount of TSS settles below 10 cm in the first hour (54-93 percent). The 80th St. site, however, does not, probably because this site is at the end of a drainage system containing eight detention ponds. The rest of the data for 80th St. enforce the idea that most solids-associated pollutants have settled prior to reaching the 80th St. pond outflow. One-hour TP values range from 34 to 82 percent for the urban (not including 80th) and only seven percent for the agricultural Bevens site. Similar values were seen for the TKN and COD measurements. Lead reductions were quite variable, ranging from 3 to 78 percent. The scant data then show that a fair amount of solids reduction can occur in just one hour of quiescent settling, but nutrients, oxygen-demanding substances and lead can be associated with fine-grained particles or be dissolved and migrate through such settling facilities.

The Aug. 30, 1980 data in Table I-2a were collected from six urban storm sewer sites. The data for all six stations show an almost total (96-98 percent) suspended solids reduction at 10 cm after 24 hours of settling. Much of the settling has actually occurred after one hour. The VSS value at zero settling is quite far from the TSS value, but the VSS:TSS ratio increases greatly with time, illustrating the fines nature of the volatile solids constituent. Total phosphorus from these sites also exhibits a strong settling pattern with a 24-hour range of 44 to 74 percent. A single dissolved phosphorus (DP) value was taken to show the dissolved to total ratio. Nitrite-nitrate-nitrogen (NN) is mostly in a dissolved state and therefore shows little association with particulates, except for Wesley for an unknown reason. Total Kjeldahl nitrogen (TKN) shows the same behavioral characteristics as TP, having a range of 38 to 65 percent. Notice that the dissolved Kjeldahl comprises a large part of the initial TKN, and that in four cases the initial dissolved concentration exceeds the final total concentration; this DKN_0 exceeding TKN_{24} could be due to ammonia gases being driven off and/or by mineralization of nitrogen from ammonia to an organic form. Finally, the COD data shows results slightly higher than the nutrients in percent reduction.

The heavy metals data in Table I-2b are fairly consistent in the percent reductions with a few exceptions. The data typically show a 50 to 90 percent reduction at 10 cm in 24 hours. A substantial portion of the percent reduction does occur after only three hours at most sites where data exist. However, settling is slow to start with generally little reduction associated with the silt fraction; this shows the general association of the metals with fine particulates.

Table I-3 gives the results of sample analysis for an Oct. 23, 1980 event at four sites for various limbs of the hydrograph. Three of the sites are urban and one (Vermillion) is rural. Again the TSS and VSS at time zero are quite far apart, but converge after 24 hours of settling. Also as before, the suspended solids decrease substantially in 24 hours, with a large part of the reduction occurring in just three hours. PDQ and Vermillion data are for the falling limb of the hydrograph, so comparison with other parts of the hydrograph is not possible. For Sandburg, approximately twice the rising limb suspended solids are associated with clay or larger particles as compared to the falling limbs; that is, more coarse material is concentrated in the rising limb and at a higher initial concentration. The same behavior is seen for the Hwy. 100 site, where the rising limb has more coarse particles than the roughly equivalent peak and falling limb. For Sandburg and Hwy. 100 the total solids settled after 24 hours are a lesser percentage than the rising limb, again indicating the coarser character of initial runoff. For Vermillion and PDQ, however, the three-hour and 24-hour settling reductions are even higher than Sandburg and Hwy. 100, thus showing the variability in runoff behavior and danger in generalizing conclusions.

The phosphorus data are difficult to interpret because it appears as though some erroneous data are introduced. From the data that do appear to be correct, the phosphorus reduction in 24 hours is in the 25 to 50 percent range, similar to the two previous periods (Tables I-1 and I-2). The TKN data are again interspersed with apparently incorrect figures, but ignoring these still shows that reductions of about 50 percent occur at 10 cm depth in 24 hours. The Sandburg and Hwy. 100 data show a small tendency toward association with coarser particles on the rising limb. The dissolved Kjeldahl and dissolved ammonia data show that most of the DKN is in fact in the organic form, and much of the remaining TKN after 24 hours is, therefore, composed of dissolved organic nitrogen. The dissolved nitrite-nitrate-nitrogen stays very constant from time zero to 24 hours and is generally high relative to ammonia, except for the Hwy. 100 rising limb. This behavior seems to suggest that nitrification is proceeding because oxygen is plentiful, a condition known to exist in runoff events. The COD data are similar to previous events in that about 50 to 75 percent reduction occurs in the urban areas. The Vermillion rural site, however, has a rather large dissolved constituent load and is reflected in the low COD reduction for 24 hours.

Table I-3b presents metals data for the October event. The discrepancy seen in a prior event again occurs wherein the PDQ falling reductions are greater than the falling reductions for the other sites. For Sandburg and Hwy. 100, rising limb reduction exceeds peak and falling reductions, but the 24-hour reductions are all essentially equal or very close. Again, the initial washoff shows metals associated with coarser-grained material, tending toward finer material as the hydrograph proceeds.

To summarize the settling substudy, it appears that very good reductions in suspended solids can be achieved in a quiescent settling situation with outflow coming from near the surface of the water column. Such a facility could be designed to discharge through a riser or over a spillway, or to discharge through a filter (gravel, sand, fabric) that filters all but very fine-grained material. The data also appear to show that fairly good reductions could be achieved for nutrients (25-50 percent), COD (25-50 percent) and metals (50-75 percent) under most conditions as described above. To again emphasize, the conclusions reached for this substudy are very preliminary and based upon a limited set of experimental circumstances. Discharge of settled water below 10 cm or any turbulence introduced to the detention facility will likely decrease the reductions presented in Tables I-1 through I-3.

Table I-1
SAMPLING STUDY - MAY AND JUNE 1980 (COMPOSITE SAMPLES)

Site (Rainfall)	Date	Settling Time	TSS	Percent Reduction	VSS	Percent Reduction	TP	Percent Reduction	TKN	Percent Reduction	TCOD	Percent Reduction	TPb	Percent Reduction
Shingle (1.57")	June 5	None	526		132		.62		2.84		145		.23	
		7 min.	190	64	52	61	--		1.72	40	81	44	.15	35
		1 hr.	38	93	14	89	.18	71	.80	72	33	77	--	
Shingle (1.02")	June 12	none	--		--		1.30		9.60				.60	
		7 min.					.57	56	3.12	68			.28	53
		1 hr.					.23	82	1.40	86			.13	78
Yates (0.27")	May 29	none	161		--		.49		2.60		110		.32	
		7 min.	119	26			.48	2	2.48	5	--		.31	3
		1 hr.	42	74			.32	35	1.84	29	74	33	--	
Bevens (0.64")	June 5	none	186		28		1.45		2.64		--			
		7 min.	140	25	22	22	1.40	4	2.58	2				
		1 hr.	85	54	14	50	1.35	7	2.40	9				
Hwy 100. (0.29")	May 29	none	329		--		1.25		5.00		289		.55	
		7 min.	217	34			1.15	18	4.40	12	--		--	
		1 hr.	59	82			.83	34	--		184	36	.22	60
Sandburg (0.29")	May 29	none	731		--		1.30		5.20		329		.68	
		7 min.	575	21			.90	31	4.80	8	274	17	--	
		1 hr.	198	73			.45	65	2.24	57	160	51	.43	37
80th St. (3.64")	June 5	none	326		46		.67		1.60		51		.026	
		7 min.	316	3	--		--		--		49	4	--	
		1 hr.	248	24	44	4	.60	10	1.40	12	43	6	.023	12

Table I-2a.
SETTLING STUDY AUGUST 30, 1980

Site	Settling Time	TSS	Percent Reduction	VSS	Percent Reduction	TP	Reduction	DP	DP/TP	NN	Percent Reduction	TKN	Percent Reduction	DKN	DKN/TKN	TCOD	Reduction
Wesley (0.93")	None	130		16		.71	--	.29	.37	.70		1.36		.96	.70	34	
	7 min.	69	47	12	25	.62	13			.65	7	1.08	21			36	--
	1 hr.	13	90	4	75	.50	30			.55	21	.76	44			21	38
	3 hrs.	6	95	4	75	.46	35			.45	36	.86	37			19	44
	24 hrs.	1	99	1	94	.40	44			.25	64	.82	40			15	56
Iverson (0.60")	None	1088		146		2.0		.05	.02	.55		2.6		1.2	.46	176	
	7 min.	660	39	100	32	1.7	15			.55	0	2.4	8			162	8
	1 hr.	336	69	68	53	1.25	38			.55	0	1.8	31			132	25
	3 hrs.	160	85	44	70	.98	51			.50	9	1.6	38			106	40
	24 hrs.	32	97	28	81	.70	65			.40	27	1.4	46			82	53
Hwy. 100 (1.12")	None	112		36		.45		.09	.20	.30		1.76		.62	.35	54	
	7 min.	80	29	40	--	.43	4			.30	0	1.66	6			48	26
	1 hr.	16	86	14	61	.33	27			.25	17	1.10	38			32	41
	3 hrs.	14	88	8	78	.29	36			.25	17	1.06	40			21	41
	24 hrs.	5	96	1	97	.21	53			.30	0	.76	57			16	70
Estates (1.28")	None	80		30		.32		.09	.28	.75		1.54		.76	.49	78	
	7 min.	26	68	16	47	.23	28			.55	27	1.20	22			52	33
	1 hr.	1	99	1	97	.15	53			.55	27	.80	48			35	55
	3 hrs.	--		--		--				-		--				--	
	24 hrs.	1	99	1	97	.11	66			.55	27	.68	56			23	71
PDQ (0.67")	None	264		70		.39		.09	.23	.65		1.96		.84	.43	108	
	7 min.	48	82	18	74	.24	38			.55	15	1.28	35			71	34
	1 hr.	1	99	1	99	.16	59			.55	15	.90	54			47	56
	3 hrs.	--		--		--				--			--			--	
	24 hrs.	1	99	1	99	.10	74			.55	15	.68	65			46	57
Sandburg (1.12")	None	146		36		.23		.10	.43	.30		1.16		.84	.72	86	
	7 min.	4	97	2	94	.14	39			.30	0	.86	26			26	70
	1 hr.	1	99	1	99	.12	48			.30	0	.82	29			21	76
	3 hrs.	--		--		--				--		--				--	
	24 hrs.	1	99	1	99	.09	61			--		.72	38			13	85

Table I-2b.
AUGUST 1980 SETTLING STUDY - METALS (ug/l)

Site	Settling Time	Pb	Percent Reduction	Zn	Percent Reduction	Cd	Percent Reduction	Fe*	Percent Reduction	Mn*	Percent Reduction	Cr	Percent Reduction	Cu	Reduction
Wesley	None	32		90		.5		4.4		.23		22		22	
	7 min.	18	44	--		.2	60	3.1	30	.15	52	15	32	18	18
	1 hr.	8	75	60	30	.2	60	1.4	68	.05	78	11	50	13	41
	3 hrs.	6	81	50	44	.2	--	1.0	77	.02	91	9	59	12	45
	24 hrs.	3	91	30	67	.2	--	.6	86	.02	91	3	86	12	45
Iverson	None	65		200		.7		52.0		1.60		50		41	
	7 min.	62	5	190	5	.7	0	49.0	6	1.45	9	43	14	38	7
	1 hr.	53	18	190	5	.4	43	39.5	24	1.05	34	35	30	34	17
	3 hrs.	46	29	--		.4	43	33.5	36	.86	46	28	44	28	32
	24 hrs.	27	58	160	20	.3	57	24.0	54	.51	68	18	64	19	54
Hwy. 100	None	130		120		.6		5.5		.25		7		12	
	7 min.	108	17	--		.5	17	5.3	4	.22	12	--		12	0
	1 hr.	49	62	70	42	.2	67	3.0	45	.10	60	6	14	7	12
	3 hrs.	40	69	40	67	.2	67	2.4	56	.07	72	6	14	--	
	24 hrs.	21	84	20	83	.2	--	1.6	71	.04	84	5	29	4	67
Estates	None	189		160		.7		4.6		.24		7		16	
	7 min.	89	53	120	25	.4	43	2.2	52	.10	58	5	29	10	38
	1 hr.	20	89	60	62	.2	71	.6	87	.02	92	4	43	6	62
	3 hrs.	--		--		--		--		--		--		--	
	24 hrs.	11	94	20	88	.2	--	.4	91	.01	96	4	43	5	69
Sandburg	None	58		100		.6		3.0		.16		6		14	
	7 min.	14	76	60	40	.2	67	.8	73	.06	62	--		6	57
	1 hr.	8	86	--		.2	67	.4	87	.04	75	4	33	5	64
	3 hrs.	--		--		--		--	--	--		--		--	
	24 hrs.	4	93	30	70	.2	67	.2	93	.02	88	3	50	4	71
PDQ	None	92		220		1.0		4.8		.26		7		13	
	7 min.	41	55	150	32	.9	10	2.3	52	.11	58	4	43	9	31
	1 hr.	13	86	100	55	.3	70	.8	83	.04	85	4	43	5	62
	3 hrs.	--		--		--		--		--		--		--	
	24 hrs.	4	90	70	68	.2	80	.3	94	.02	92	3	57	3	77

Table I-3a
SETTLING STUDY - SEPTEMBER 1980

Station (Rainfall)	Settling Time	TSS	Percent Reduction	VSS	Percent Reduction	TP	Percent Reduction	DP	TKN	Percent Reduction	DKN	DN/N	DNH_4	COD	Percent Reduction
PDQ	none	932		144		.12			.28			1.60		196	
- falling	7 min.	524	44	152	(-6)	.10	17		.26	7				138	30
limb	1 hr.	252	73	92	36	.12	0		.26	7				90	54
	3 hrs.	112	88	80	44	.05	58		.06	79				68	65
	24 hrs.	20	98	17	88	.37	(-208)	.22	.70	(-150)	.56	1.65	.02	46	76
Vermillion	none	56		42		.23			1.16			2.55		56	
- falling	7 min.	39	30	27	36	.17	26		.90	22				82	(-46)
limb	1 hr.	15	73	10	76	.14	39		.78	33				52	7
	3 hrs.	7	88	7	83	.19	17		1.12	3				48	14
	24 hrs.	1	98	1	98	.15	35	.12	1.04	10	1.04	2.50	.02	46	18
Sandburg	none	216		57		.40			1.34			.30		92	
- rising	7 min.	173	29	42	26	.39	2		1.34	0				88	4
limb	1 hr.	68	68	22	61	.27	32		.90	32				58	37
	3 hrs.	41	81	15	74	.22	45		.70	48				50	46
	24 hrs.	16	93	10	82	.17	58	.09	.64	52	.50	.30	.03	36	61
Sandburg	none	133		33		.31			1.10			.50		36	
- falling	7 min.	120	8	32	3	.31	0		1.14	(-4)				46	(-28)
limb	1 hr.	81	39	23	30	.25	19		.98	11				54	(-50)
	3 hrs.	42	68	18	45	.20	35		.82	25				46	(-28)
	24 hrs.	18	86	10	70	.15	52	.07	.62	44	.48	.50	.05	54	(-50)
Hwy. 100	none	116		58		.84			2.64			.10		154	
- rising	7 min.	84	28	46	21	.79	6		2.40	9				126	18
limb	1 hr.	33	72	21	64	.59	30		1.80	32				82	47
	3 hrs.	21	82	19	67	.48	43		1.46	45				66	57
	24 hrs.	6	95	6	90	.40	52	.29	1.28	52	.88	.20	.19	34	78
Hwy. 100	none	55		24		.40			1.32			.30		92	
- peak	7 min.	52	5	34	(-42)	.51	(-28)		1.32	0				82	11
	1 hr.	37	33	22	8	.55	(-38)		1.68	(-27)				58	37
	3 hrs.	20	64	17	29	.35	12		.98	26				41	55
	24 hrs.	7	87	7	71	.92	(-130)	.25	.84	36	.68	.30	.03	35	62
Hwy. 100	none	46		23		.38			1.26			.30		72	
- falling	7 min.	39	15	21	9	.38	0		1.14	10				51	29
limb	1 hr.	27	41	15	35	.34	10		.92	27				54	25
	3 hrs.	18	61	9	61	.34	10		.82	35				56	22
	24 hrs.	7	85	7	70	.28	26	.20	.68	46	.42	.30	.03	35	51

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Table I-3b.
SETTLING STUDY FOR METALS (mg/l)
September 1980

Station	Settling Time	Pb	Percent Reduction	Zn	Percent Reduction	Fe	Percent Reduction	Mn	Percent Reduction
PDQ falling	None	.300	--	.320	--	29.0	--	1.43	--
	7 min.	.210	30	.225	30	21.5	26	1.02	29
	1 hr.	.080	73	.120	62	14.5	50	0.53	63
	3 hrs.	.057	81	.100	69	11.0	62	0.35	76
	24 hrs.	.025	92	.040	88	3.9	87	0.10	93
Vermillion falling	None	--	--	--	--	2.5	--	0.13	--
	7 min.	--	--	--	--	2.2	12	0.11	15
	1 hr.	--	--	--	--	1.1	56	0.04	69
	3 hrs.	--	--	--	--	0.8	68	0.02	85
	24 hrs.	--	--	--	--	0.5	80	0.01	92
Sandburg rising	None	.150	--	.130	--	7.2	--	0.34	--
	7 min.	.150	0	.125	4	6.6	8	0.32	6
	1 hr.	.063	58	.075	42	4.5	38	0.16	53
	3 hrs.	.046	69	--	--	3.1	57	0.10	71
	24 hrs.	.029	81	.060	54	1.8	75	0.06	82
Sandburg falling	None	.090	--	.110	--	5.5	--	0.26	--
	7 min.	.090	0	---	--	5.5	0	0.26	0
	1 hr.	.072	20	.090	18	4.0	27	0.17	35
	3 hrs.	.050	44	.060	45	3.4	38	0.12	54
	24 hrs.	.035	61	.060	45	2.4	56	0.06	77
Hwy. 100 rising	None	.225	--	.150	--	4.8	--	0.56	--
	7 min.	.210	7	120	20	3.8	21	0.50	11
	1 hr.	.110	51	.090	40	1.6	67	0.44	21
	3 hrs.	.110	51	.060	80	1.6	67	0.43	23
	24 hrs.	.050	78	.060	80	0.7	85	0.41	27
Hwy. 100 peak	None	.110	--	.090	--	2.5	--	0.38	--
	7 min.	.120	(-9)	.100	(-11)	2.4	4	0.36	5
	1 hr.	.130	(-18)	.080	11	1.6	36	0.34	11
	3 hrs.	.074	33	.060	33	1.2	52	0.31	18
	24 hrs.	.052	53	.060	33	0.5	80	0.27	29
Hwy. 100 falling	None	.100	--	.080	--	2.0	--	0.27	--
	7 min.	.130	(-20)	.080	0	2.0	0	0.27	0
	1 hr.	.076	24	.070	12	1.4	30	0.24	11
	3 hrs.	.076	24	.060	25	1.1	45	0.24	18
	24 hrs.	.057	43	.070	12	0.6	70	0.19	30