THE POTOMAC RIVER MODEL: DATA REPORT

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Chapter 1. Introduction

Potomac River Model

The Potomac River Model (PRM) is currently being developed for the Maryland Department of the Environment. This model will be used as an analytical tool that can describe the transport of nutrients from the headwaters to the fall line under different flow regimes and, different point and non-point source load scenarios. This model has application to several current water management issues. The PRM will be used for evaluating point source permit decision alternatives under extreme, steady state and hydrologic events such as ${}_7Q_{10}$ flow conditions. With linked river segments from Luke, MD to Chain Bridge, the model also addresses the far-field effect of point and non-point control measures on the water quality of the mainstem Potomac River.

Assessing the relative fall line nutrient contribution of significant watersheds over seasonal time periods is another issue to which the model will be applied. The fall line contribution from watersheds must be evaluated over aggregate time intervals that capture the range of flow and transport regimes observed throughout the year. For example, nutrient loads delivered in spring runoff will vary significantly from summer loadings under low flow conditions. While a fully time variable model would be best suited to evaluate fluvial transport on short time scales, water quality managers are interested in aggregate loadings calculated over critical seasonal time periods. For this purpose, an approximate time variable model such as the PRM, in which model inputs are mean flows for periods of days to weeks, can be utilized.

The study area of the Potomac River covers a distance of approximately 224 miles from Luke, MD. to Chain Bridge at Washington, D.C. (Figure 1). This area is divided into 47 segments identical to a segmentation plan used by Hydroscience (1976; Table 1). The segments were based on: a) tributary or point source inputs, b) significant changes in physical characteristics including width, depth, velocity, cross sectional area, and c) changes in chemical reaction rates or DO demand.

The Water Quality Simulation Program-4, or WASP4, was chosen to be the framework for the Potomac River Model (PRM). WASP4 is a one to three dimensional box model whose processes encompass physical transport (advection and dispersion), biogeochemical processes, and external inputs (point and non-point source inputs and tributaries). The model is capable of simulating time varying advection and dispersion processes, and boundary exchanges subject to point and diffuse mass loadings. The model simulates the physical and chemical interactions of up to eight constituents (state variables or parameters). These constituents include: dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), organic nitrogen (ON), organic phosphorus (OP), ortho-phosphorus (inorganic phosphorus or IP), and phytoplankton carbon (PHY).

In WASP4 the study area is divided into a series of connected compartments (i.e., segments, Table 1). For each time step, the interactions between each constituent are computed within the upstream compartment and then transport down-gradient into the adjacent compartment by advection and dispersion processes. Equations are solved for each successive downstream segment, adding point and non-point sources as necessary. The procedure is then repeated for the next time step. A limitation of this approach is that, within each segment, complete mixing is assumed to occur that segmentation adequately distinguishes significant changes in physical, chemical, and biological characteristics.

The equations employed in the model are designed to simulate the cycle of phytoplankton growth, its relation to the supply of nutrients and its effect on dissolved oxygen. To accomplish this the model requires as inputs the total loadings, by segment, of the eight water constituents listed above as well as miscellaneous functions (e.g., solar radiation) and kinetic reaction rate constants (e.g., phytoplankton growth rates).

Organization of This Report

This document is a report on the data used for the Potomac River Model. The segment loadings of the eight water quality constituents are derived or computed from tributary water quality monitoring data and from municipal wastewater treatment plants and industrial dischargers with outfalls in the mainstem Potomac or unmonitored tributaries. Mainstem water quality monitoring station data are used to develop upstream and downstream boundary conditions for the model as well as for calibration.

Water quality data for both mainstem and tributary stations are reviewed in **Chapter 2**. This section includes a review of the nutrient trends observed from the data set and a comparison to previous trend reports. It should kept in mind that this report is intended to discuss the data that will be used for the PRM and is not a **trend** analysis of the water quality conditions of the Potomac River. **Chapter 3** presents the point source data for both municipal wastewater treatment plants and industrial sources. With the information in **Chapters 2 and 3** a mass balance is derived and is presented in **Chapter 4.** The mass balance is to provide a rough analysis of the type and forms of data obtained for the PRM. While the nutrient data are presented in previous chapters, certain transformation must be done on the "raw" data for input to the PRM. **Chapter 5** describes these transformations and the limitations that follow from these changes. Miscellaneous time functions and kinetic rate constants are presented in **Chapter 6** and include stream flow, solar radiation, water temperature, and kinetic rate constants. Following the analysis of data requirements, **Chapter 7** presents the processes for selecting the calibration and verification periods for the PRM. Finally, **Chapter 8** is a summary and assessment of the data and its usefulness for the PRM.

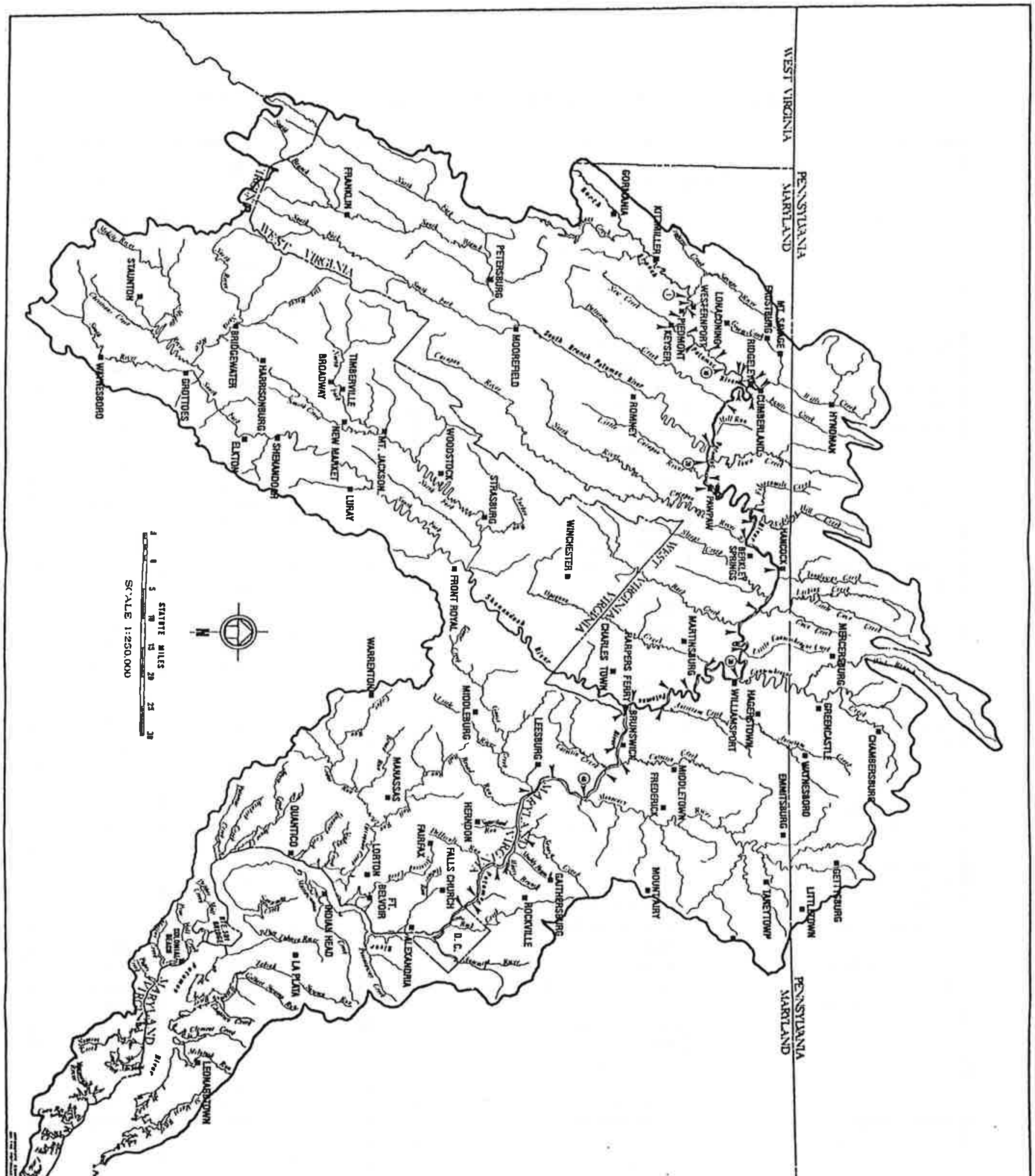

Figure 1. Potomac River Model Segmentation.

Table 1. List of Potomac River Model Segments and River Mile

Model Segment		Segment Number	River Mile	
From	To		From	To
Westvaco	Georges Creek	1	340	338.7
Georges Creek	UPRC STP	2	338.7	338.2
UPRC STP	Stony Run	3	333.2	336.3
Stony Run	Keyser	4	336.3	332.7
Keyser	21st Bridge	5	332.7	331.4
21st Bridge	Dawson	6	331.4	328.5
Dawson	Black Oak	7	328.5	326
Black Oak	Rawlings	8	326	322
Rawlings	Pinto	9	322	318.3
Pinto	Cresaptown	10	318.3	314.1
Cresaptown	Celanese	11	314.1	313.4
Celanese	Md. Junction	12	313.4	309.6
Md. Junction	Wills Creek	13	309.6	307.3
Wills Creek	Wiley Ford	14	307.3	305.2
Wiley Ford	Cumberland STP	15	305.2	304
Cumberland STP	Mexico Field	16	304	298.5
Mexico Field	Patterson Creek	17	298.5	294.1
Patterson Creek	South Branch	18	294.1	285.1
South Branch	Town Creek	19	285.1	282.6
Town Creek	Little Cacapon River	20	282.6	279.8
Little Cacapon River	Paw Paw	21	279.8	276.5
Paw Paw	15 Mile Creek	22	276.5	255.2
15 Mile Creek	Sideling Hill Creek	23	255.2	251.3
Sideling Hill Creek	Cacapon River	24	251.3	247.7
Cacapon River	Hancock	25	247.7	238.6
Hancock	Licking Creek	26	238.6	231.2
Licking Creek	Fort Frederick	27	231.2	227.1
Fort Frederick	Dam #5	28	227.1	217.4
Dam #5	Conococheague Creek	29	217.4	210.8
Conococheague Creek	Opequon Creek	30	210.8	201.9
Opequon Creek	Dam #4	31	201.9	195.3
Dam #4	Shepherdstown	32	195.3	183.6
Shepherdstown	Antietam Creek	33	183.6	179.3
Antietam Creek	Pleasantville Dam	34	179.3	173.1
Pleasantville Dam	Shenandoah River	35	173.1	171.5
Shenandoah River	Brunswick	36	171.5	165.8
Brunswick	Catoctin Creek, MD	37	165.8	163.4
Catoctin Creek, MD	Point of Rocks	38	163.4	159.5
Point of Rocks	Monocacy River	39	159.5	153.1
Monocacy River	Whites Ferry	40	153.1	147.1
Whites Ferry	Goose Creek	41	147.1	142.2
Goose Creek	Seneca Creek	42	142.2	133.9
Seneca Creek	Watts Branch	43	133.9	129.1
Watts Branch	Great Falls Dam	44	129.1	126.3
Great Falls Dam	Ruppert Island	45	126.3	118.4
Ruppert Island	Little Falls Dam	46	118.4	117.4
Little Falls Dam	Chain Bridge	47	117.4	115.9

Chapter 2. Water Quality Monitoring Data

Water Quality Data Sources

Water quality monitoring data provide information for the creation of tributary loads, boundary conditions and for the calibration and validation of the PRM. Table 2 lists the nutrient parameters needed for the PRM and definitions used throughout this report. This chapter describes the ambient monitoring data and how the data from different sources were merged to create a single water quality data set for the nutrient inputs (Table 2). Finally, this chapter provides a description of both water quality conditions in the river during 1983-1989 as well as an assessment of the available monitoring data for use in the PRM.

Data were obtained from government agencies that conduct monitoring programs on the Potomac and its tributaries. The US EPA STORET database was used to make initial searches to determine agencies, stations, and parameters for which data are available. Government agencies include the United States Geological Survey (USGS), the Virginia Water Control Board (VWCB), the West Virginia Department of Natural Resources (WVDNR), and the Maryland Department of the Environment (MDE). All data collected by the State of Maryland is referenced in this report as from MDE, but includes that recorded by MDE's predecessor organization, the Office of Environmental Programs. Following the initial search, water quality data were retrieved from STORET for these agencies for the period 1983 - 1989.

The agencies were contacted to assure the adequacy of STORET as a source and to inquire about additional data that might be available. The USGS, VWCB, and WVDNR confirmed that STORET was an accurate source for their data and that additional data, if any, were a) not digitized, b) of very short duration, c) difficult (for them) to find. Therefore we concluded that STORET would be our source of data from these agencies. MDE indicated that there are quality problems with their data on STORET and that the period of record is not complete. Therefore we obtained that data directly from MDE.

Data were also obtained from the Occoquan Watershed Monitoring Laboratory which maintains a monitoring station at Chain Bridge and which conducted monitoring at four stations from Point of Rocks to Seneca Pool and on the Monocacy River in 1983-4.

Summary information about monitoring data obtained from these agencies is provided in Tables 3-5. Table 3 is a list of stations, showing model segment number, river mile, and indicating whether each is a mainstem or tributary station. Table 4 lists water quality parameters obtained from MDE, OWML, and from STORET (for the USGS, VWCB, and WV DNR). Table 5 shows the number of observations, and minimum and maximum values for each parameter.

Creating a Common Nutrient Data Set from Source Data Sets

Water quality data retrieved from these monitoring programs included parameters that are directly included in model input files (Table 2), or that may assist in evaluating water quality conditions in the river. Each of the agencies monitored a different set of parameters, and within agencies there are changes in parameters between stations and through time. Some parameters required by the model were monitored infrequently or not at all. For the preparation of model input files, a subset of parameters was extracted or computed from the available data. These parameters include when available the dissolved and total concentrations of ammonium (NH4), nitrate (NO3), organic nitrogen (ON), organic phosphorus (OP) and inorganic phosphorus (IP); as well as biochemical oxygen demand (BOD), chlorophyll (CHL), and dissolved oxygen (DO). The chlorophyll data is converted to phytoplankton carbon (PHY) for model input. For the assessment of a nutrient mass balance both total nitrogen (TN) and total phosphorus (TP) were also obtained or calculated. For the purposes of this entire report, the terms ammonia (NH3) and ammonium (NH4) are used interchangeably. It is recognized that both ammonia and ammonium exist in river water and are measured as NH3+NH4. When discussing data from various sources (see below), the actual term each agency or organization uses is presented. The following sections describe the availability of water quality information for these parameters from all sources.

The set of parameters available from each agency differed and in some cases changed through time. Some conversions of source data were necessary to obtain the nutrient parameters listed above and are described in the following paragraphs.

The Occoquan Watershed Monitoring Lab provided a data set that included: ammonia (NH3), dissolved inorganic phosphorus (ORTHOP), total phosphorus (TP), biochemical oxygen demand (BOD5), dissolved oxygen (DO), and chlorophyll-a (CHLA). Oxidized nitrogen (OXN) is the sum of the dissolved nitrite and dissolved nitrate concentrations. For the purpose of this report nitrite is assumed to be negligible and therefore OXN is equivalent to dissolved nitrate concentrations. This was considered to be acceptable because the nitrite:nitrate ratio is generally about 0.01. Total organic nitrogen was calculated as TKN - NH3 and total nitrogen was estimated by TKN + OXN. Some OWML values were flagged as being at or below detection limits and in such cases the value used was the detection limit.

Data were obtained from the Maryland Department of the Environment for the period 1983 to 1989. The data from 1982 - 1985 might be considered a separate data set because lab methods (in some cases) and data management procedures were different, with consequences that are discussed below. Ammonia (NH3), nitrate (NO3), dissolved inorganic phosphorus (PO4 or DIP), total phosphorus (TP), biochemical oxygen demand (BOD5), dissolved oxygen (DO), and chlorophyll (CHAA) were directly available. Total organic nitrogen was estimated as TKNW - NH3. Total nitrogen was estimated as TKNW + NO3.

In the MDE data set, total nitrogen (TN) concentrations prior to 1986 are uniformly lower than the sum of the TKNW and NO3 concentrations. This is not possible and suggests an error in either the reported TN, TKNW, or NO3 concentrations. The reported TN concentrations from 1986-89 do not have this problem because they are already the sum of TKNW and NO3. After comparison of these concentrations with the same parameters from the 1986-89 data and with data from other agencies for the 1983-85 period, and after discussion with MDE, it was concluded that the reported TN concentrations for 1983-85 are incorrect. Therefore, TN was estimated as the sum of TKNW + NO3. This makes the TN concentrations for the entire MDE data set consistent with the OWML and STORET data sets. The error introduced by estimating TN = TKNW + NO3 rather than TN = TKNW + NO3 + NO2 was evaluated by calculating NO2/(TKNW + NO2 + NO3) using MDE 1986-89 data. The mean error was 0.9% and the 95th percentile error was 3.5%.

MDE reported that there may also be problems with TKNW concentrations for 1983-85 data. Bergstrom (1990), for Chesapeake Bay mainstem data, evaluated TKNW measured by the "helix" and "block" digestion methods and found that the helix method underestimates TKNW. He proposed an adjustment equation, in which the size of the adjustment varies with CHLA and with TKNW. However, we did not apply this adjustment to 1983-85 TKNW values because Bergstrom's study did not include non-tidal data, and his regressions were based on trichromatic chlorophyll (CHLA) which is not reported for 1983-85 data.

The potential for underestimating TKNW was evaluated by comparing TKNW at mainstem stations from the 1983-85 to 1986-89 data sets. For each monitoring station, summer (July-September) TKNW values prior to 1986 were pooled. Summer TKNW values for 1986-89 were also pooled, and an F statistic was computed to test whether the two samples have different means. Of 22 stations, ten stations had higher mean TKNW during 1986-89, with two stations significantly higher at alpha $<= 0.05$ level. At twelve stations the mean TKNW was lower for the 1983-1989 data set, however none of these differences were significant. Thus there appears to be no compelling evidence that TKNW during 1983-85 was biased low.

The EPA STORET database was the source of water quality monitoring data for the USGS, the Virginia Water Control Board, and the West Virginia DNR. There were differences in parameters reported between agencies, and within agencies over time. Ammonia was reported as dissolved (DAmmon; i.e., DNH3), or total (TAmmon; i.e., TNH3), or both. DAmmon was used if available, otherwise TAmmon was used. Nitrate was reported in a variety of forms. The value selected for nitrate came from, in order of preference, dissolved nitrate (DNO3), total nitrate (TNO3), dissolved nitrite+nitrate (DNO23; i.e., DOXN), and total nitrite+nitrate (TNO23; i.e., TOXN). Out of 622 records with some form of nitrate reported, there were 5 records with DNO3, 240 with TNO3, 167 with DNO23, and 210 with TNO23. Total organic nitrogen was estimated as, in order of preference, total Kjeldahl nitrogen - total ammonia (TNKJ - TAmmon) or total Kjeldahl nitrogen - dissolved ammonia (TNKJ - DAmmon). Total nitrogen was estimated as TNKJ + TNO3. Dissolved inorganic phosphorus was estimated with dissolved orthophosphorus (i.e., dissolved inorganic P; DIP). Total phosphorus (TP) and biochemical oxygen demand (BOD) were used as reported. As with MDE and OWML data, detection limit flags were stripped and the detection limit was used.

When nutrient data from each source file was combined as described above, the result was a data set that consisted of 3,121 records from 23 mainstem (Potomac and North Branch) and 22 tributary stations. Because the monitoring agencies sometimes sample the same places, these 45 stations actually represent 14 mainstem locations and 17 tributaries.

Longitudinal and temporal patterns in nutrient constituents are discussed in the following sections. Median concentrations for nutrient constituents, both observed and derived, for these combined data sets are shown in Appendix B.

Table 2. Forms of nitrogen (N) and phosphorus (P) and the ratios needed for nutrient inputs to the model and definitions used throughout this report

Form	**Ratio**
Total NH_4^+	Dissolved NH_4^+/Total NH_4^+
Total NO_3^-	Dissolved NO_3^-/Total NO_3^-
Total Inorganic P	Dissolved Inorg. P/Total Inorg. P
Total Organic N	Dissolved Org. N/Total Org. N
Total Organic P	Dissolved Org. P/Total Org. P

Relevant equations:

Phosphorus	**Nitrogen**
TP = TDP+PP	TN = DN+PN
PP = PIP+POP	DN = DIN+PN
TDP = DOP+DIP	DIN = DNH_4^++DNO_3^- (NO_2^- << NO_3^-)
TOP = DOP+POP	PN = PNH_4^++PNO_3^-+PON
TIP = DIP+PIP	TON = PON+DON
	TKN = TNH_4^++TON

where:	
TP = Total Phosphorus	TN = Total Nitrogen
PP = Particulate Phosphorus	DN = Dissolved Nitrogen
TDP = Total Dissolved P	DIN = Dissolved Inorganic N
TOP = Total Organic P	PN = Particulate N
TIP = Total Inorganic P	TON = Total Organic N
POP = Particulate Organic P	TKN = Total Kjeldahl N
PIP = Particulate Inorganic P	PNO_3^- = Particulate Nitrate
DIP = Dissolved Inorganic P	DNO_3^- = Dissolved Nitrate
DOP = Dissolved Organic P	PNH_4^+ = Particulate Ammonium
	DNH_4^+ = Dissolved Ammonium
	TNH_4^+ = Total Ammonium
	DON = Dissolved Organic N
	PON = Particulate Organic N

Table 3. List of Water Quality Monitoring Stations

No.	Station	Seg.	RM	M/T	Location
1	NBP0534	1	341.1	M	North Branch Potomac, Just upstream from Savage River
	01597500 SAV0000		341.0	T	Savage River near Bloomington, MD (3.7 mi) Savage River at MD 135 (0.02 mi)
2	01598500	2	240.8	M	North Branch Potomac at Luke
	01599000 GEO0009		338.7	T	Georges Creek at Franklin, MD (1.2 mi) Georges Creek at Franklin, MD (0.9 mi)
3	NBP0461	5	332.7	M	North Branch Potomac at Rt 220 Bridge
4	NBP0326 550467	10	317.3	M	North Branch Potomac at Pinto, MD
5	01601500 WIL0013	14	307.2	T	Wills Creek near Cumberland, MD (2.0 mi) Wills Creek (1.38 mi)
6	01603000	16	304.6	M	North Branch Potomac Near Cumberland, MD
7	NBP0103	17	295.4	M	North Branch Potomac-Mooreshollow Rd. & Rt 51
8	NBP0023	18	287.4	M	North Branch Potomac at Oldtown Toll Bridge
9	01608500 550468	19	285.1	T	South Branch Potomac near Springfield, WV (13.4) South Branch Potomac near Springfiled, WV
10	01609000 TOW0030	20	282.6	T	Town Creek near Oldtown, MD (4.0 mi) Town Creek near USGS station 01609000
11	550461 POT2766 01610000	22	276.6	M	Potomac River at Paw Paw, WV
12	01613000 POT2386	26	238.6	M	Potomac River at Hancock, MD
13	CON0005	30	210.8	T	Conococheague Creek at MD 68 Bridge (0.5 mi)
14	550462	31	200.3	T	Opequon Creek at Bedington, WV
15	01618000 POT1830	33	183.0	M	Potomac River at Shepherdstown, WV Potomac River at gaging station, MD Rt 34 Bridge
16	01619500 ANT0044	34	179.3	T	Antietam Creek near Sharpsburg, MD (4.0 mi) Antietam Creek, gaging station below Burnside Bridge
17	01636500 550471	36	171.5	T	Shenandoah River at Millville, WV (5.0 mi) Shenandoah River at Harpers Ferry, WV
	1APOT170.40		170.4	M	Potomac River at MD/VA line; Rte 340 Bridge
18	01637500 CAC0031	38	163.4	T	Catoctin Creek near Middletown, MD (14.8 mi) Catoctin Creek, Bridge on Md Rt 464

No.	Station	Seg.	RM	M/T	Location
19	1ACAX000.19 1ACAX004.57	39	159.5	T	Catoctin Creek, across river from Point of Rocks Catoctin Creek, VA (4.57 mi)
	01638500 POT1595 POT1596 PR03		159.1	M	Potomac River at Point of Rocks, MD Potomac River near Point of Rocks USGS gaging station Potomac River at Point of Rocks, VA side Potomac River near Point of Rocks USGS gaging station
20	01643000 MON0020 MR01	40	153.1	T	Monocacy River, Jug Bridge near Frederick (16.9 mi) Monocacy River, Bridge on MD Rte 28
21	POT1471 POT1472 PR02	41	147.1	M	Potomac River at eastern terminus Whites Ferry Potomac River at western terminus Whites Ferry
22	1AGOO002.38 1ABRB002.15	42	142.2 139.1	T	Goose Creek (2.38 mi) Board Run (2.15 mi)
23	01645000 SEN0008	43	133.9	T	Seneca Creek at Dawsonville, MD (5.8 mi)
	PR04		133.3	M	Potomac River at Seneca Rocks
24	CJB0005	45	119.0	T	Cabin John Creek (0.5 mi)
25	01646500 POT1184 016646580 PR01	47	117.4 115.9	M	Potomac River near Washington, DC at Little Falls Potomac River, Chain Bridge near Washington, DC

M - mainstem T - tributary

Table 4. List of water quality parameters retrieved from various agencies

A. Maryland Department of the Environment		
	Summary: 24 stations on the North Branch, Potomac mainstem, and mouths of tributaries for the period 1982 to mid 1989. Total number of records is 2475. Fields 1,3,4,5 were added by ICPRB.	
	Field	Description
1	Agency	Agency ID
2	STATION	Station ID
3	Segment	Model Segment
4	RM	River Mile
5	M/T	Mainstem/Tributary Flag
6	YYMMDD	Date
7	HHMM	Time
8	DEPTH	Depth
9	AIRTEMP	Air Temperature
10	WATEMP	Water Temperature
11	WEATHYES	
12	WEATHTOD	
13	PERCLOUD	Cloud cover
14	WIND_MAX	Wind Speed, Max
15	WIND_MIN	Wind Speed, Min
16	TSS	Total Suspended Solids, mg/l
17	DSOL	Diss. Solids, mg/l
18	PH_FLD	pH, field, SU
19	DO_FLD	Diss. Oxygen, field, mg/l
20	COND	Conductivity,
21	SALINITY	Salinity
22	DO	Dissolved Oxygen, mg/l
23	SI	Silicon, mg/l
24	TOC	Total Organic Carbon, mg/l
25	TKNW	Tot. Kjeldahl Nitrogen whole water, mg/l
26	NH4	Diss. Ammonia as N, mg/l
27	NO23	Diss. Nitrite + Nitrate, mg/l
28	NO2	Diss. Nitrite, mg/l
29	TP	Total Phosphorus as P, mg/l
30	PO4	Diss. Orthophos. as P, mg/l
31	BOD5	Bioch. Oxygen Demand, 5 day, mg/l
32	TURB	Turbidity, FTU
33	TALK	Total Alkalinity, mg/l
34	SO4	Sulfate, mg/l
35	FE_T	Iron, total, mg/l
36	NO3	Diss. Nitrate, mg/l
37	TN	Nitrogen, total, mg/l
38	FCOL	Fecal Coliforms, mpn/100 ml
39	TCOL	Total Coliforms, mpn/100 ml
40	CHLA	Trichromatic Chlorophyll-a, ug/l
41	CHLB	Trichromatic Chlorophyll-a, ug/l
42	CHLC	Trichromatic Chlorophyll-a, ug/l
43	CHTO	Total Chlorophyll-a, ug/l
44	CHAA	Active Chlorophyll-a, ug/l
45	PHEA	Pheophytin-a, ug/l

B. STORET

Summary: STORET retrieval includes data from the USGS (731 records, 17 stations), VWCB (253 records, 3 stations), and WVDNR (255 records, 4 stations). Period of record is 1982 - mid 1989.

	Field Name	STORET Code	Field Name
1	Agency		Agency ID
2	STATION		Station ID
3	Segment		Model Segment
4	RM		River Mile
5	M/T		Mainstem/Tributary Flag
6	Date		Date, YYMMDD
7	Time		Time, HHMM
8	Depth		Depth, ft
9	Temp	00010	WATER TEMP CENT
10	Turb	00070	TURB JKSN JTU
11	Turb	00076	TURB TRBIDMTR HACH FTU
12	Conduc	00095	CNDUCTVY AT 25C MICROMHO
13	DO	00300	DO MG/L
14	DO%Sat	00301	DO SATUR PERCENT
15	BOD	00310	BOD 5 DAY MG/L
16	COD	00340	COD HI LEVEL MG/L
17	TDS	00530	RESIDUE TOT NFLT MG/L
18	Diss_N	00602	DISS. NITROGEN MG/L N
19	Org_N	00605	ORG N N MG/L
20	DissOrg_N	00607	ORG N DISS-N MG/L
21	D_Ammon	00608	NH3+NH4- N DISS MG/L
22	T_Ammon	00610	NH3+NH4- N TOTAL MG/L
23	DNO2	00613	NO2-N DISS MG/L
24	TNO2	00615	NO2-N TOTAL MG/L
25	DNO3	00618	NO3-N DISS MG/L
26	TNO3	00620	NO3-N TOTAL MG/L
27	D_N_KJ	00623	KJELDL N DISS MG/L
28	S_N_KJ	00624	KJELDL N SUSP MG/L
29	T_N_KJ	00625	TOT KJEL N MG/L
30	T_NO2+3	00630	NO2&NO3 N-TOTAL MG/L
31	D_NO2+3	00631	NO2&NO3 N-DISS MG/L
32	O_PO4	00660	ORTHOPO4 PO4 MG/L
33	T_P	00665	PHOS-TOT MG/L P
34	D_P	00666	PHOS-DIS MG/L P
35	D_O_P	00671	PHOS-DIS ORTHO MG/L P
36	T_ORG_C	00680	T ORG C C MG/L
37	T_Cl	00940	CHLORIDE TOTAL MG/L
38	T_Col_E	31501	TOT COLI MFIMENDO /100ML
39	F_Col	31616	FEC COLI MFM-FCBR /100ML
40	Chl_a_c	32211	CHLRPHYL A UG/L CORRECTD
41	TDS_180	70300	RESIDUE DISS-180 C MG/L
42	D_NO3	71851	NITRATE DISS-NO3 MG/L AS NO3
43	D_NO2	71856	NITRITE DISS-NO2 MG/L AS NO2
44	TP_PO4	71886	TOTAL P AS PO4 MG/L

C. Occoquan Watershed Monitoring Lab. (OWML)

Summary: OWML data for Chain Bridge consists of 419 records over the period 1983 through 1989. OWML data for other Potomac and Monocacy stations consists of 151 records over the period 1983 through 1984. Water quality parameters collected by OWML differed between the Chain Bridge and Potomac data sets.

a). Chain Bridge water quality data parameters

Field #	Field Name	Field #	Field Name	Field #	Field Name
1	Agency	17	DO	33	SOC
2	STA	18	FIELDPH	34	TOC
3	Seg	19	TEMP	35	BOD5
4	RMile	20	COND	36	BOD5I
5	M/T	21	PALK	37	BOD20
6	LABID	22	TALK	38	BOD20I
7	DATE1	23	THARD	39	BOD40
8	TIME1	24	ORTHOP	40	BOD40I
9	DATE2	25	TSP	41	TURB
10	TIME2	26	TP	42	TSS
11	STRMNO	27	NH3_N	43	VSS
12	SAMNO	28	SKN	44	CHLA
13	DEPTH	29	TKN	45	CHLAM
14	STAGE	30	OX_N	46	PHPA
15	FLO	31	SRSI	47	TCOLI
16	TOTFLO	32	COD	48	FCOLI

b). Monocacy and Potomac stations water quality data parameters

Field #	Field Name	Field #	Field Name	Field #	Field Name
1	Agency	12	DO	23	SKN
2	STA	13	FIELDPH	24	TKN
3	Seg	14	TEMP	25	OX_N
4	RMile	15	COND	26	COD
5	M/T	16	COND25	27	BOD5
6	LABID	17	PALK	28	TSS
7	DATE1	18	TALK	29	CHLA
8	TIME1	19	OP	30	CHLAM
9	UPDATECHAR	20	TSP	31	PHPA
10	UPDATE	21	TP	32	RATIO
11	STAGE	22	NH3_N		

Description of water quality parameters retrieved from Occoquon Watershed Monitoring Lab.

Parameter	Description
BOD20	20-Day Biological Oxygen Demand, mg/L
BOD20I	20-Day Biological Oxygen Demand, Nitrif. Inhib., mg/L
BOD40	40-Day Biological Oxygen Demand, mg/L
BOD40I	40-DAY Biological Oxygen Demand, Nitrif. Inhib., mg/L
BOD5	Five Day Biological Oxygen Demand, mg/L
BOD5I	5-Day Biological Oxygen Demand, Nitrif. Inhib., mg/L
CHLA	Chlorophyll A Trichromatic, ug/L
CHLAM	Chlorophyll A Monochromatic, ug/L
COD	Chemical Oxygen Demand, mg/L
COND	Conductivity, umho
DATE1	Date of Grab Sample or First Aliquot in Composite, mm/dd/yy
DATE2	Date of last aliquot in composite, mm/dd/yy
DEPTH	Depth, feet
DO	Dissolved Oxygen, mg/L
FCOLI	Fecal Coliforms, mpn/100ml
FLDPH	Field pH
FLO	Flow, Instantaneous or Average, cfs
LABID	Lab. ID
NH3_N	Ammonia Nitrogen, mg/L as N
OP	Ortho-Phosphate Phosphorus, mg/L as P
OX_N	Oxidized Nitrogen, mg/L as N
PALK	Phenolphtalein Alkalinity, mg/L as CaCO3
PHPA	Pheophytin A, ug/L
SAMNO	Sample Number
SKN	Soluble Kjeldahl Nitrogen, mg/L
SOC	Soluble Organic Carbon, mg/L
SRSI	Soluble Reactive Silica, mg/L
STA	Station Number
STAGE	Elevation above Datum, Feet
STRMNO	Storm Number, yyddd.nn
TALK	Total Alkalinity, mg/L as CaCO3
TCOLI	Total Coliforms, mpn/100ml
TDS	Total Dissolved Solids, mg/L
TEMP	Temperature, C
TIME1	Time of grab sample or first aliquot in composite, HHMM
TIME2	Time of last aliquot in composite, HHMM
TKN	Total Kjeldahl Nitrogen, mg/L
TOC	Total Organic Carbon, mg/L
TOTFLO	Total Flow Volume, cf
TP	Total Phosphorus, mg/L as P
TS	Total Solids, mg/L
TSP	Total Soluble Phosphorus, mg/L as P
TSS	Total Suspended Solids, mg/L
TURB	Turbidity, NTU

Table 5. Number of observations for parameters retrieved from various agencies

A. Maryland Department of the Environment				
col	Desc.	Count	Min.	Max.
1	AGENCY	2475	NA	NA
2	STATION	2475	NA	NA
3	SEGMENT	2475	1	47
4	RM	2475	117.4	341.1
5	M/T	2475	NA	NA
6	YYMMDD	2475	820104	891219
7	HHMM	2474	0	1715
8	DEPTH	2475	0	0
9	AIRTEMP	2384	-17	40
10	WATEMP	2455	-7	31.7
11	WEATHYES	1024	10	15
12	WEATHTOD	1031	10	15
13	PERCLOUD	1021	0	100
14	WIND_MAX	57	0	20
15	WIND_MIN	57	0	15
16	TSS	1012	0	456
17	DSOL	470	0	2232
18	PH_FLD	2377	0.6	9.9
19	DO_FLD	1028	1.4	17.5
20	COND	2418	1	1600
21	SALINITY	1030	0	1.13
22	DO	2331	1.6	52
23	SI	293	0.1	10.3
24	TOC	1144	0.01	47.6
25	TKNW	2293	0.05	36.13
26	NH4	2279	0	5.25
27	NO23	989	0.02	7.1
28	NO2	2066	0	1.6
29	TP	2283	0.01	14
30	PO4	2199	0.004	2.35
31	BOD5	603	0	19
32	TURB	1972	0.1	1052
33	TALK	2206	0	730
34	SO4	467	0.1	2910
35	FE_T	470	0	42
36	NO3	2088	0	60.7
37	TN	2215	0.02	60.71
38	FCOL	900	3	460000
39	TCOL	901	3	2400000
40	CHLA	543	0.1572	82.591
41	CHLB	543	0	18.4934
42	CHLC	543	0	14.5725
43	CHTO	892	0.21	113.4
44	CHAA	794	0	79.335
45	PHEA	794	0	24.7

B. STORET

col	Desc.	Count	Min.	Max.
1	Agency	1239	NA	NA
2	Station	1239	NA	NA
3	Segment	1239	1	47
4	RM	1239	115.9	341
5	M/T	1239	NA	NA
6	Date	1239	820104	890815
7	Time	1239	540	2500
8	Depth	1239	1	99999
9	Temp	1145	-17.8	40
10	Turb	167	0.8	288
11	Turb	138	0.6	3500
12	Conduc	407	100	650
13	DO	428	4.2	634
14	DO%Sat	159	53	166
15	BOD	333	0.2	14
16	COD	366	1	180
17	TDS	439	1	569
18	D_N	8	1.5	2.3
19	Org_N	6	0.08	3.2
20	D_Org_N	4	0.23	0.49
21	D_Ammon	161	0.01	0.45
22	T_Ammon	407	0.01	5.5
23	D_NO2	96	0.001	0.04
24	T_NO2	238	0.01	28
25	D_NO3	5	0.66	2
26	T_NO3	240	0.05	27
27	D_N_KJ	30	0.1	0.9
28	S_N_KJ	10	0	8.3
29	T_N_KJ	593	0.08	10
30	T_NO2+3	214	0.01	4.8
31	D_NO2+3	172	0.1	5
32	O_PO4	27	0.06	0.43
33	T_P	608	0.001	3.3
34	D_P	161	0.01	0.16
35	D_O_P	409	0.01	0.7
36	T_ORG_C	312	1	29
37	T_Cl	311	1	84
38	T_Col_E	83	10	94000
39	F_Col	315	0	14700
40	Chl_a_c	38	0	88.7
41	TDS_180	257	76	436
42	D_NO3	1	7.1	7.1
43	D_NO2	2	0.03	0.03
44	TP_PO4	74	0.06	10

C. OWML: Chain Bridge station				
col	Desc.	Count	Min.	Max.
1	Agency	419	NA	NA
2	STA	419	NA	NA
3	Seg	419	47	47
4	RMile	419	115.9	115.9
5	M/T	419	NA	NA
6	LABID	419	-517	17624
7	DATE1	419	830103	891220
8	TIME1	419	10	2324
9	DATE2	106	830402	891121
10	TIME2	106	108	2324
11	STRMNO	150	NA	NA
12	SAMNO	149	1.22	13692
13	DEPTH	0	0	0
14	STAGE	286	2.61	17.92
15	FLO	411	731	315460
16	TOTFLO	29	1400000000	56000000000
17	DO	258	0	15.3
18	FIELDPH	244	6.7	8.8
19	TEMP	256	-1	30.5
20	COND	250	70	500
21	PALK	316	0	11.5
22	TALK	325	39.5	143.5
23	THARD	4	52	134
24	OP	410	.03	0.45
25	TSP	372	.04	0.51
26	TP	407	.01	3.29
27	NH3_N	410	.07	0.31
28	SKN	373	.52	1.13
29	TKN	406	.01	10.6
30	OX_N	410	.01	2.22
31	SRSI	339	0.02	4.2
32	COD	377	5	209.4
33	SOC	31	3.8	5.3
34	TOC	32	1	11.6
35	BOD5	102	1	5.1
36	BOD5I	40	1	4.2
37	BOD20	41	1.1	8.3
38	BOD20I	41	1	8.2
39	BOD40	0	0	0
40	BOD40I	0	0	0
41	TURB	238	0.9	150
42	TSS	405	1	2276
43	VSS	0	0	0
44	CHLA	262	1	157
45	CHLAM	156	0	142
46	PHPA	156	1	48
47	TCOLI	73	2	46000
48	FCOLI	73	2	24000

D. OWML: Potomac and Monocacy stations				
col	Desc.	Count	Min.	Max.
1	Agency	151	NA	NA
2	STA	151	NA	NA
3	Seg	151	39	43
4	RMile	151	133.3	159.1
5	M/T	151	NA	NA
6	LABID	151	-27	1456
7	DATE1	151	830620	840821
8	TIME1	151	634	1332
9	UPDATECHAR	64	NA	NA
10	UPDATE	64	NA	NA
11	STAGE	52	0.83	11.05
12	DO	144	6.1	14.6
13	FIELDPH	135	6.5	8.5
14	TEMP	144	1.5	30.5
15	COND	92	120	460
16	COND25	120	190	575
17	PALK	120	0	7.5
18	TALK	120	44.2	155.9
19	OP	147	.01	0.21
20	TSP	115	0.02	0.22
21	TP	150	0.05	0.66
22	NH3_N	147	.01	0.19
23	SKN	116	0.03	0.95
24	TKN	151	0.13	1.79
25	OX_N	147	0.59	3.7
26	COD	135	0.73	51.9
27	BOD5	84	1.1	6
28	TSS	148	1	617
29	CHLA	149	0	94
30	CHLAM	137	0	78
31	PHPA	136	0	25
32	RATIO	132	1	1.8

Water Quality Assessment

Assessment of Water Quality Conditions for the Freshwater Potomac, 1983-1988.

This section describes water quality conditions in the Potomac and its major tributaries as provided by monitoring data (MDE, 1988; ICPRB, 1987) and by state 305(b) reports. The 305(b) reports along with the ICPRB (1987) and MDE (1988) reports provide a general description of water quality trends and problems through the 1980s.

Potomac Highlands, RM220-390

In its water quality report for 1982-83, ICPRB (1987) characterized the upper North Branch of the Potomac as having poor water quality resulting from acid mine drainage, agricultural runoff, and raw sewage discharges. From 1975-1984, increasing trends in total phosphorus and nitrate occurred in the North Branch at Bloomington, Pinto, and Cumberland (ICPRB, 1987). In contrast, MDE (1988) found no trend in phosphorus in the lower North Branch. Increasing nutrients and dissolved oxygen concentrations at several mainstem stations in this reach were noted.

Reaches of the North Branch that do not support designated uses, which include water contact recreation and natural trout waters, are the Upper North Branch, Georges Creek, and Wills Creek (MDE, 1988). Westvaco, a pulp and paper mill in Luke (Md), is the largest industrial facility in the North Branch watershed. The main cause of stream impairment is acid water runoff from mining activities (MDE, 1988), although an improving trend in pH has been observed. In the past, local towns discharged raw and diluted wastewaters directly into Georges Creek, which was also heavily polluted by drainage from abandoned coal mines. A wastewater treatment plant serving residents of the towns was completed in 1984 (ICPRB, 1985). Both Georges Creek (RM390; i.e., river mile from Point Lookout) and Wills Creek (RM307) showed increasing nitrate and total phosphorus concentrations from 1973 to 1984 (ICPRB, 1987). According to a 1987 survey, raw sewage was piped directly into Evitts Creek in Pennsylvania, creating conditions of high BOD and turbidity (PADER, 1988). Overflows from combined sewers occurred at Cumberland in the early 1980's (ICPRB, 1985).

The South Branch of the Potomac River (RM285) has generally good water quality. Total phosphorus, nitrogen and total organic carbon levels decreased from 1973-1984 in the South Branch (ICPRB, 1987). Town Creek (RM282) also has good water quality; a slight increase in nitrate and total phosphorus over the years has occurred in this tributary (ICPRB, 1987).

Upper Great Valley, RM220-172

From 1973 to 1984, total nitrogen, total phosphorus, and nitrate levels increased significantly in the Potomac at Shepherdstown, WV (RM183) and in Antietam, Conococheague, and Opequon Creeks (approximately RM282 to RM180).

In Big Cove Creek, a tributary of Conococheague Creek, only the reach above the McConnelsburg WWTP meets the requirements for a cold water fishing stream. Just below the WWTP, chlorine caused a toxic impact; the remainder of the stream is degraded by agricultural runoff (PADER, 1988). Water uses in Johnston Run, which also drains into Conococheague Creek, are impaired by ammonium from the Loewengart Tannery, inadequately treated sewage from the Mercersburg

WWTP, and poor agricultural practices (1985 report as cited by PADER, 1988).

The lower portion of Conococheague Creek and the mainstem Potomac do not support designated uses of natural trout waters and water contact recreation because of elevated bacterial levels in agricultural runoff (MDE, 1984; MDE, 1988). Portions of the creek and the river near Williamsport have been closed to swimming because of elevated bacterial levels.

Before joining Opequon Creek, Abrams Creek receives the discharge of the Winchester WWTP. Recent biological monitoring near the mouth of Abrams Creeks has indicated poor water quality due primarily to the Winchester WWTP discharge. Below Winchester for example, nitrate and phosphorus increased, from 1973 to 1984 (ICPRB, 1987). A new sewage treatment facility, the Frederick-Winchester Service Authority WWTP, which will serve a portion of Frederick County and the City of Winchester, began operation in the fall of 1988 (VSWCB, 1988a).

In 1982-83, water quality of Antietam Creek varied from fair in the upper creek to good at Sharpsburg. Pollution problems were failing septic systems and agricultural runoff. Both nitrate and total Kjeldahl nitrogen (total organic nitrogen+ammonium) concentrations have increased from approximately 1975 to 1984 (ICPRB, 1987). Significant increases in total nitrogen levels in Catoctin Creek were noted by MDE (1988).

Shenandoah Valley

The Shenandoah River, the largest tributary to the Potomac, drains 21% of the basin area. Water quality at the mouth of the Shenandoah River near Bolivar (WVA), is rated good (ICPRB, 1987). Nitrate plus nitrite levels have shown a significant increase from 1973 to 1984, while total organic carbon concentrations decreased substantially. The same trends occur upstream of the Shenandoah mainstem at Berryville, (VA) and at Front Royal, VA.

The main stem of the Shenandoah River showed increasing trends in ammonium, nitrate and nitrite concentrations over a ten year period, while TOC and BOD levels have decreased significantly (ICPRB, 1987). The Stephens Run WWTP, located on a tributary to the Shenandoah mainstem in Frederick County (VA), was completed and complied with final limits in March 1986. At that time, effluent quality improved from 22.2 kg O_2/day to 15.9 kg O_2/day for BOD. Stephens Run is under a consent order to further reduce infiltration/inflow to its system. A new plant will soon be constructed to take some of the load that Stephens Run is handling (VSWCB, 1988b).

Potomac Piedmont, RM170-144

The Potomac mainstem, from the mouth of the Monocacy to Little Falls, and the entire Monocacy River watershed only partially support designated uses including: recreational, natural trout waters, water contact recreation and aquatic life (MDE, 1988). Nutrients and sediments from agricultural and urban runoff are primary causes of impairment.

The Monocacy River watershed contributes a disproportionately large proportion of the nutrients to this reach of the Potomac River (ICPRB, 1987). Increasing concentrations of total nitrogen, phosphorus and nitrate have occurred in the Monocacy from 1974 to 1985 (ICPRB, 1987). In fact, the nitrate concentration of the Monocacy River is 2 to 3 times more concentrated than the Potomac upstream boundary (MWCOG, 1984). Higher levels of coliforms and lower dissolved oxygen concentrations have accompanied these nutrient trends. In 1982-83, water quality of the Rock Creek tributary to the Monocacy River in Pennsylvania was degraded by inadequately treated sewage discharges in the Gettysburg area. The creek, also received agricultural runoff and seepage from failing septic systems prior to the mid-1980s (ICPRB, 1987). A regional sewage treatment plant for the Gettysburg area is now completed. The benthic community, once dominated by blood worms and sludge worms, is now composed of a healthy, diverse assemblage of invertebrates (PADER, 1988).

From the Shenandoah River to Chain Bridge (RM115), total phosphorus, total nitrogen, and nitrate levels increased significantly in both the mainstem Potomac and its tributaries, including Goose, Cabin John and Seneca Creeks, Broad Run and the Monocacy River (ICPRB, 1987). MDE (1988) noted that significant increasing trends in nutrient concentrations occurred at Point of Rocks (RM159), near the Maryland shore, while no significant trends in the same parameters were observed at station POT1596, located a mile downstream near the Virginia shore.

Virginia tributaries showing 10 to 25 percent violations of criteria for fecal coliforms were: Catoctin Creek, Goose Creek, Difficult Run, and Sugarland Run (VSWCB, 1988a,b). Bacterial sources are thought to include livestock tanks, pasture land and leakage from sewer lines running parallel to streams. All follow a pattern of increasing bacterial concentrations following heavy rains and the subsequent flushing of local urban areas.

Discharges from the Leesburg WWTP have created water quality problems in Tuscarora and Goose Creeks (VSWCB, 1988a). During the 1986-1988 period, elevated ammonium levels exceeded EPA aquatic life criteria in 30 percent of the samples collected from Goose Creek, and in 65 percent of samples from Tuscarora Creek. Ammonium levels at the Tuscarora station exceeded EPA aquatic life criteria in 65 per cent of the samples collected. Nitrite concentrations exceeding human health criteria were also observed in Goose Creek. Elevated ammonium levels tended to occur in conjunction with elevated levels of BOD, Total P, and TKN. Recent expansion of the plant from 1.3 to 2.5 mgd is expected to alleviate loading problems at the Leesburg plant. From 1986-1988, the lack of elevated levels of fecal coliforms in Tuscarora Creek was attributed to the influence of the Leesburg WWTP and bacterial die-off from residual chlorine in the plant's effluent.

The water quality of Seneca Creek in 1982-1983 was affected by agricultural and stormwater runoff (ICPRB, 1985). MDE (1988) reported decreasing trends in total suspended solids and coliform bacteria. MWCOG (1984) reported that Seneca Creek delivers a concentrated nitrate supply which tends to hug the Maryland side of the Potomac River and does not mix laterally. Seneca Creek also delivers a highly concentrated organic nitrogen supply to the river.

Water quality has improved over the period from 1974 to 1985 in Sugarland Run. Decreased concentrations of ammonium, dissolved phosphate, nitrate, BOD, and total organic carbon were accompanied by an increase in dissolved oxygen. Dissolved oxygen levels have also increased in Cabin John Creek (ICPRB, 1987). Decreasing trends in total suspended solids and fecal coliform bacteria have been observed in Rock Creek (MDE, 1988).

The above discussion is a short review of the water quality trends in the Potomac River from approximately Luke (MD) to Chain Bridge (DC). If more specific data and related trend analysis is needed the reports of MDE (1988) and ICPRB (1987) should be consulted. The next section provides a brief description of the trends noted in the data to be used for the PRM.

Longitudinal Distributions:

In this section, the data are presented graphically in two different formats. First, the summer (July, August, September) median concentrations of nitrogen and phosphorus for each year were plotted longitudinally from approximately Luke (MD) to Chain Bridge (DC). Next, the monthly median concentrations for each year were plotted to investigate any seasonal changes within the data set. The stations, both mainstem and tributary, that were plotted for seasonal evaluation were chosen on the basis of the longitudinal distributions. The stations that were reviewed were selected to provide a general overview of the water quality of the mainstem Potomac River and tributaries. Again, this review is not intended to be a trend analysis but to provide an overview of the nutrient data. The lines drawn on each plot connect median concentrations from either station to station or month to month. In the longitudinal graphs, the Chain Bridge is at RM115 while the upper station is at Barnum (WVA) (RM340). The water quality station at Barnum is outside of the model boundaries and is used only as a descriptive reference point for the trends along the mainstem (i.e., as a riverine endmember).

Total Nitrogen and Phosphorus

The median summer (July, August and September) nutrient concentrations from Luke, MD to Chain Bridge reflect the major loads to the Potomac River. Overall, both total nitrogen (TN) and total phosphorus (TP) exhibit similar longitudinal distributions (Figure 2 and 3). The median concentrations range from 0.7 to 2.9 mg N/L and 0.02 to 0.3 mg P/L for TN and TP respectively. Concentrations of TN and TP are elevated above RM290 (Oldtown) to RM340 (near Luke, MD). Below RM290 concentrations decrease sharply to RM277 (Paw-Paw). The decrease in TN and TP concentrations are most likely related to a decrease in nitrogen and phosphorus inputs in this reach and dilution related to the inflow of the South Branch at RM285. From Paw-Paw (RM277) to approximately White Ferry (RM147) both TN and TP increase to the highest levels in the river; approximately 2.9 mg N/L and 0.2 mg P/L, respectively. The increase in the concentrations of nitrogen and phosphorus are associated with significant loading of TN and TP from tributaries such as the Antietam, Conococheaque, Catoctin (MD) Creeks and the Monocacy and Shenandoah Rivers. MWCOG (1984) suggested that increased nutrient concentrations around Whites Ferry were related to nutrient loading from the Monocacy River. For example both the Monocacy River and Antietam Creek appear to have 2 to 3 times higher concentrations of TN and TP than the mainstem reach above them. Concentrations of TN and TP are slightly lower below RM147 to RM115 (Chain Bridge) which could be due to either algal uptake (of nitrogen or phosphorus), dilution by low concentration discharge from the Virginia side of the river or settling of particulate matter.

Nitrogen Speciation

The nitrogen system is broken into three fractions: dissolved ammonium (NH_3+NH_4), nitrate (NO_3) and total organic nitrogen (TON). Ammonium concentrations are relatively low throughout the river and are generally lower than 0.1 mg N/L (Figure 4). The median concentrations of dissolved ammonium are highest at RM340 (Luke, MD) and decrease to a "baseline" of 0.03 mg N/L by RM315 (Pinto, MD). Generally, dissolved ammonium is $<<10\%$ of the TN throughout the river. Ammonium is the preferred source of nitrogen for algal uptake and the low values observed may be the result of rapid uptake of ammonium via primary production or rapid conversion to nitrate by nitrification.

Total organic nitrogen (dissolved+particulate) is approximately 40% of the TN in the Potomac River. The distribution of TON is similar to that of TN (Figure 5). Summer median concentrations range from 0.1 mg N/L to 1.2 mg N/L. Generally higher concentrations were observed between RM290 and RM340 and above RM240 (Hancock). The distribution of TON most likely reflects the increased loading from tributaries with higher concentrations of TON.

The dominant fraction of TN in the Potomac River is nitrate which is on average 58% (range 45 to 69%) of the total nitrogen. Summer median concentrations of dissolved nitrate range from 0.03 to 1.9 mg N/L (Figure 6, Appendix B). Concentrations increase to 1.8 mg N/L from RM277 to RM147 (Whites Ferry) and then decrease slightly to Chain Bridge (RM115). This distribution, which is similar to TN, reflects point source and tributary loadings above Oldtown (RM290), dilution between Oldtown and Paw-Paw (RM277), and increased loads from RM240 (Hancock) to approximately Whites Ferry (RM147).

Phosphorus Speciation

Dissolved inorganic phosphorus (DIP) is a major fraction of phosphorus throughout the river (Figure 7). Median summer DIP concentrations from 1983 to 1989 range from <0.01 to 0.2 mg P/L. Approximately 40% of the TP is DIP; the remaining approximately 60% is presumably a mixture of particulate phosphorus and dissolved organic phosphorus. Overall, the distribution of DIP is similar to that of TP. Concentrations are lowest between RM317 (Pinto) and RM340. Between RM277 and RM317, concentrations are generally higher reflecting the nutrient inputs to this reach. Similar to TP, the median concentrations of DIP increase from RM277 to RM147 (Whites Ferry) and then decrease slightly to RM115 (Chain Bridge).

Summary of Longitudinal Trends

Overall, Whites Ferry had the highest concentrations of nitrogen and phosphorus followed by Point of Rocks, Chain Bridge and Hancock (Appendix B). This distribution was especially noted for TN, TP, TON and DIP. The concentrations of ammonium were approximately the same at each mainstem station except for Whites Ferry where concentrations were slightly higher. Both Point of Rocks and Chain Bridge had lower nitrate concentrations than Whites Ferry, whereas the concentrations of nitrate at Hancock were the lowest in the river. Tributaries had concentrations of nitrogen and phosphorus were generally higher than mainstem stations. Except for dissolved ammonium, Antietam Creek had the highest concentrations of all nutrients followed by the Monocacy River, Georges Creek, Shenandoah River and Savage Run. The concentrations of ammonium were highest in Georges Creek and lowest in the Savage River. The South Branch (RM285) of the Potomac River had some of the lowest median concentrations of nitrogen and phosphorus of all the tributaries.

These spatial trends reflect changes in dilution and nutrient loadings from both point and non-point sources. For example, the decrease in the concentrations of nitrogen and phosphorus (Figures 2 to 7) between Oldtown (RM282) and Paw-Paw (RM277) is consistent with dilution by the South Branch (at RM285) which contains lower concentrations of nitrogen and phosphorus. The higher concentrations of nitrogen and phosphorus around Whites Ferry (RM147) reflect increased loading from upstream tributaries. Antietam Creek as well as the Monocacy River most likely supply a substantial amount of the nitrogen and phosphorus to the reach centered around Whites Ferry. However, biogeochemical processes related to uptake and remineralization can not be discounted.

The distributions from Figures 2 and 3 were used to help guide the construction of a simplified mass balance of the inputs (tributaries and point sources) and outputs of TN and TP for the Potomac River **(see Chapter 4)**.

Temporal Distributions:

Mainstem Stations

Generally, higher total nitrogen (TN) concentrations were observed in the winter/fall and lower concentrations in the summer months of all locations that were examined (Figures 8-12). Nitrate, which is the dominant form of nitrogen, exhibited a similar pattern as TN (Figures 13-17). This is especially noted in the Whites Ferry and Chain Bridge data. Although there is scatter in the data, the concentrations of total organic nitrogen (TON) were generally higher in the summer than in the winter (Figures 18-22; see Point of Rocks and Whites Ferry as examples). A large portion of the organic nitrogen may be tied-up in algal biomass in the river. As such, the higher concentrations of TON in the summer may be indicative of higher rates of primary production and increases in algal biomass. It has been suggested that TON is correlated with river flow (MWCOG, 1984). An analysis of the data set from Chain Bridge (OWML, 1990) however, reveals no significant trend for flows below 50,000 cfs.

Median ammonium concentrations were low throughout the year and exhibited no distinct seasonal trend. This may be due to algal uptake or low ammonium inputs in the river. An exception to this pattern is observed at Whites Ferry where higher concentrations were observed from July to September (especially noted in 1987).

Total phosphorus (TP) and dissolved inorganic phosphorus (DIP) median concentrations exhibited no distinct seasonal trend among most of the mainstem stations. Whereas, Whites Ferry had slightly higher TP and DIP concentrations between August and October (especially in 1984); Chain Bridge, Point of Rocks and Hancock exhibited little seasonality.

Yearly trends for the summer median concentrations between 1983 and 1989 are evident for nitrate and possibly for dissolved inorganic phosphorus and total phosphorus (Appendix B). Total nitrogen concentrations did not exhibit any apparent trend from 1983 to 1989. Median nitrate concentrations increased for most stations from 1983 to 1989. This trend was also noted by ICPRB (1987) for the years between 1979 and 1984. Ammonium and total organic nitrogen concentrations exhibited no distinct yearly trend.

Trends between 1983 and 1989 for dissolved inorganic and total phosphorus are not as evident as for nitrate. Concentrations of total phosphorus exhibited either no noticeable trend or a slight decrease from 1983 to 1989, however dissolved inorganic phosphorus concentrations generally decreased with time. The decrease in dissolved inorganic phosphorus concentrations as a result of the phosphorus ban may be evident from this data set. The State of Maryland imposed a phosphorus ban in 1986 while Virginia did not initiate a ban until 1988.

Tributaries

Seasonally, the tributary distributions of nitrogen and phosphorus exhibited greater scatter than the mainstem stations. This scatter makes any interpretation tenuous at best. The trends noted below, therefore, are based on the overall monthly median concentrations.

Monthly median total nitrogen and nitrate concentrations exhibited similar trends in most tributaries reviewed (Figures 23-34). Generally, lower concentrations are observed in the summer months. However, the Savage River showed slightly higher concentrations of TN and nitrate in the early spring, whereas Georges Creek exhibited higher concentrations in the late fall and early winter. The Monocacy River had lower nitrate concentrations in the summer although the scatter in the data makes this a guarded inference. The Shenandoah River had lower nitrate concentrations in the late summer/early fall with highest median concentrations in the winter. The median concentrations of nitrate in the South Branch were almost undetectable in mid to late summer; highest concentrations were observed between January and March. The median concentrations of TON for all tributary stations did not exhibit any distinct seasonal patterns. Monthly median ammonium concentrations, except for the Shenandoah River and the South Branch, showed slightly higher median concentrations in the winter and lower concentrations in the summer. This trend indicates either increased consumption of ammonium via algal uptake or nitrification and/or a decrease in the input of ammonium from point and non-point sources during the summer. Lower concentrations of ammonium were observed in the fall at Antietam Creek and Savage River.

The monthly median concentrations of TP and DIP were higher in the late summer and early fall at the Monocacy River and Antietam and Georges Creeks (Figures 36-46). The Savage River exhibited no seasonal trend in either the median concentrations of DIP or TP. The Shenandoah River exhibited slightly higher median concentrations of TP in the summer, while DIP showed no distinct monthly trend throughout this time period. The monthly median concentrations of TP from the South Branch exhibited little seasonality. However, in 1984, higher concentrations were detected in the late summer/fall.

Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand (BOD) determination is an empirical test in which standardized procedures are used to determine the relative oxygen requirements of wastewaters, effluent, and surface waters. The test measures the oxygen demand produced by the immediate (5 day) biological oxidation of carbon and nitrogen compounds. The oxidation of carbon and nitrogen compounds therefore has a direct bearing on the oxygen balance of stream waters and the BOD must be considered in the discharge of wastes to such waters.

Data for both mainstem and tributary stations are very limited (Appendix B). There are only ca. 150 (summer) observations between 1983 and 1989 for all mainstem stations, while there were less than 140 observations for all tributary stations over the same time period. Overall, median summer BOD concentrations between 1983 and 1989 range from 0.5 to 6 mg O_2/L and 0.5 to 8 mg O_2/L for mainstem and tributary stations, respectively. Longitudinal trends along the mainstem are difficult to discern due to the lack of data. However, BOD concentrations are highest near Little Falls (RM117) and lowest at Chain Bridge (RM115). Similarly, tributary BOD median concentrations are highest near the Monocacy River and Goose Creek. These tendencies must be viewed with caution because there are few observations (median summer values) in the Potomac River and tributaries, especially above Shepardstown (RM183).

Summary of Nutrient Distributions

Based on the preceding discussion concerning the water quality of the free-flowing Potomac River, a qualitative description of the nutrient dynamics and cycle of the river can be constructed. Soluble nutrients enter the North Branch of the Potomac River and concentrations increase due to point source loadings upstream of Oldtown (RM290). Dilution by the South Branch of the mainstem Potomac River combined with possible uptake and settling of nitrogen and phosphorus results in concentrations decrease between Oldtown and Paw-Paw (RM277). From Paw-Paw to approximately Whites Ferry (RM147), nitrogen and phosphorus increase to the highest concentrations observed in the river. This increase is associated with the relatively high nutrient inputs from tributaries in the middle Potomac (e.g., Monocacy River and Antietam Creek). Below Whites Ferry, nutrient concentrations decrease slightly. This may be the result of a combination of dilution, algal uptake, microbial transformations and settling of particulate material. As noted by MWCOG (1984), the decreased nutrient concentrations between Whites Ferry and Chain Bridge (RM115) is interesting due to the fact that Seneca Creek has higher nutrient concentrations than the mainstem and could be expected to elevate mainstem nutrient concentrations. Poor lateral mixing between the Virginia and Maryland sides of the Potomac River has been previously noted (MWCOG, 1984). If the lateral variations between the Maryland and Virginia sides of the river are large enough, a dilution of the Seneca Creek load could occur. The longer residence time of the water behind Seneca Pool may enhance greater uptake of the nutrients by algae and thus lowering the concentrations dissolved nutrients in the river.

Definitive seasonal trends within the river basin are difficult to notice due to the variations in the data. Seasonal variations in the concentrations of the nutrients should be expected due to seasonal changes in flow, transport, loading and algal primary productivity. However, variations related to primary productivity, which should be highest in the summer, may be dampened by the short residence time of the water in the various reaches of the river. Between Point of Rocks and Chain Bridge the water residence time varies between one day at high flow and approximately seven days at flows of approximately 1500 cfs. The effects of algal uptake on the nutrient concentrations in the mainstem would be most evident during low flow periods (late summer/fall). This is also the time when point source loadings would tend make a greater contribution in the river. Therefore, during the summer low-flow time period, the removal of nitrogen and phosphorus via algal uptake and settling may be masked by point source inputs which would be a greater proportion of the total load during this time of the year.

Overall Water Quality Monitoring Data Assessment

Based on the water quality monitoring data obtained from various state and federal agencies, it appears that there is sufficient data to perform "steady-state" simulation of the mainstem Potomac River with some assumptions. The data presented above is sufficient for tributary load calculations and for calibration and verification of the PRM. As stated in the previous sections, all the monitoring data except those from OWML, are monthly grab samples. Thus it is assumed that the monthly sample approximates the "steady-state" concentration for the calibration and validation period. As the OWML data at Chain Bridge show, there is wide variations in the observed concentration within a month. Hence, this assumption could underestimate the "steady-state" concentration. On the other hand, there are differences in the constituents monitored and reported by the different agencies. As discussed earlier, assumptions were made to allow for reconciliation of these differences, thus increase the uncertainties in model calibration and validation. Finally, the lack of observed BOD and Chl-a, especially for stations above Point of Rocks, MD, would hamper the modeling effort.

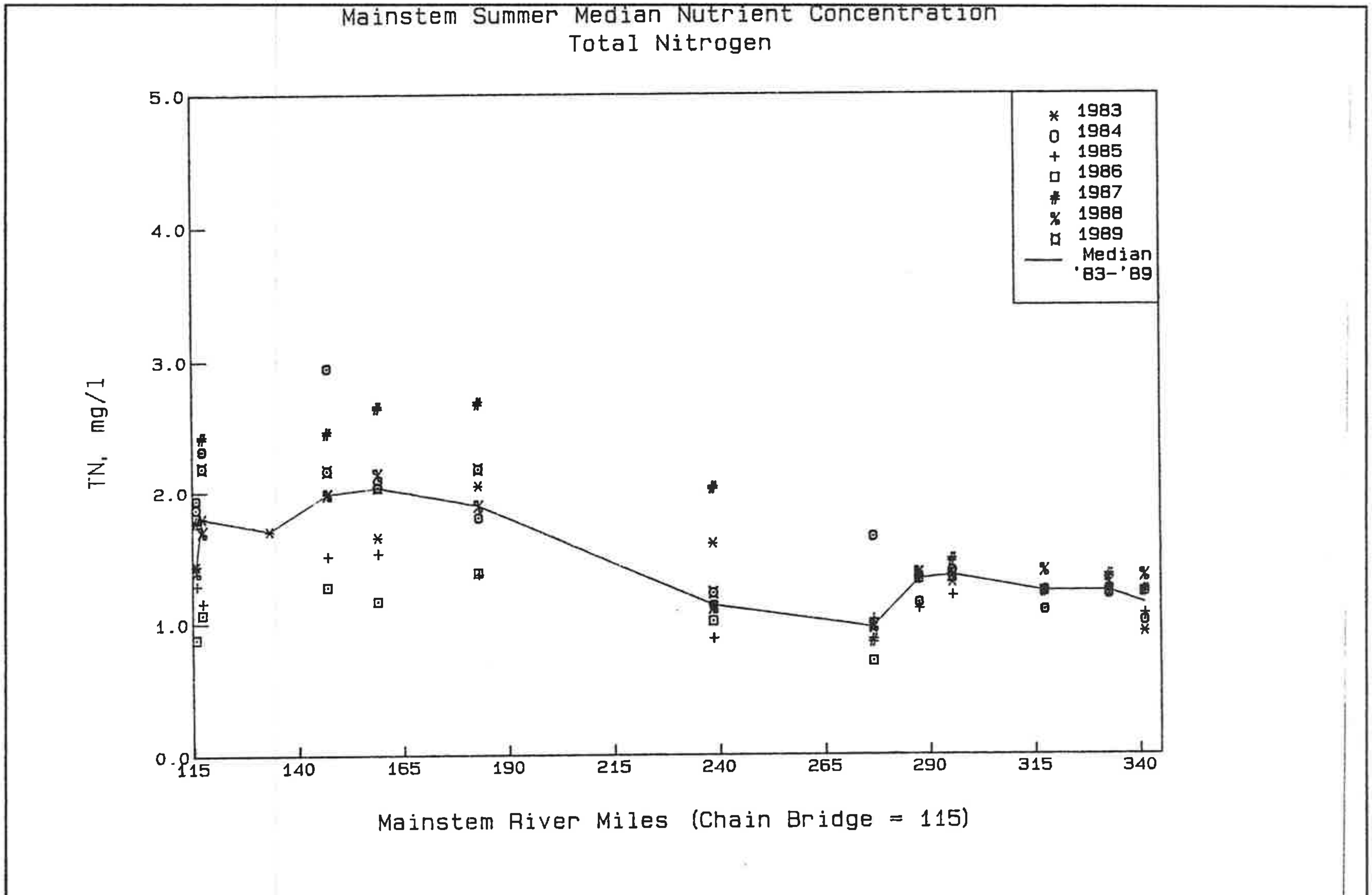

Figure 2. Mainstem Summer Median Total Nitrogen

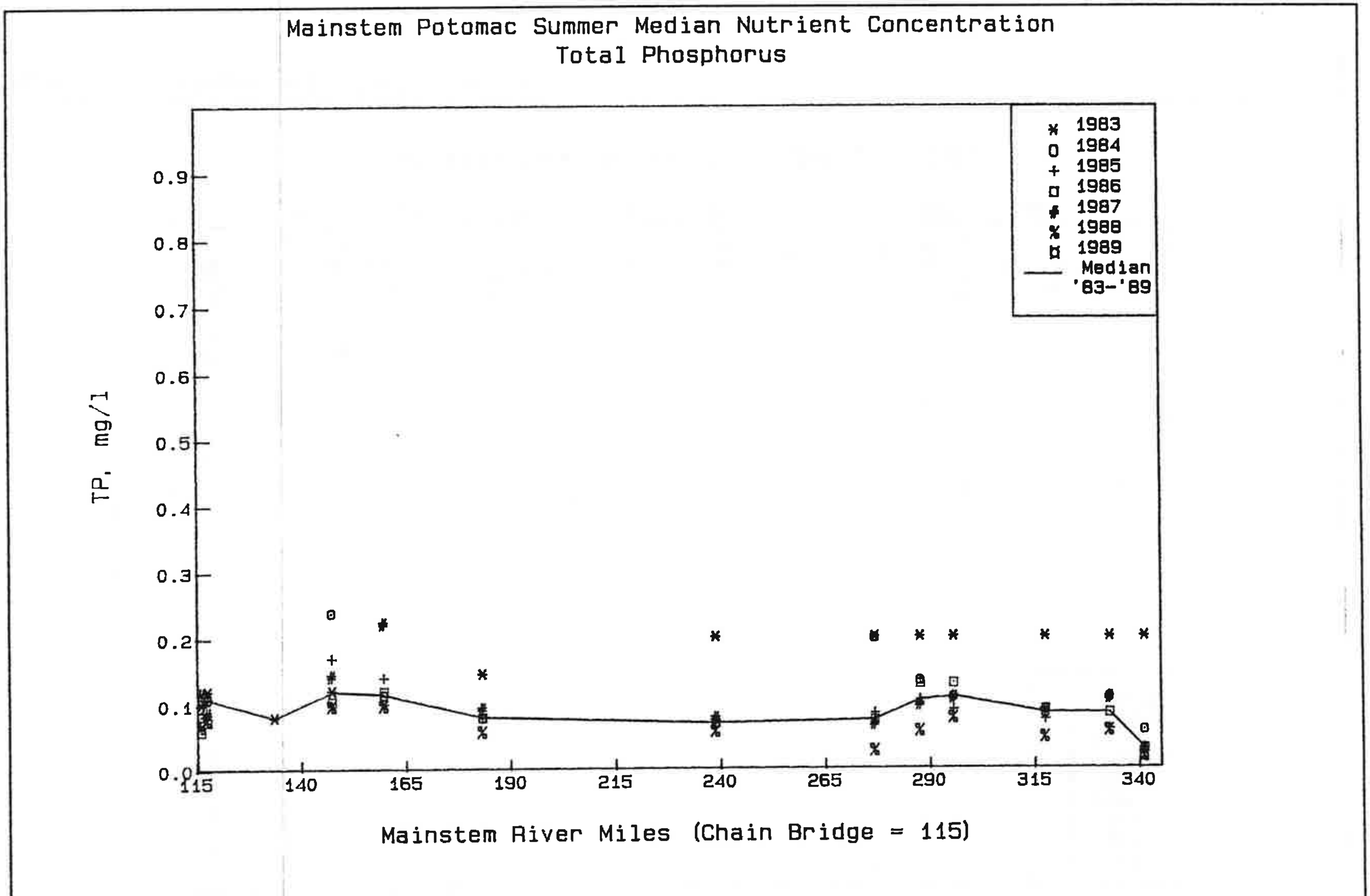

Figure 3. Mainstem Summer Median Total Phosphorus

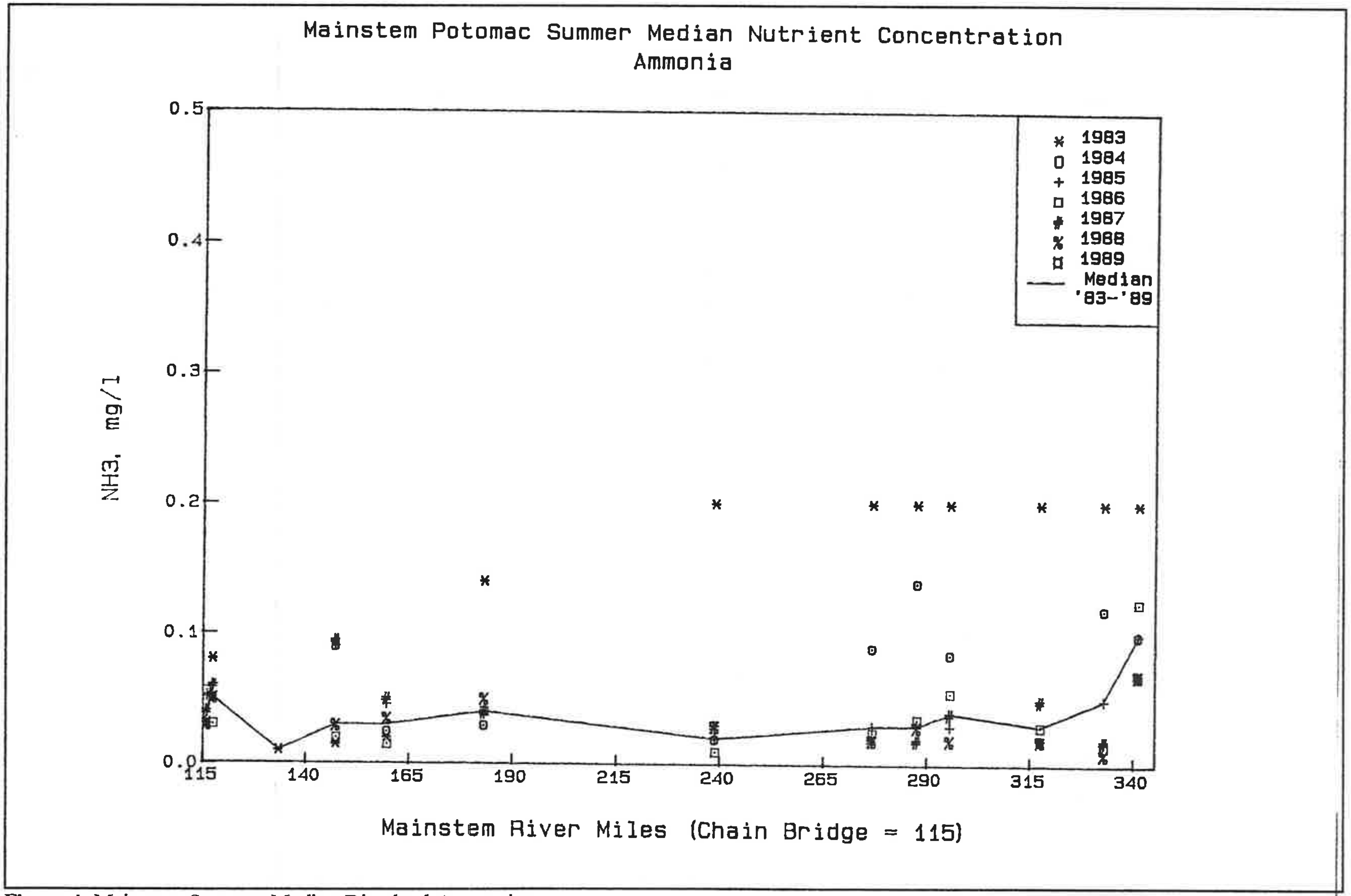

Figure 4. Mainstem Summer Median Dissolved Ammonium

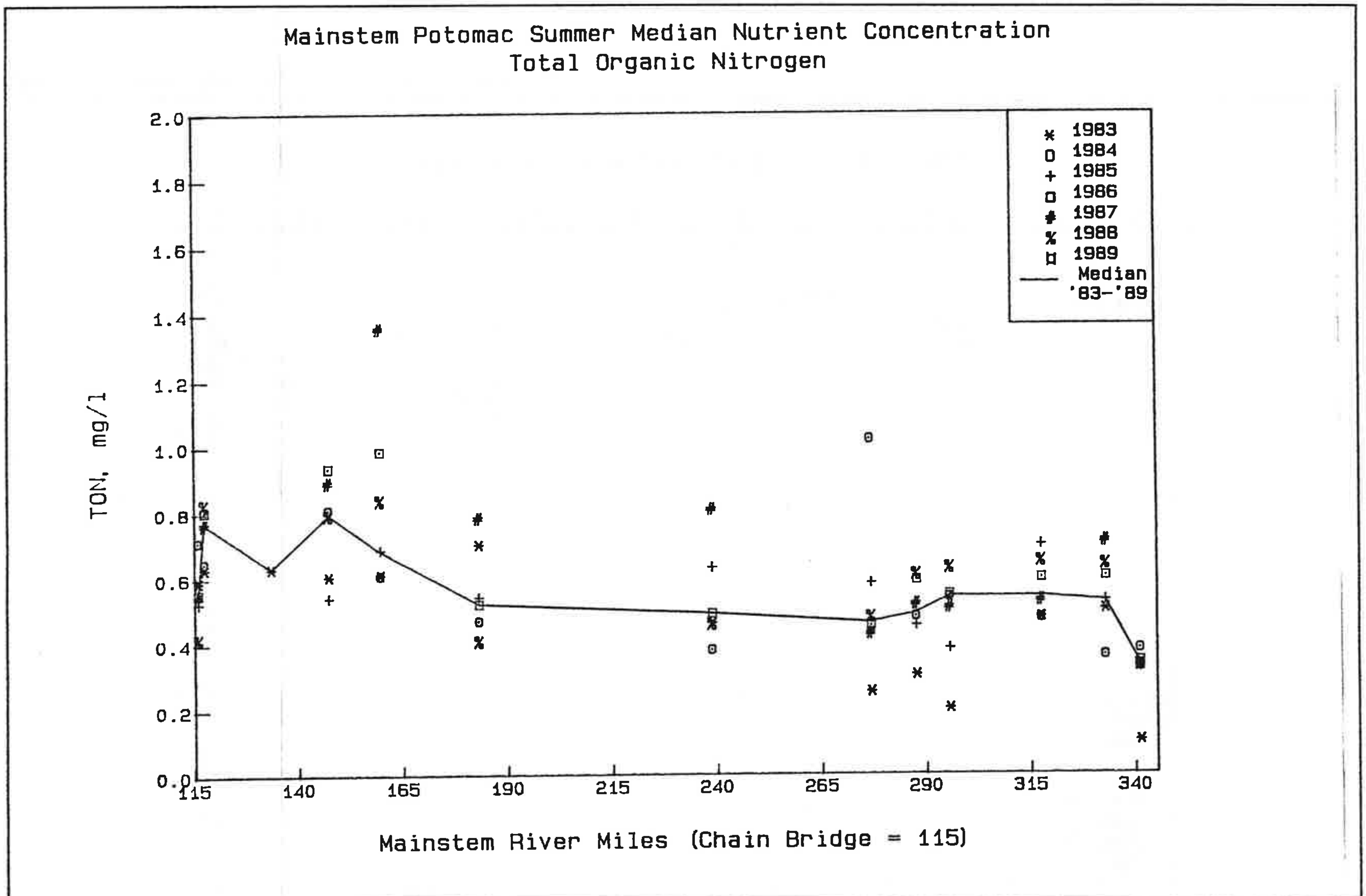

Figure 5. Mainstem Summer Median Total Organic Nitrogen

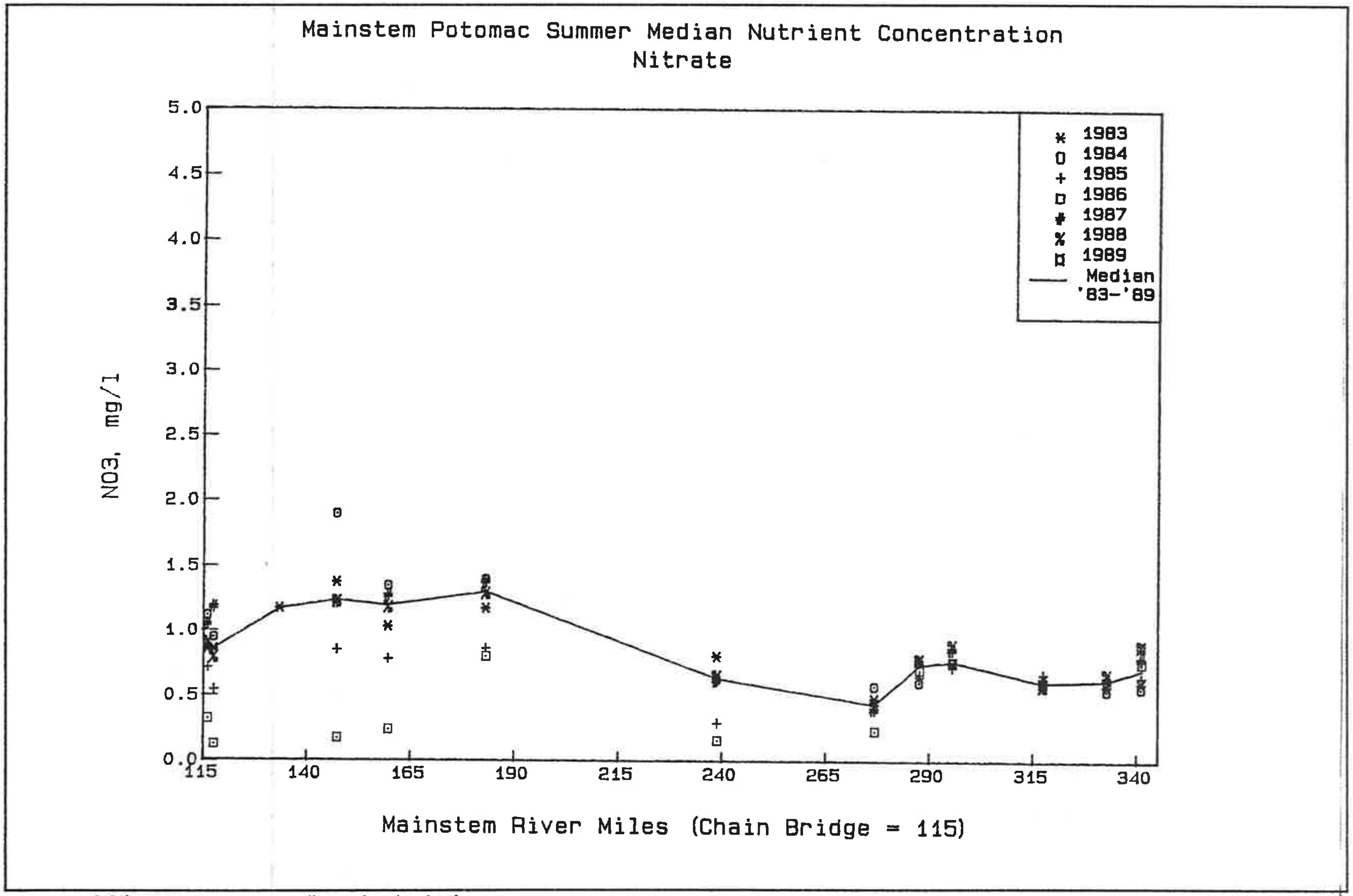

Figure 6. Mainstem Summer Median Dissolved Nitrate

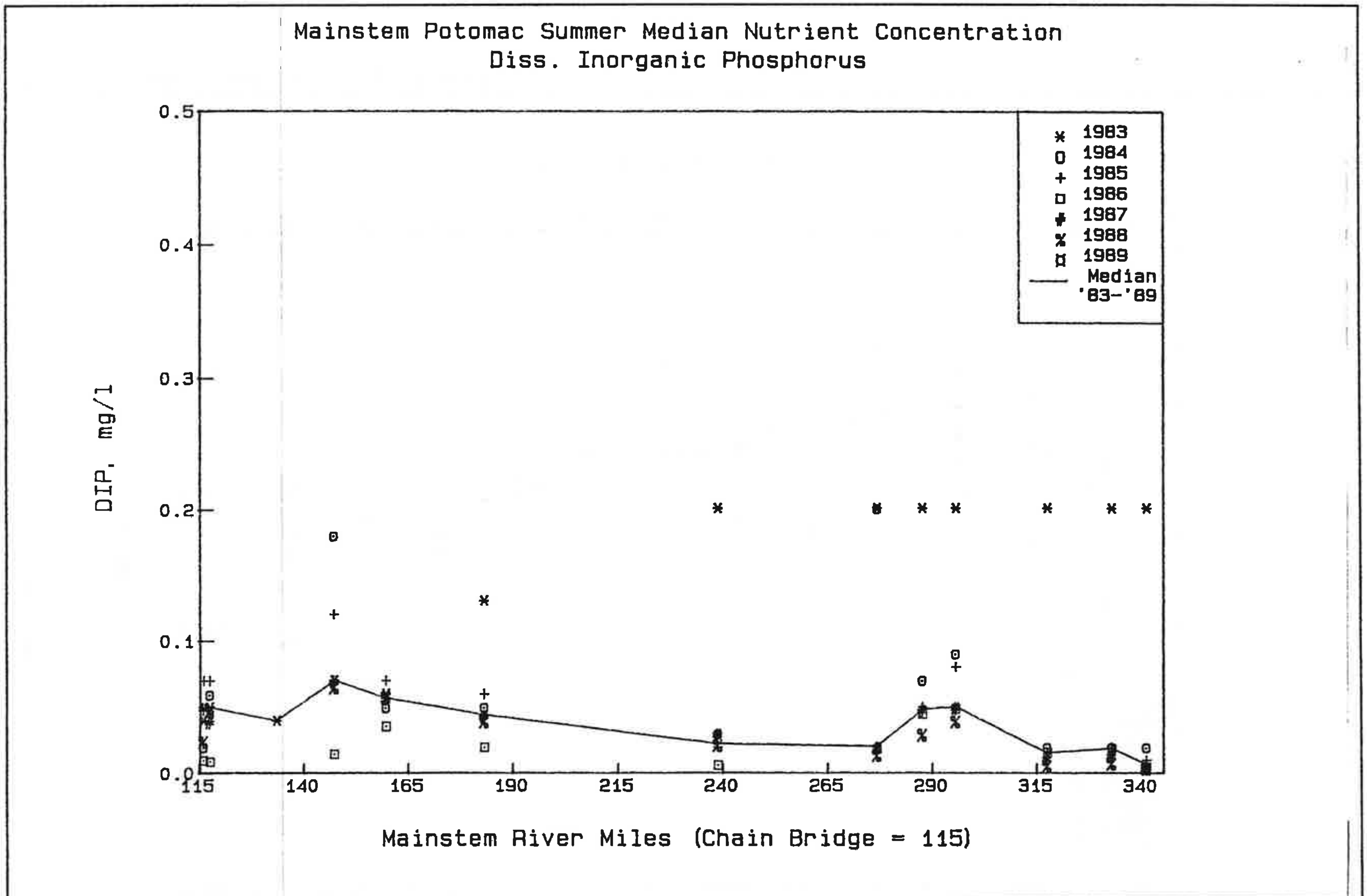

Figure 7. Mainstem Summer Median Dissolved Inorganic Phosphorus

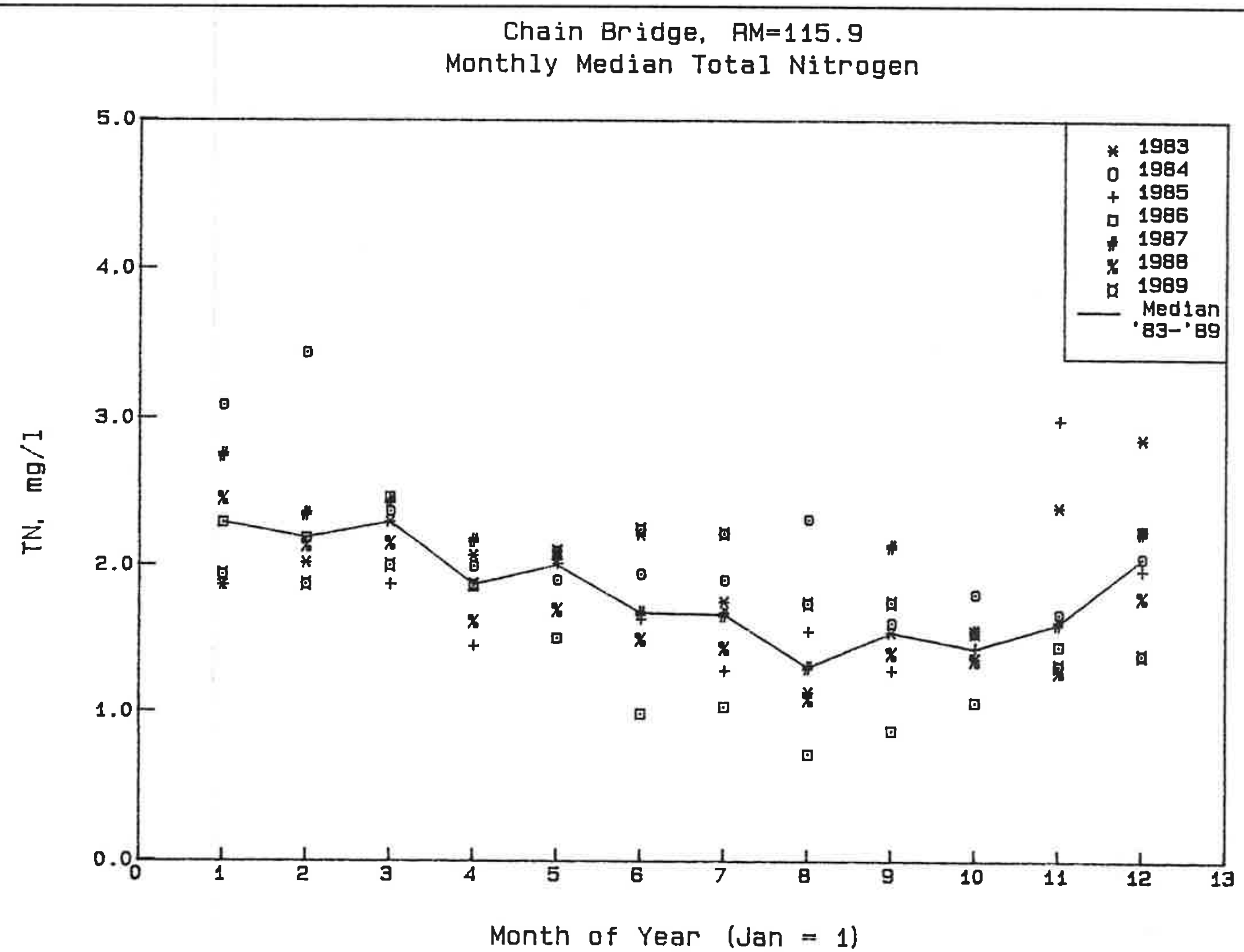

Figure 8. Monthly Median Total Nitrogen: Chain Bridge

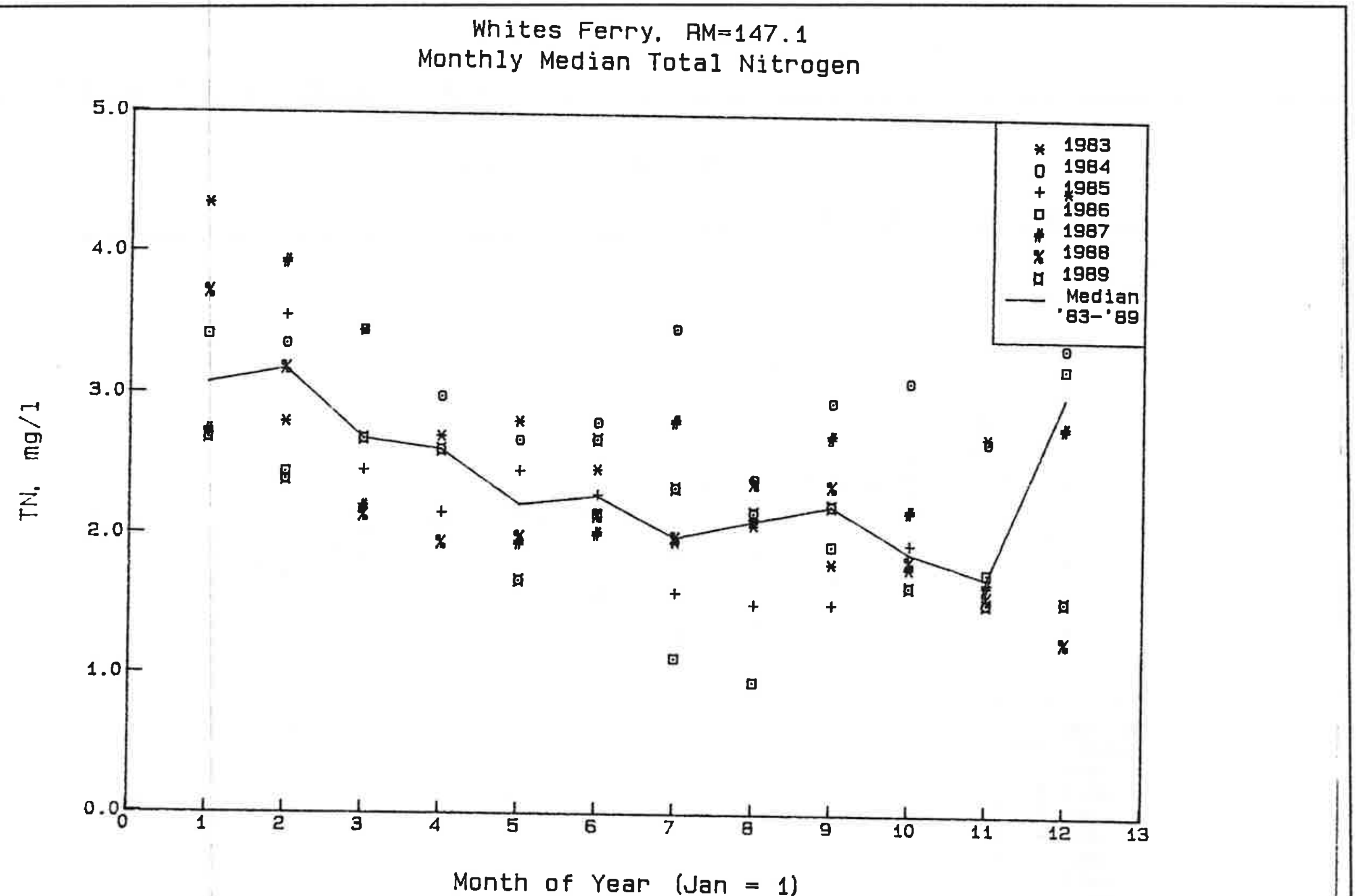

Figure 9. Monthly Median Total Nitrogen: White Ferry

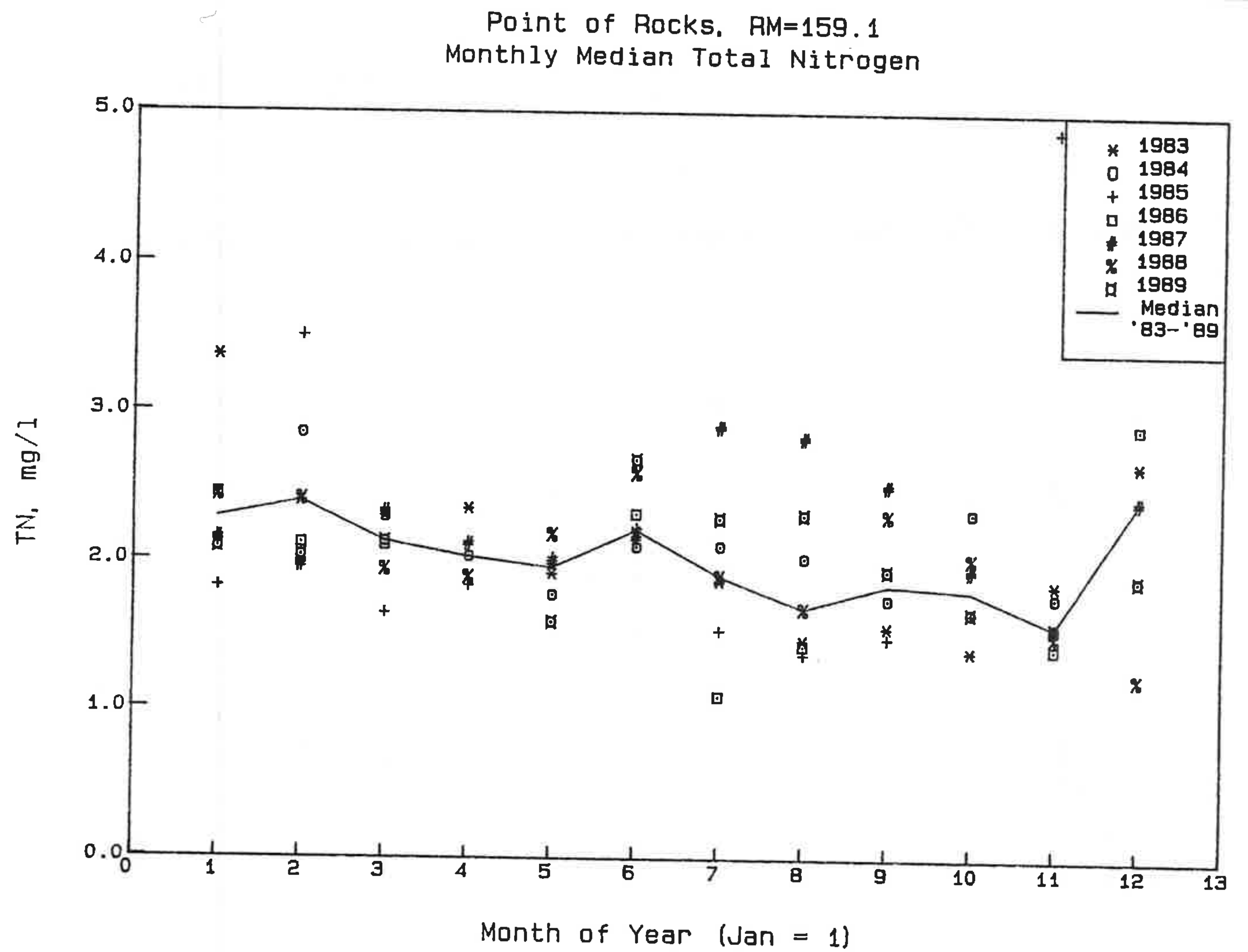

Figure 10. Monthly Median Total Nitrogen: Point of Rocks

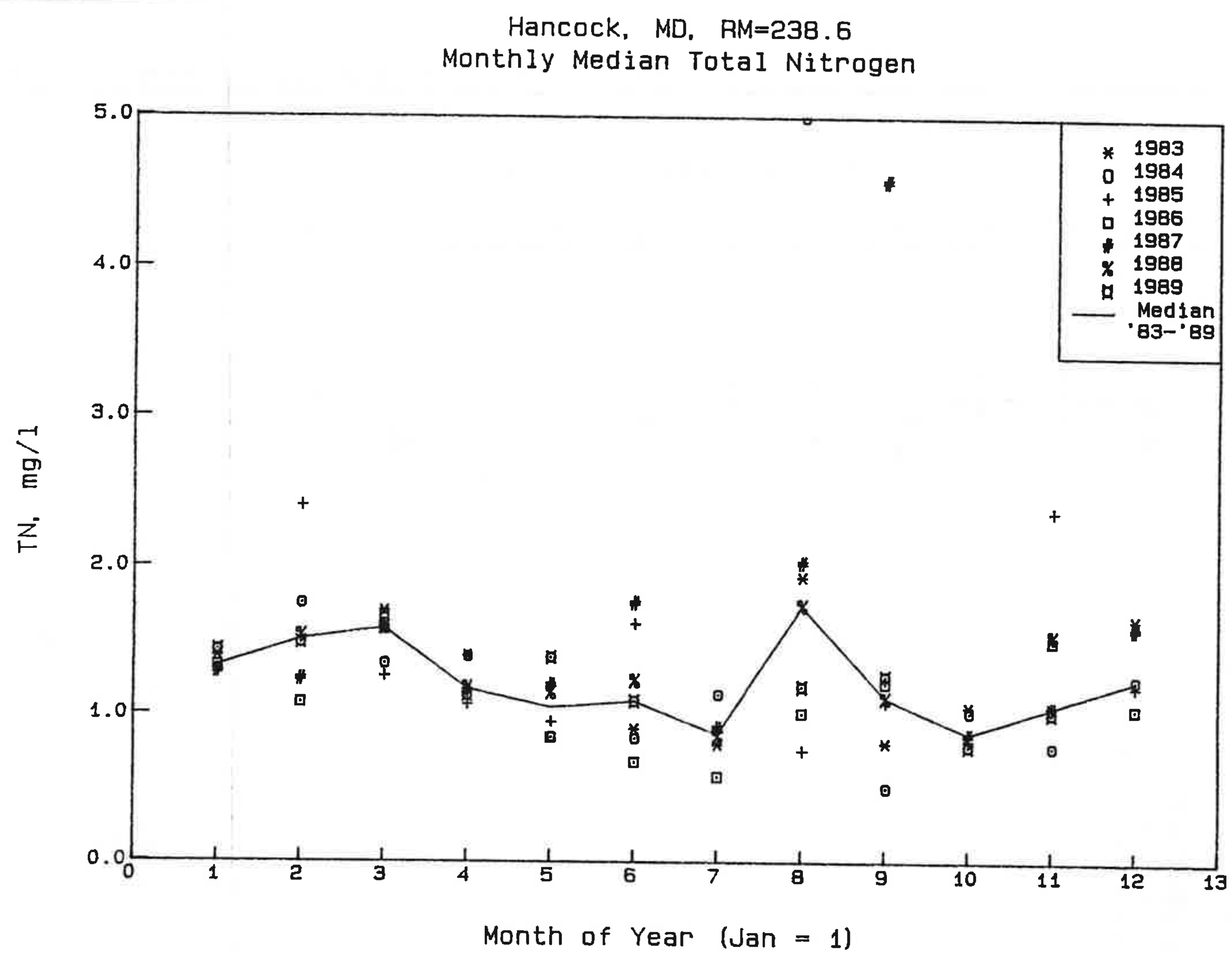

Figure 11. Monthly Median Total Nitrogen: Hancock

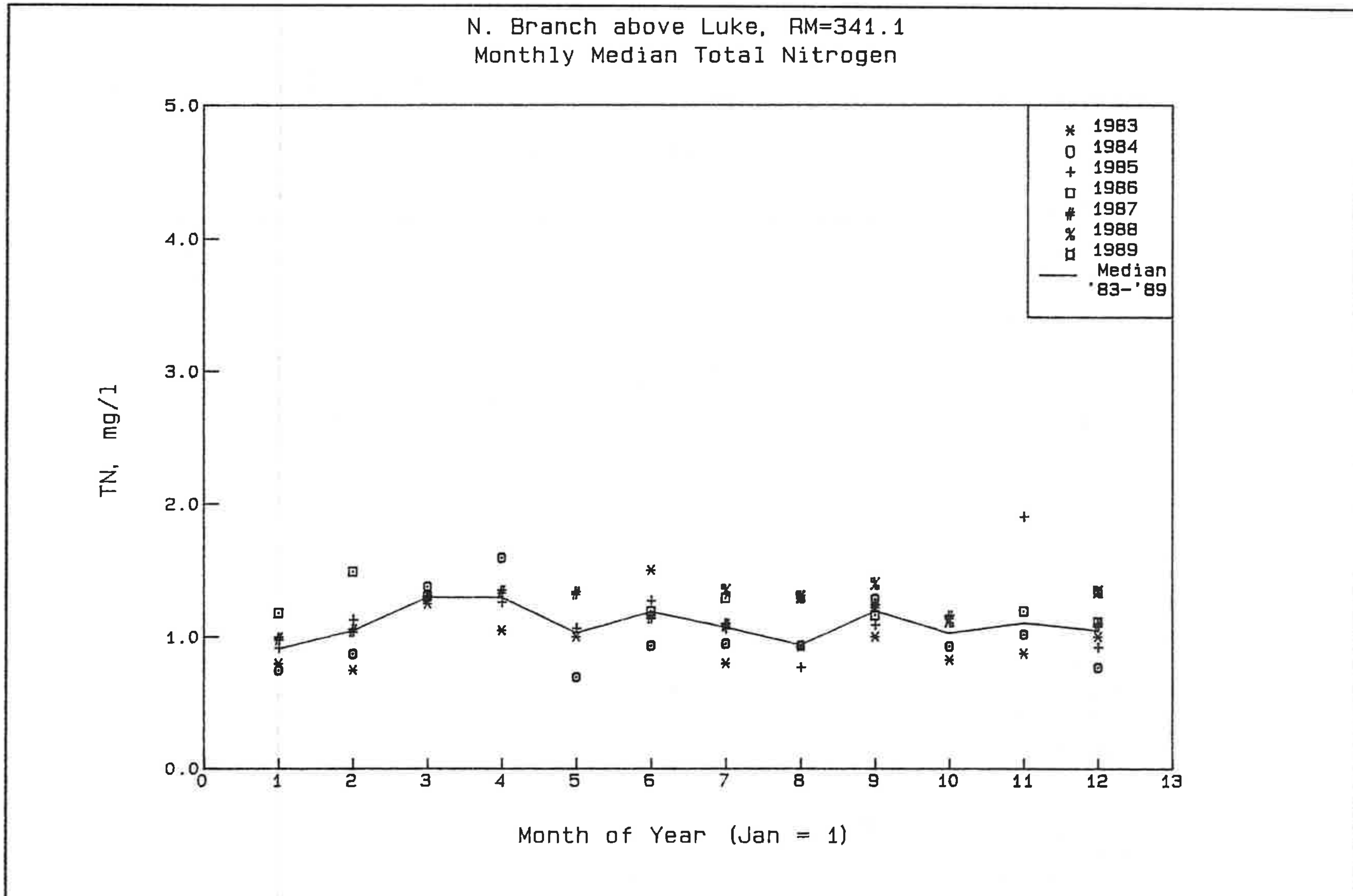

Figure 12. Monthly Median Total Nitrogen: Luke

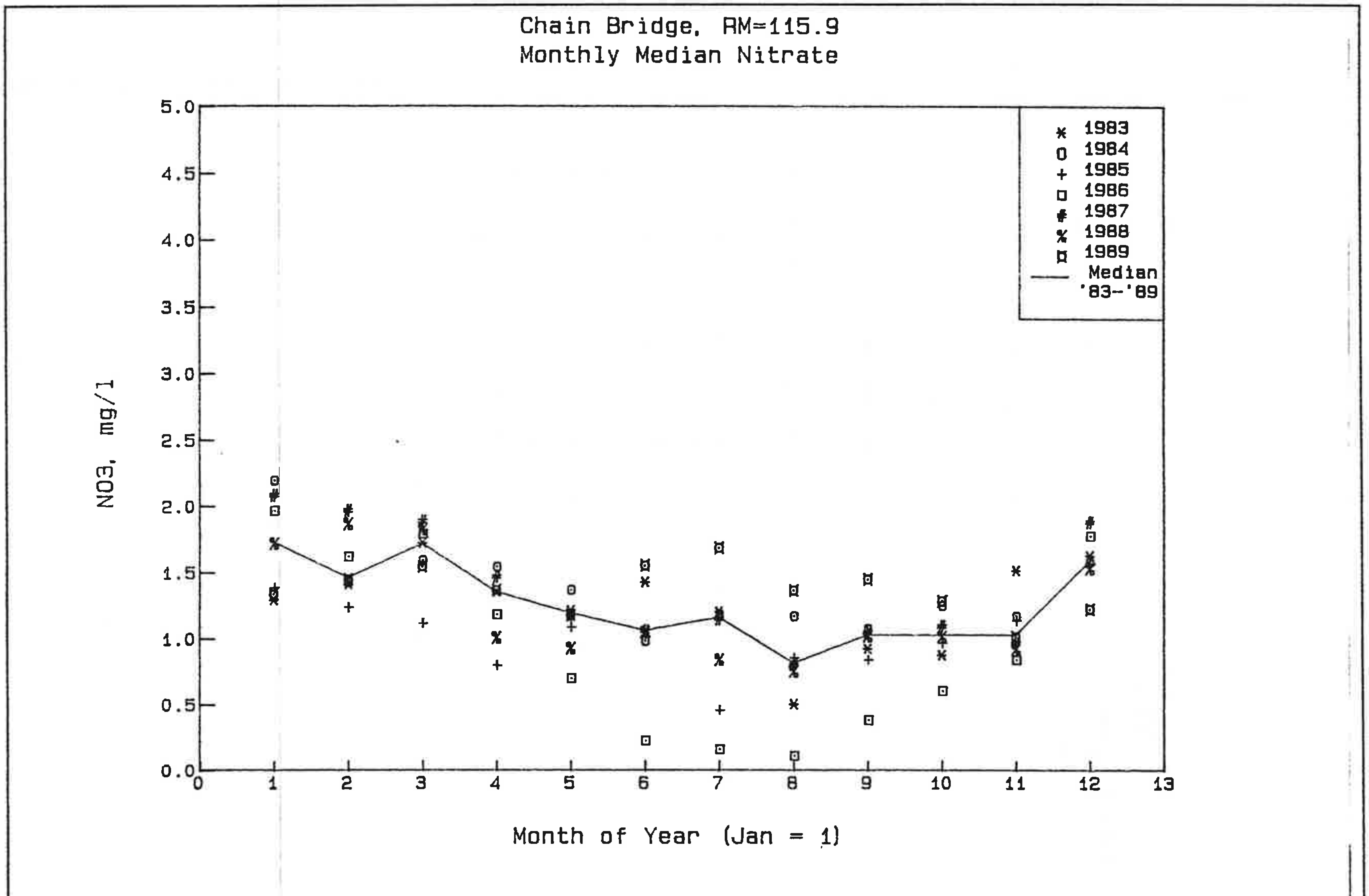

Figure 13. Monthly Median Dissolved Nitrate: Chain Bridge

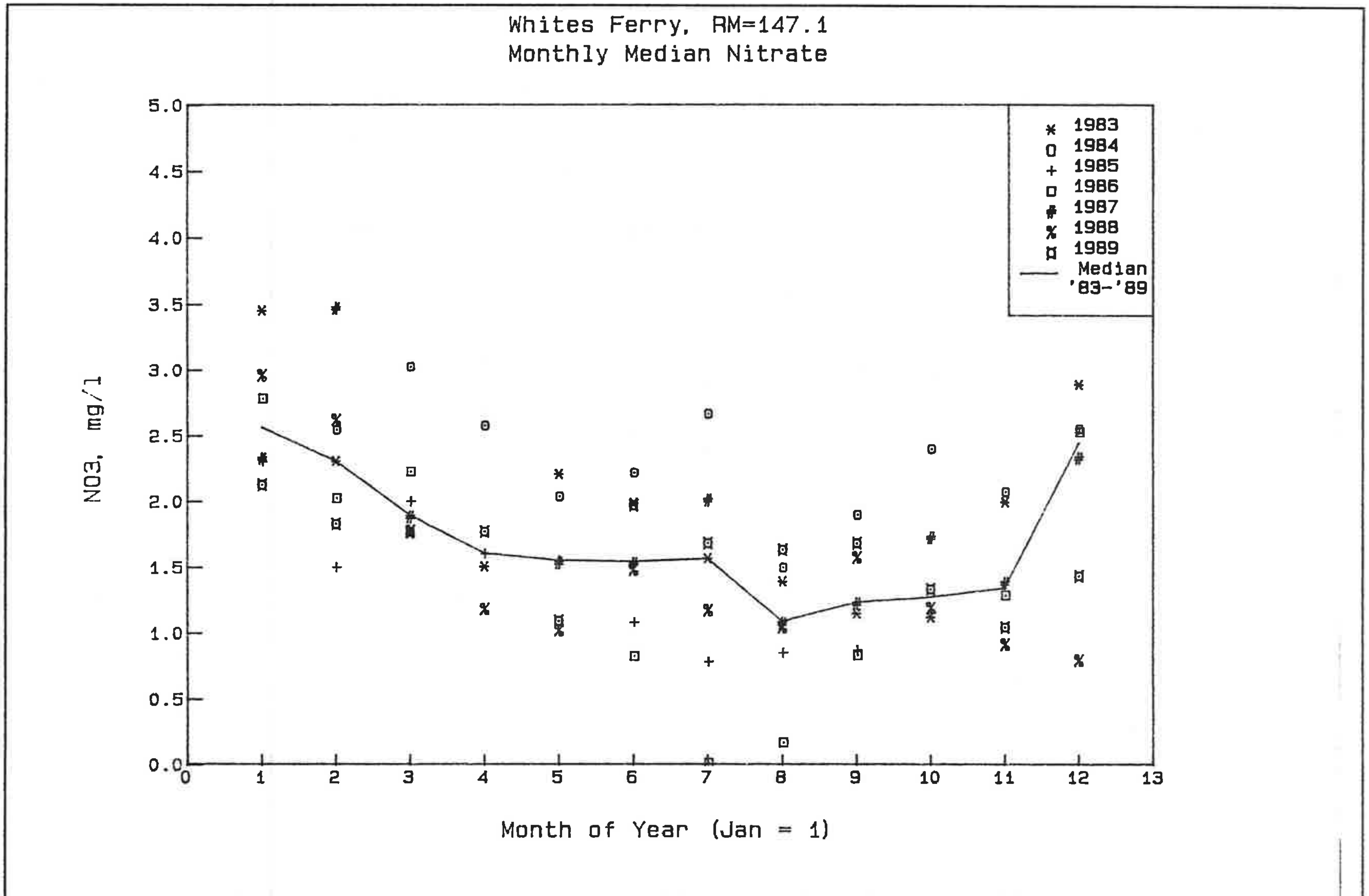

Figure 14. Monthly Median Dissolved Nitrate: Whites Ferry

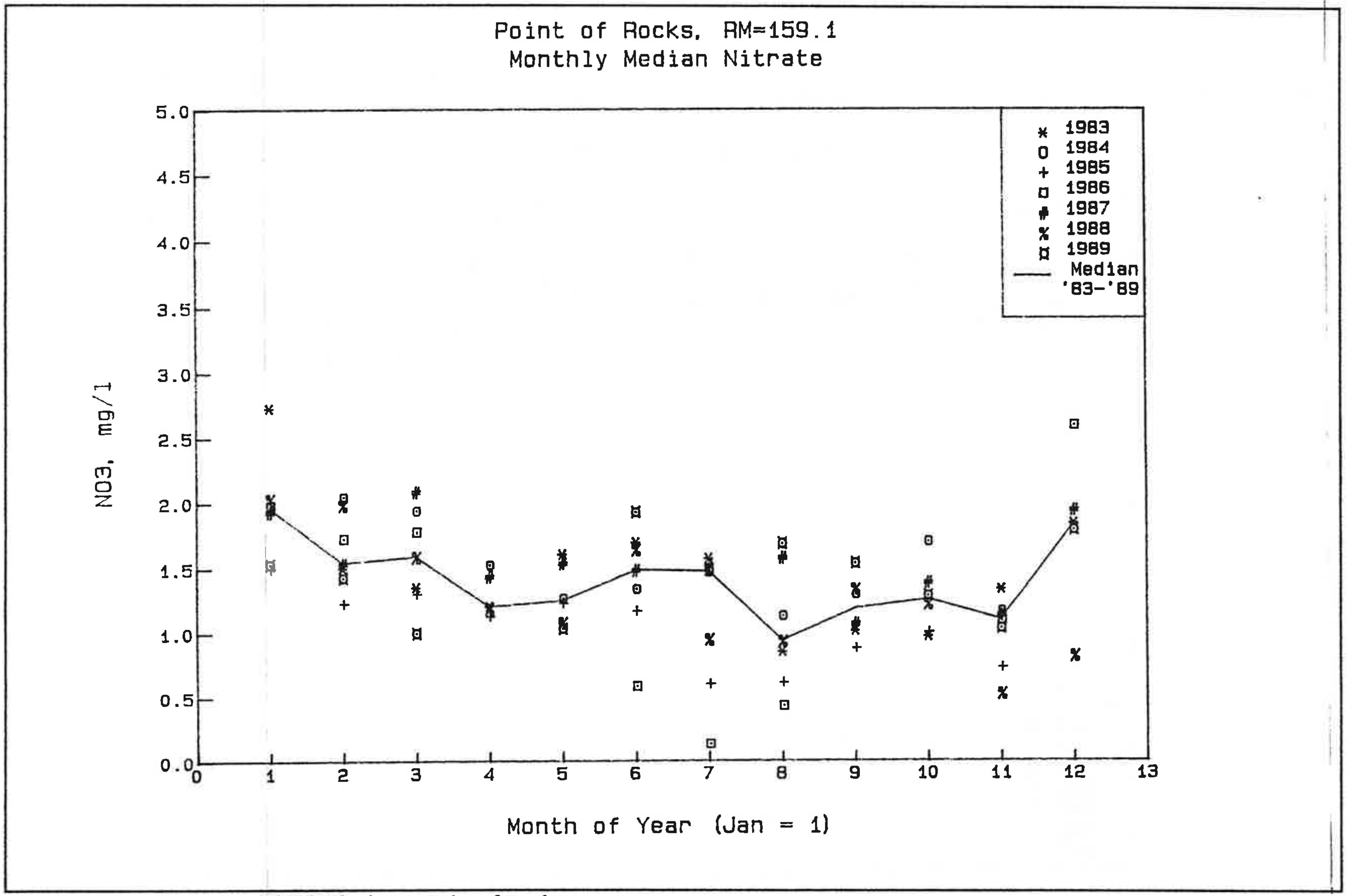

Figure 15. Monthly Median Dissolved Nitrate: Point of Rocks

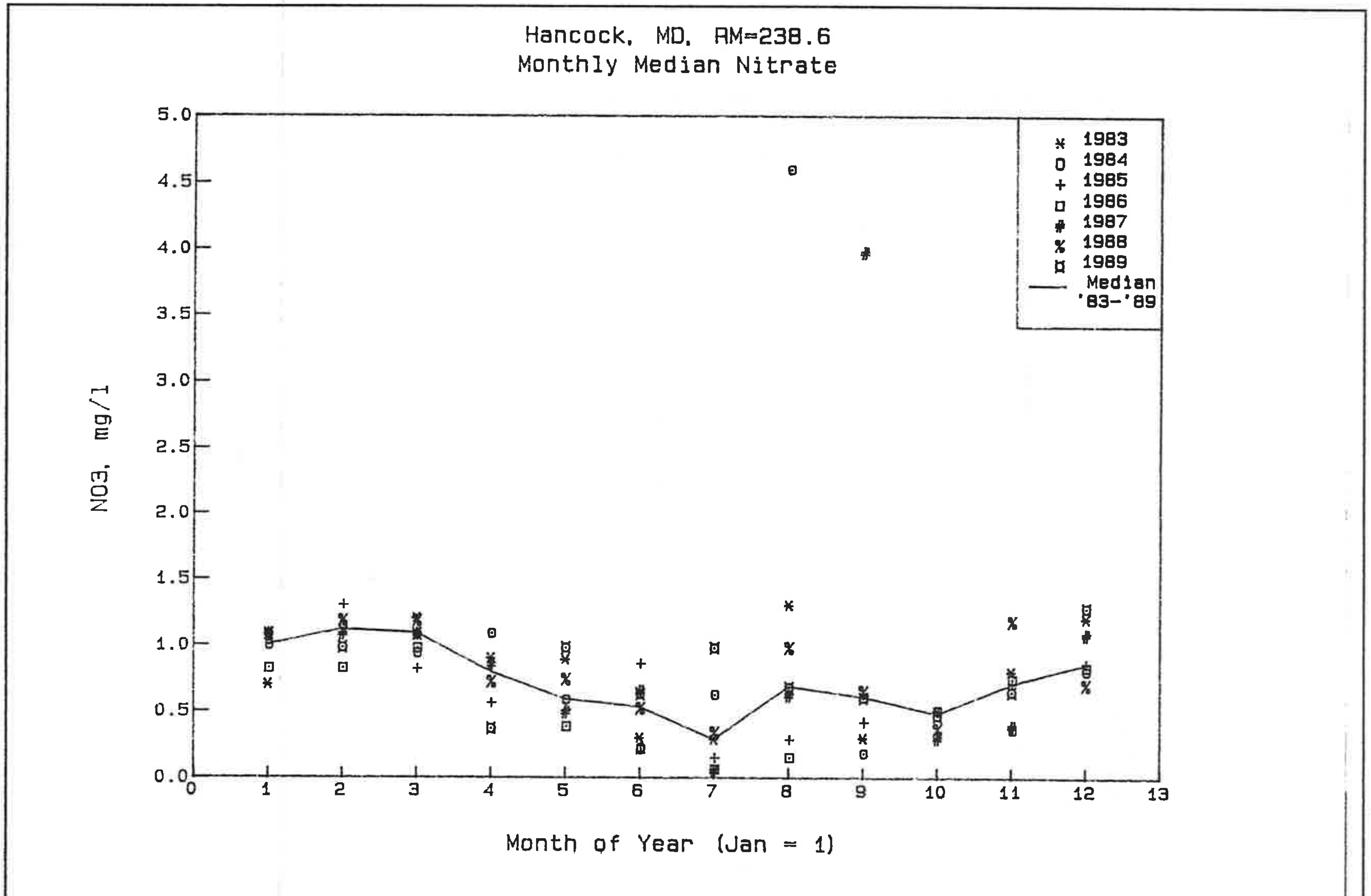

Figure 16. Monthly Median Dissolved Nitrate: Hancock

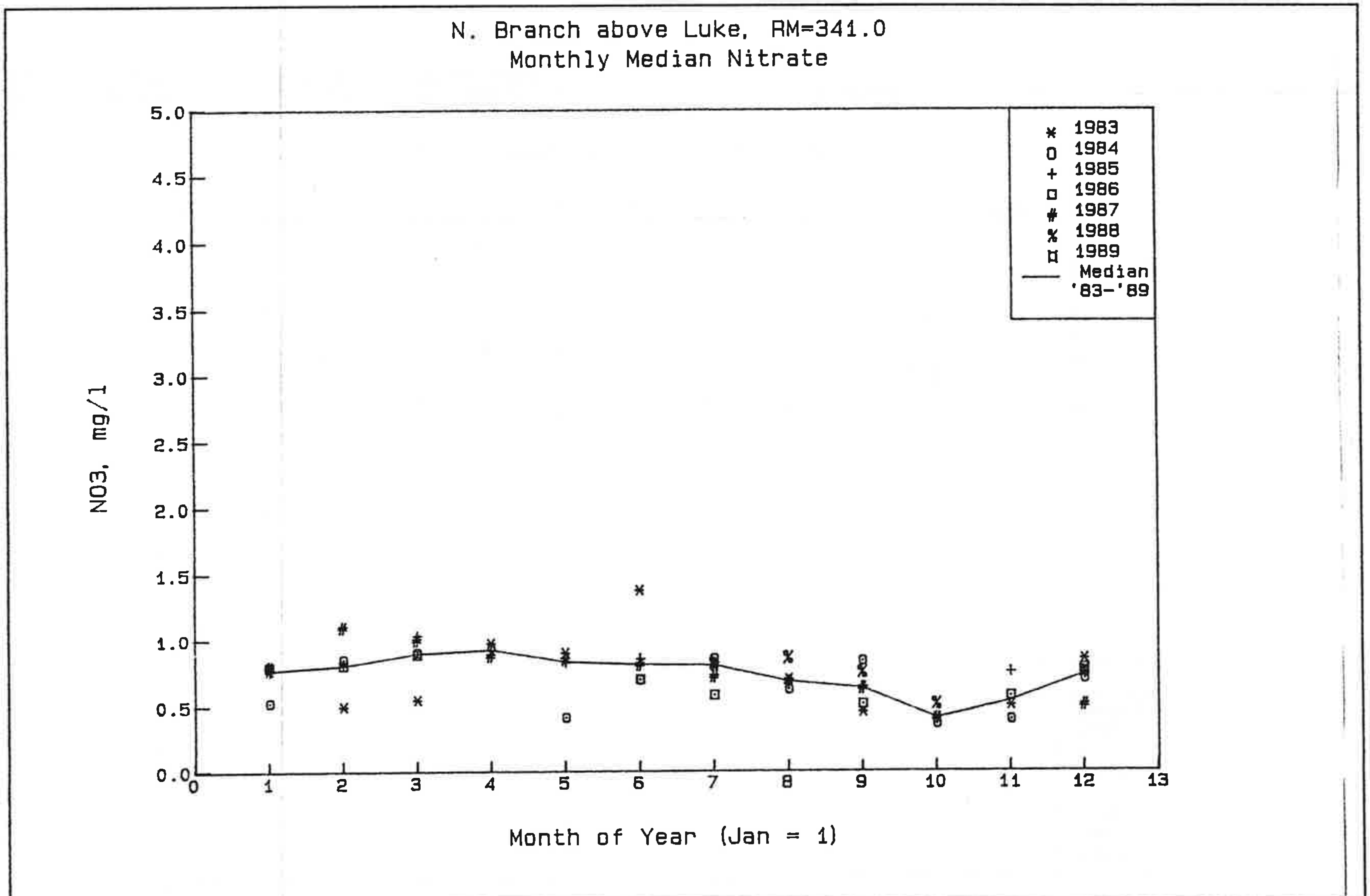

Figure 17. Monthly Median Dissolved Nitrate: Luke

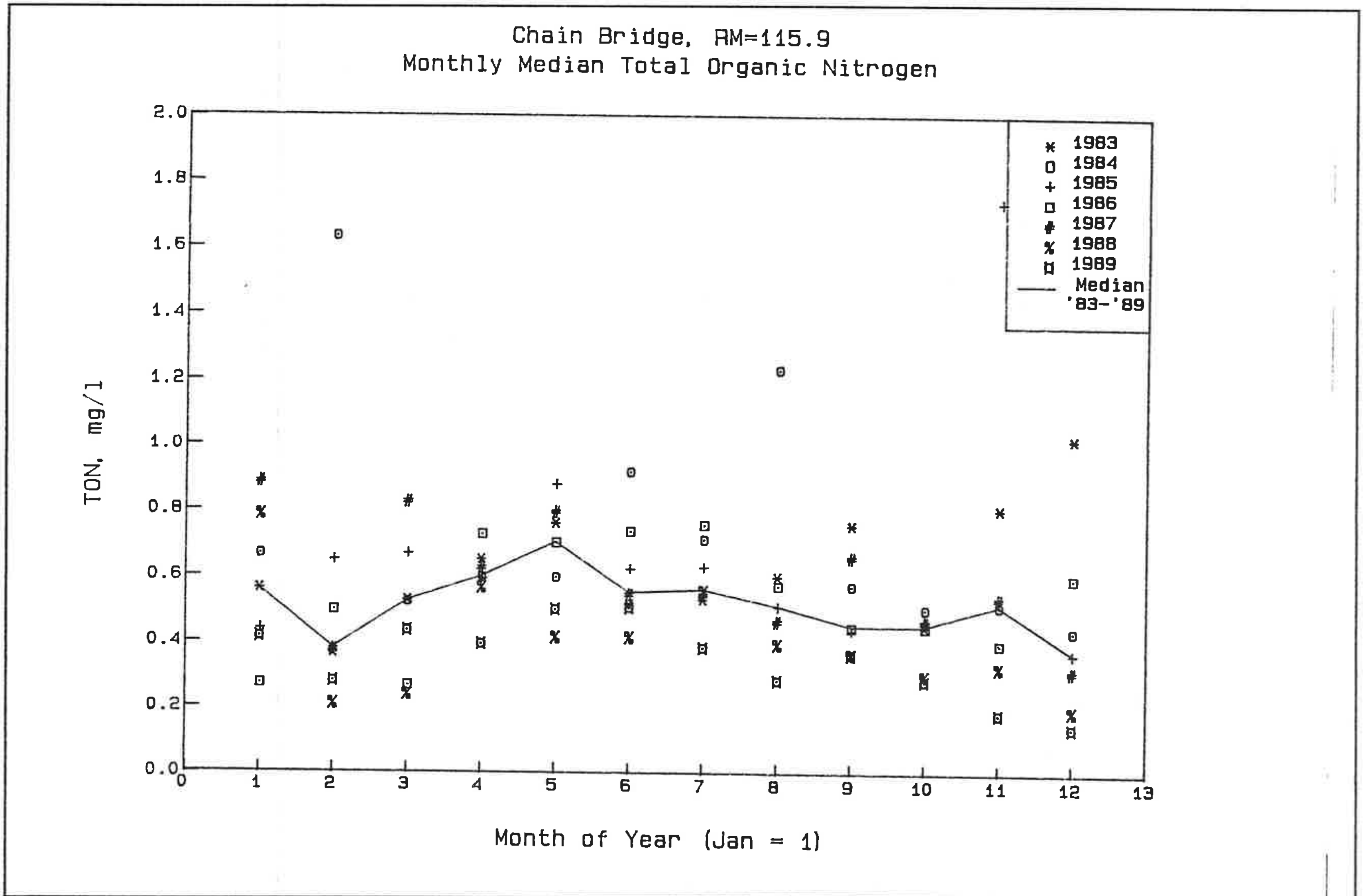

Figure 18. Monthly Median Total Organic Nitrogen: Chain Bridge

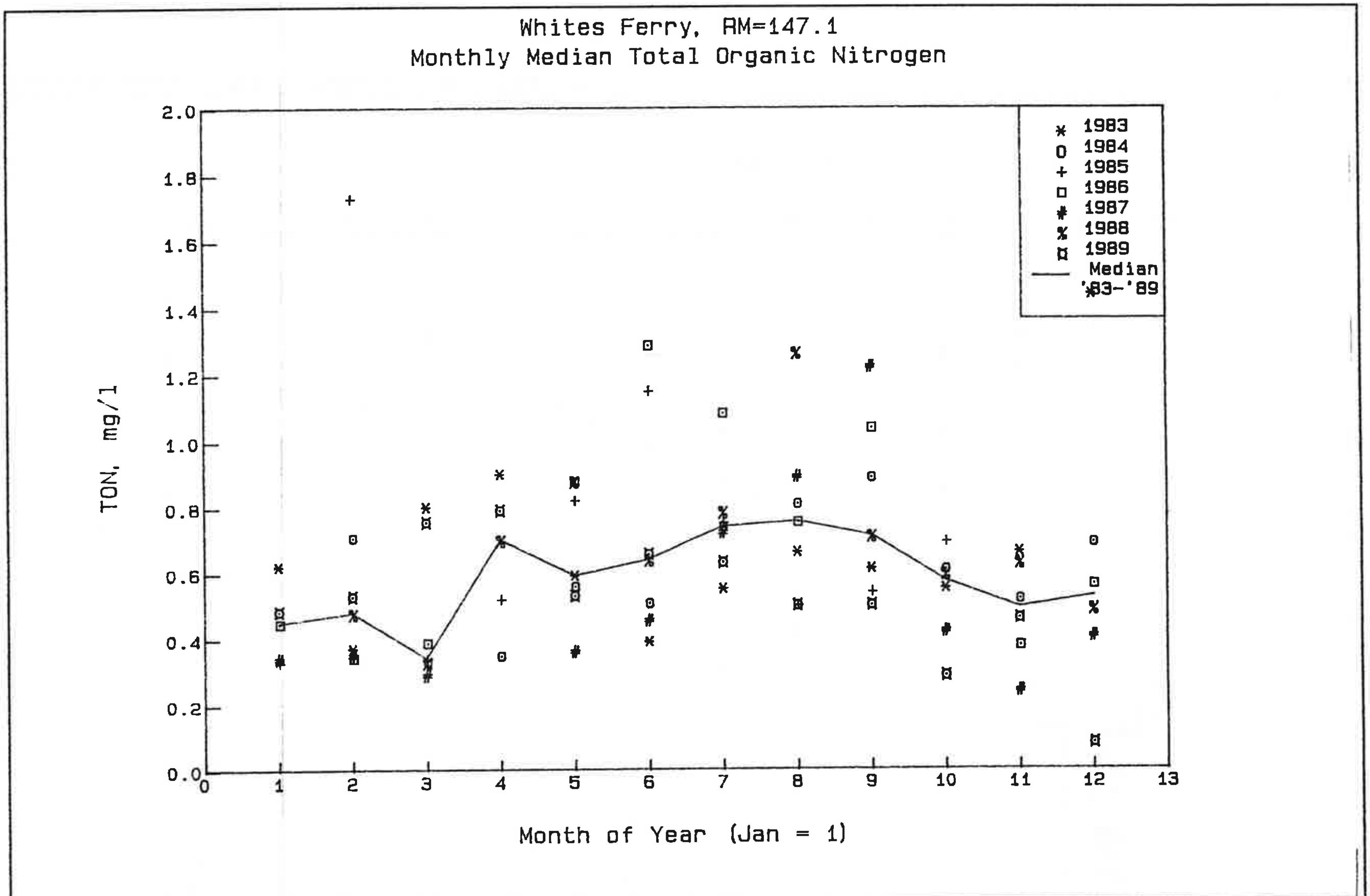

Figure 19. Monthly Median Total Organic Nitrogen: Whites Ferry

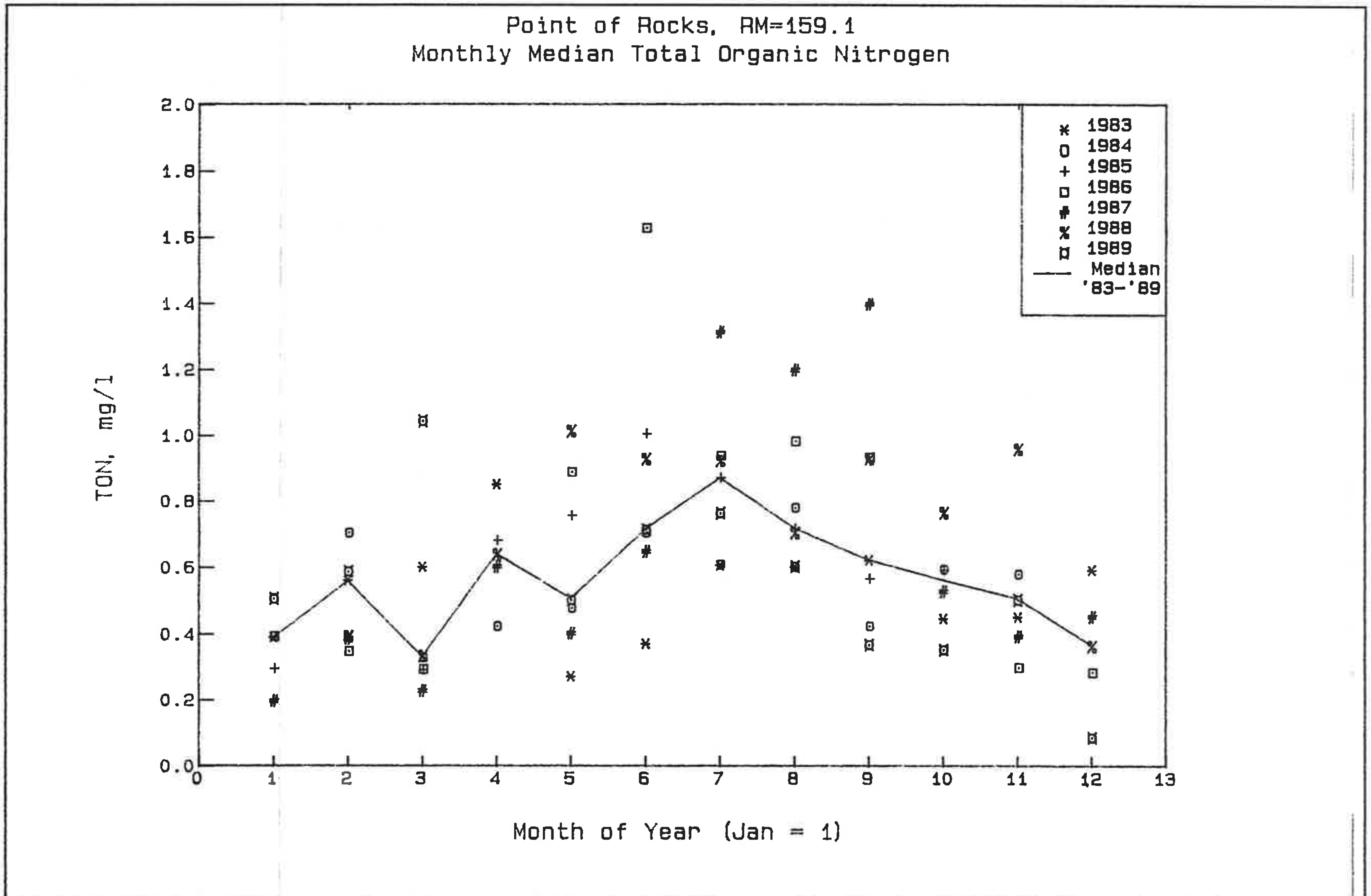

Figure 20. Monthly Median Total Organic Nitrogen: Point of Rocks

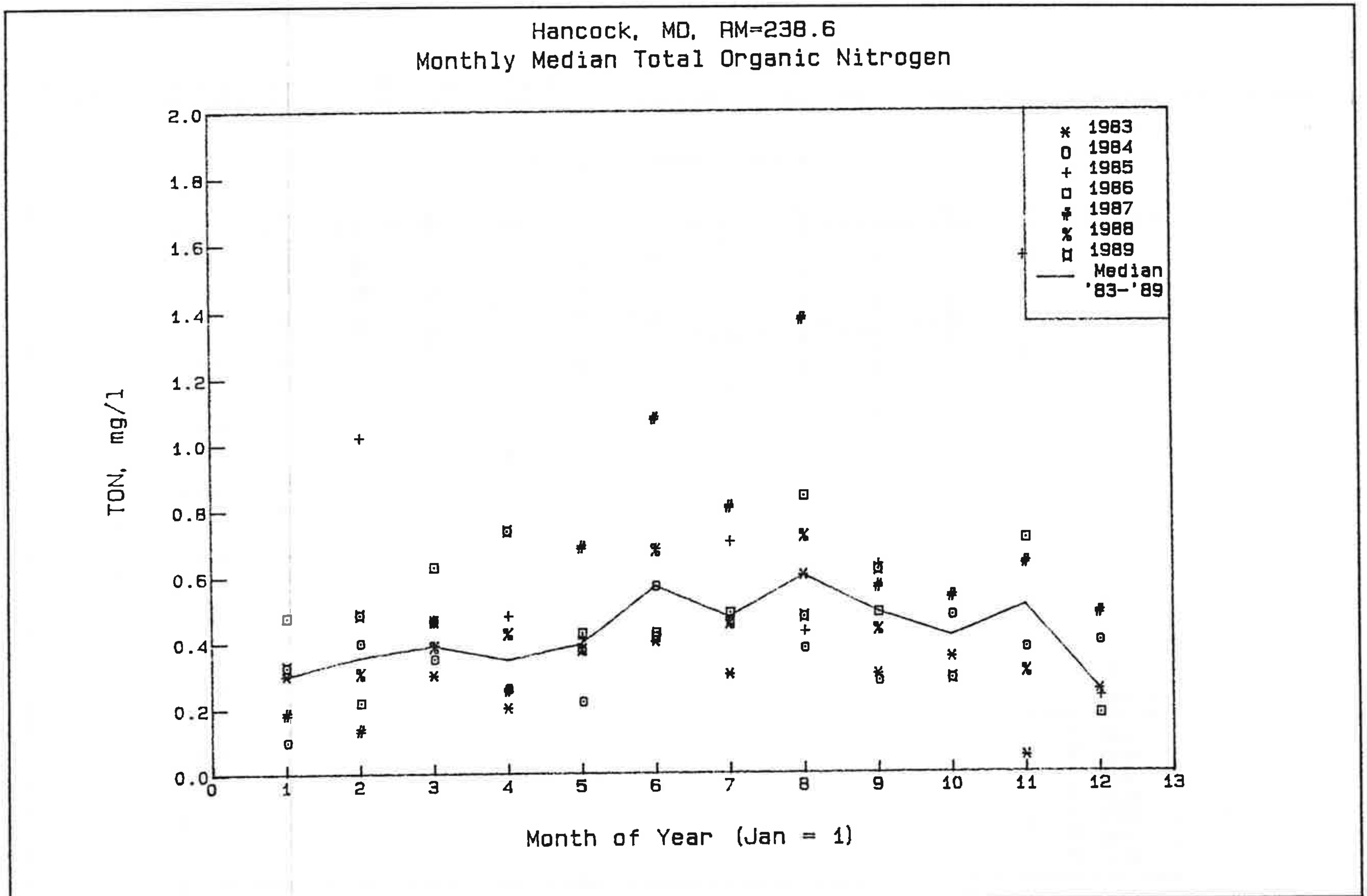

Figure 21. Monthly Median Total Organic Nitrogen: Hancock

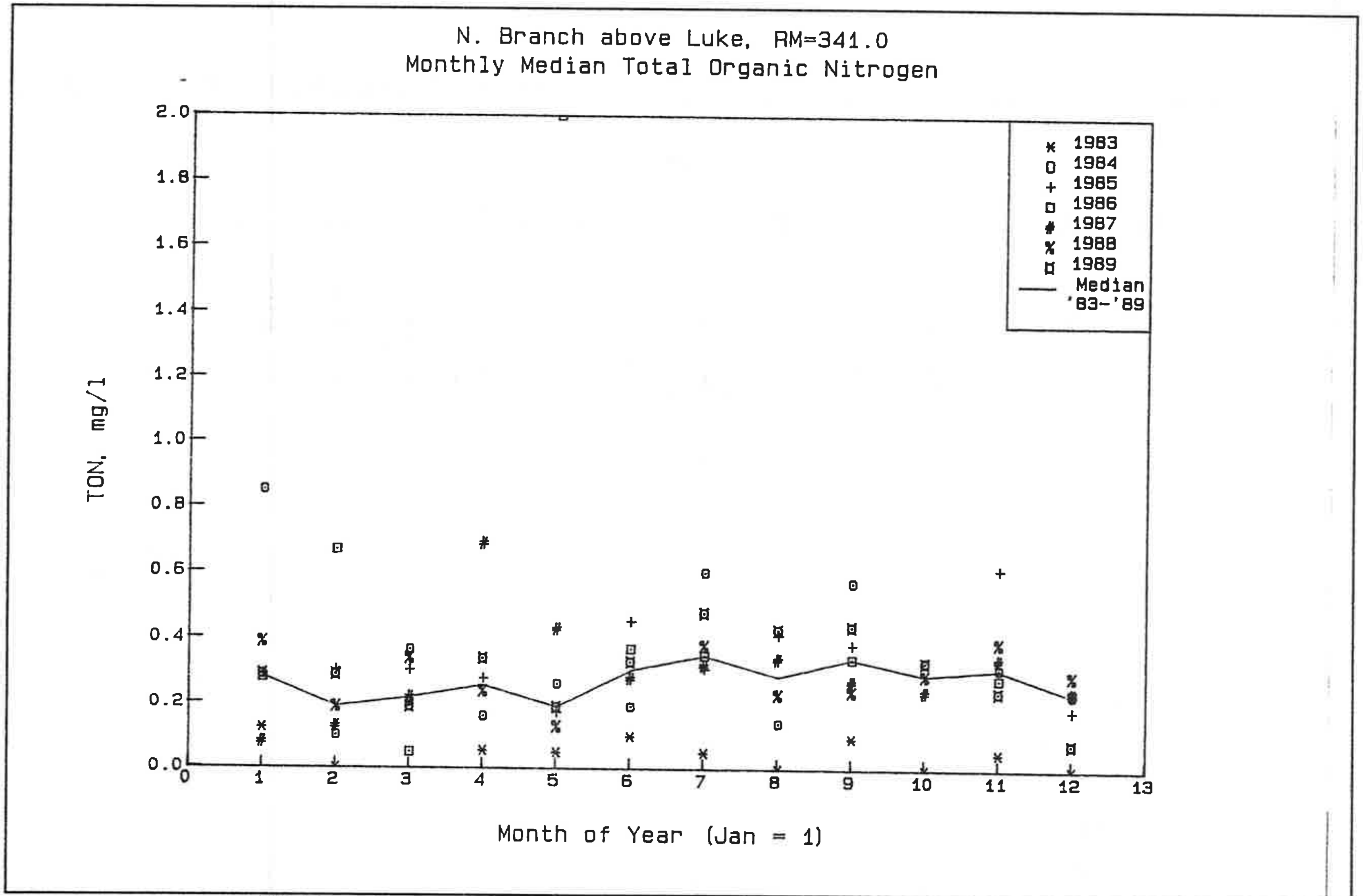

Figure 22. Monthly Median Total Organic Nitrogen: Luke

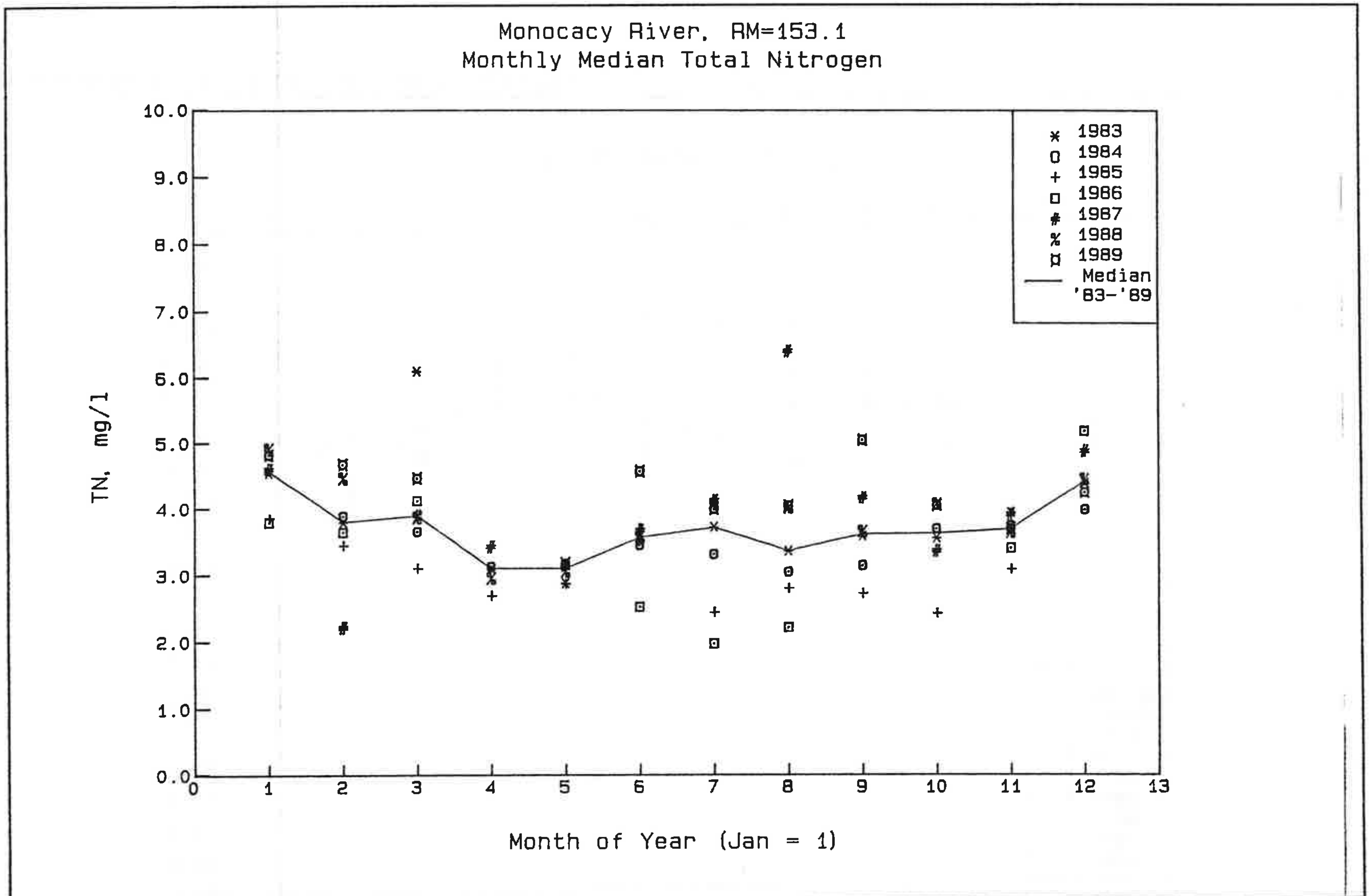

Figure 23. Monthly Median Total Nitrogen: Monocacy River

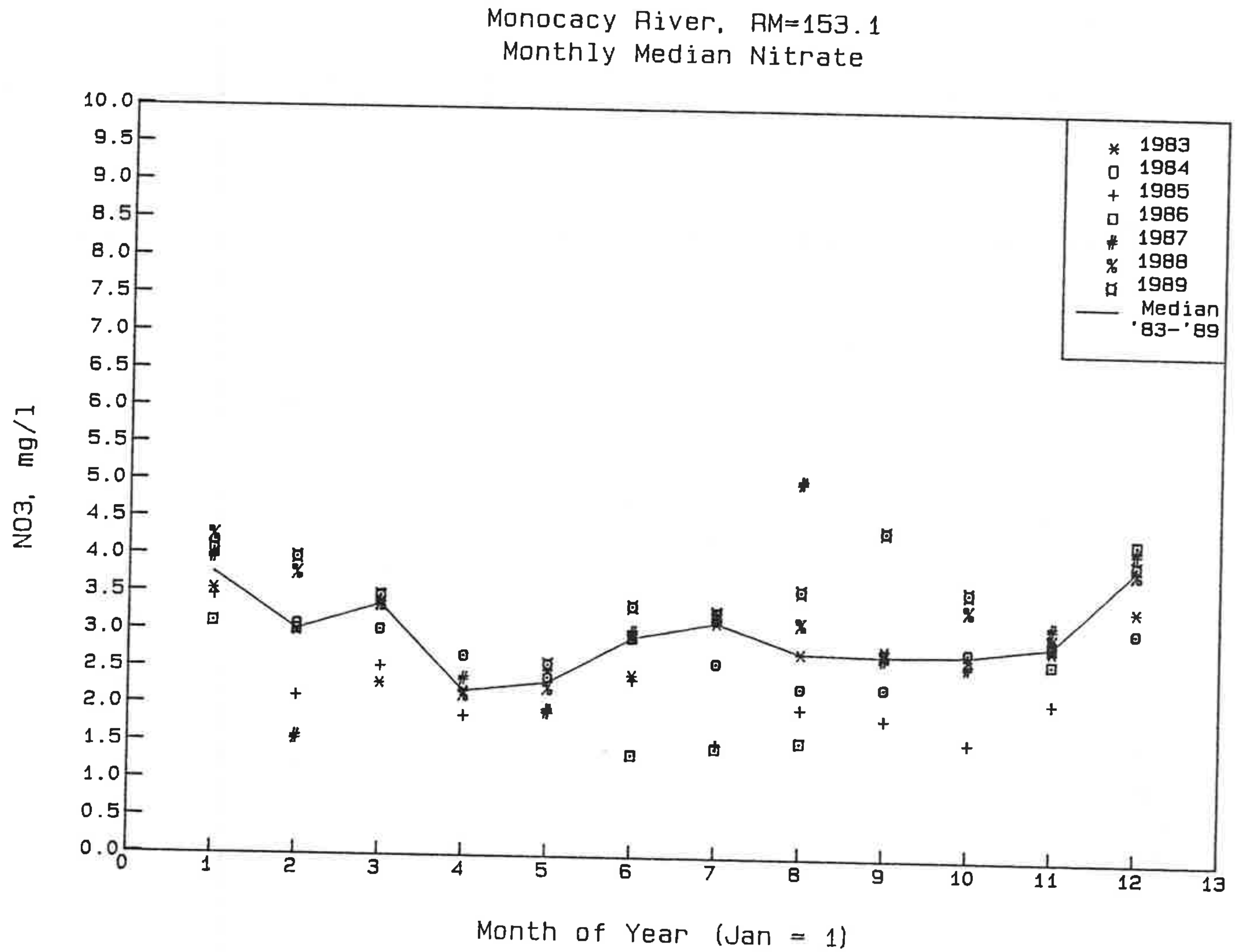

Figure 24. Monthly Median Dissolved Nitrate: Monocacy River

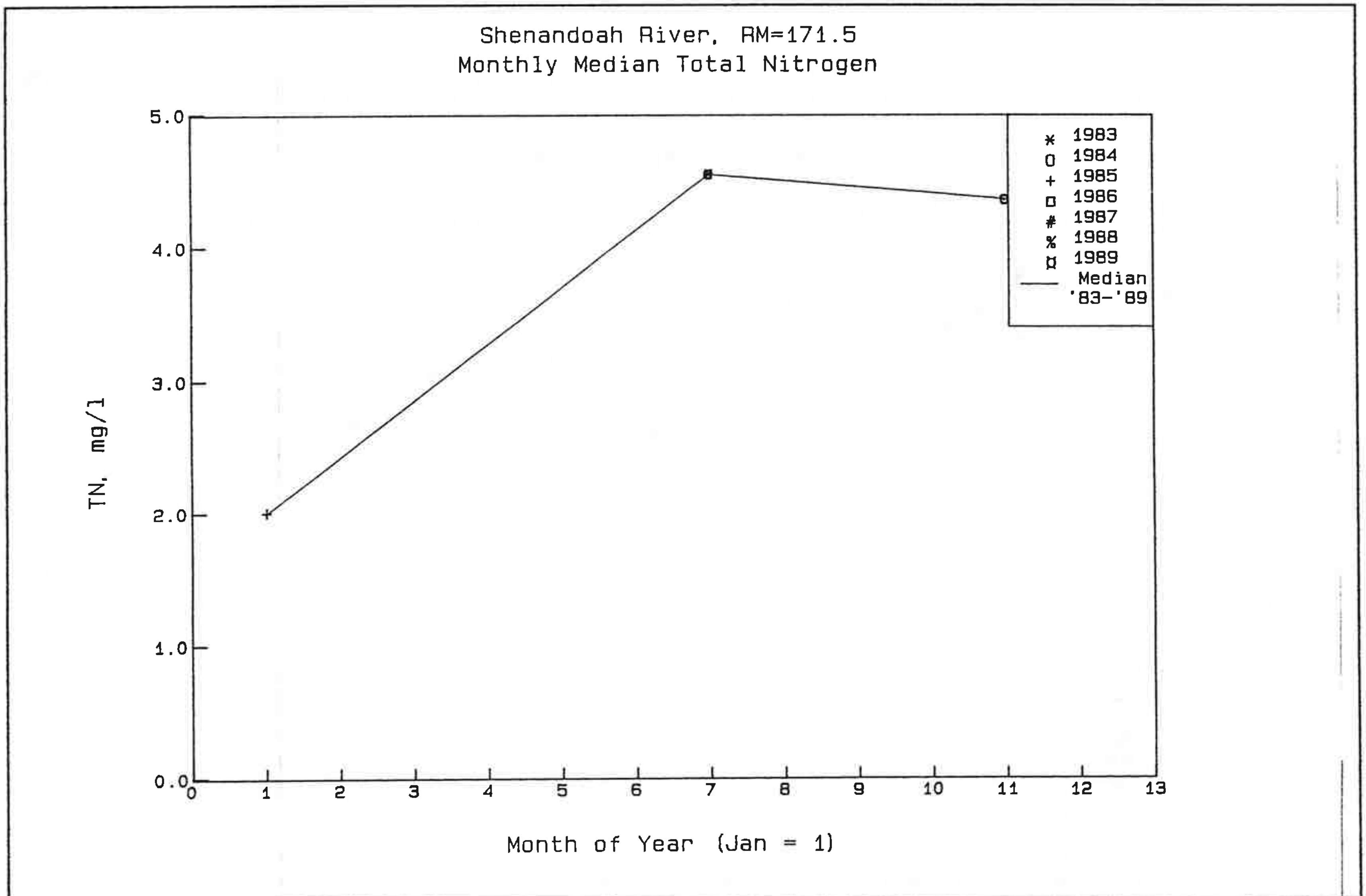

Figure 25. Monthly Median Total Nitrogen: Shenandoah River

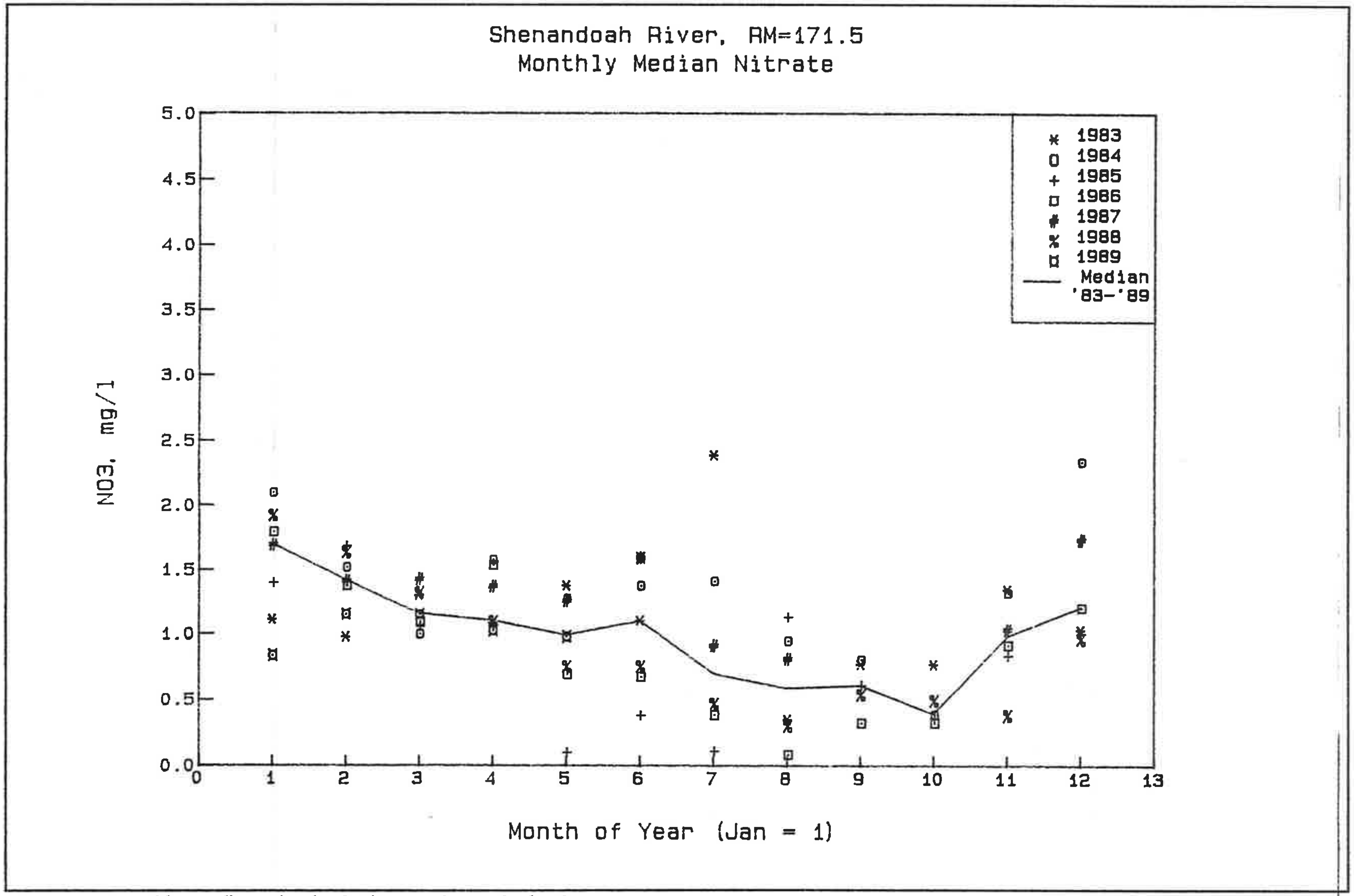

Figure 26. Monthly Median Dissolved Nitrate: Shenandoah River

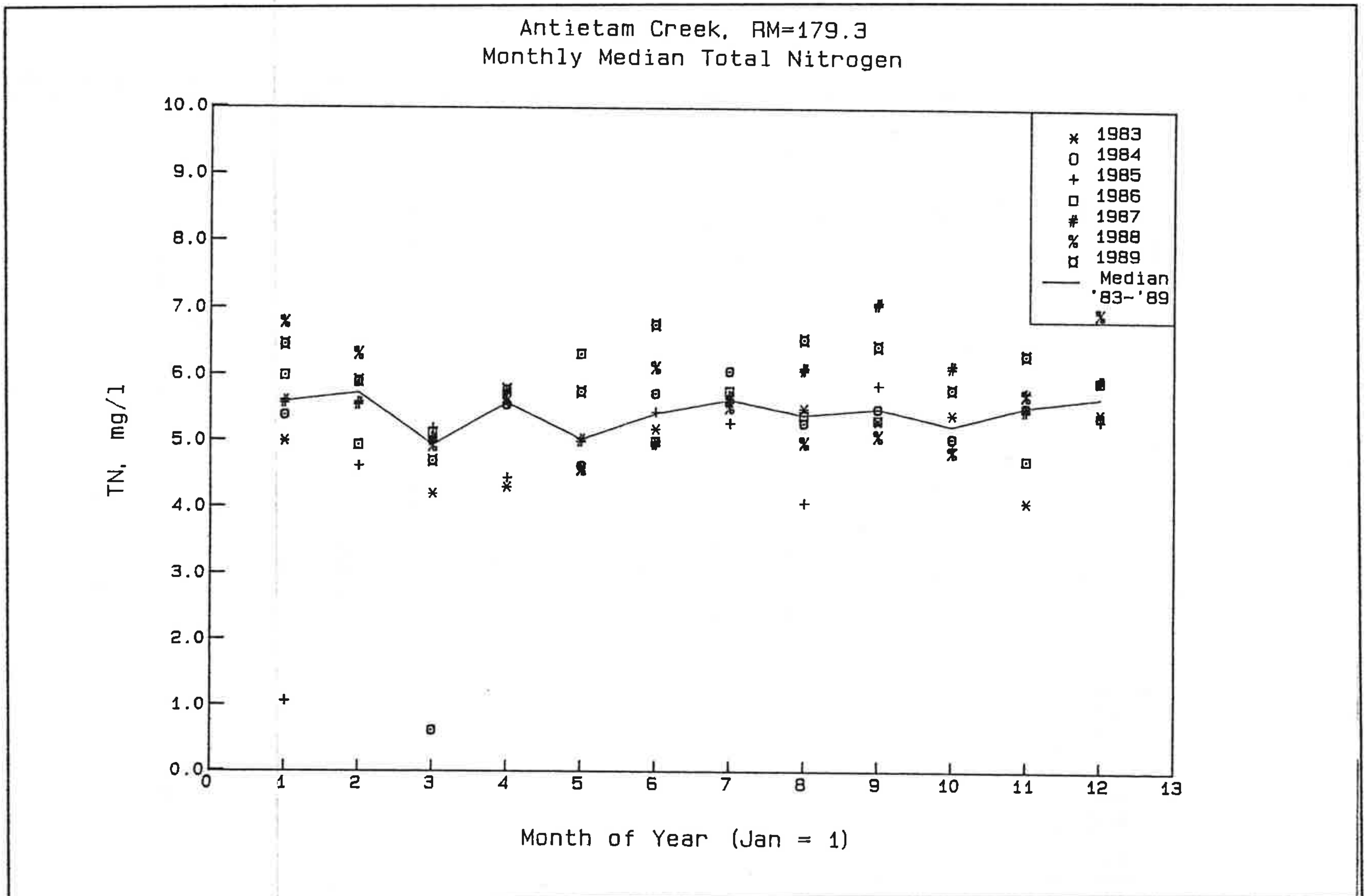

Figure 27. Monthly Median Total Nitrogen: Antietam Creek

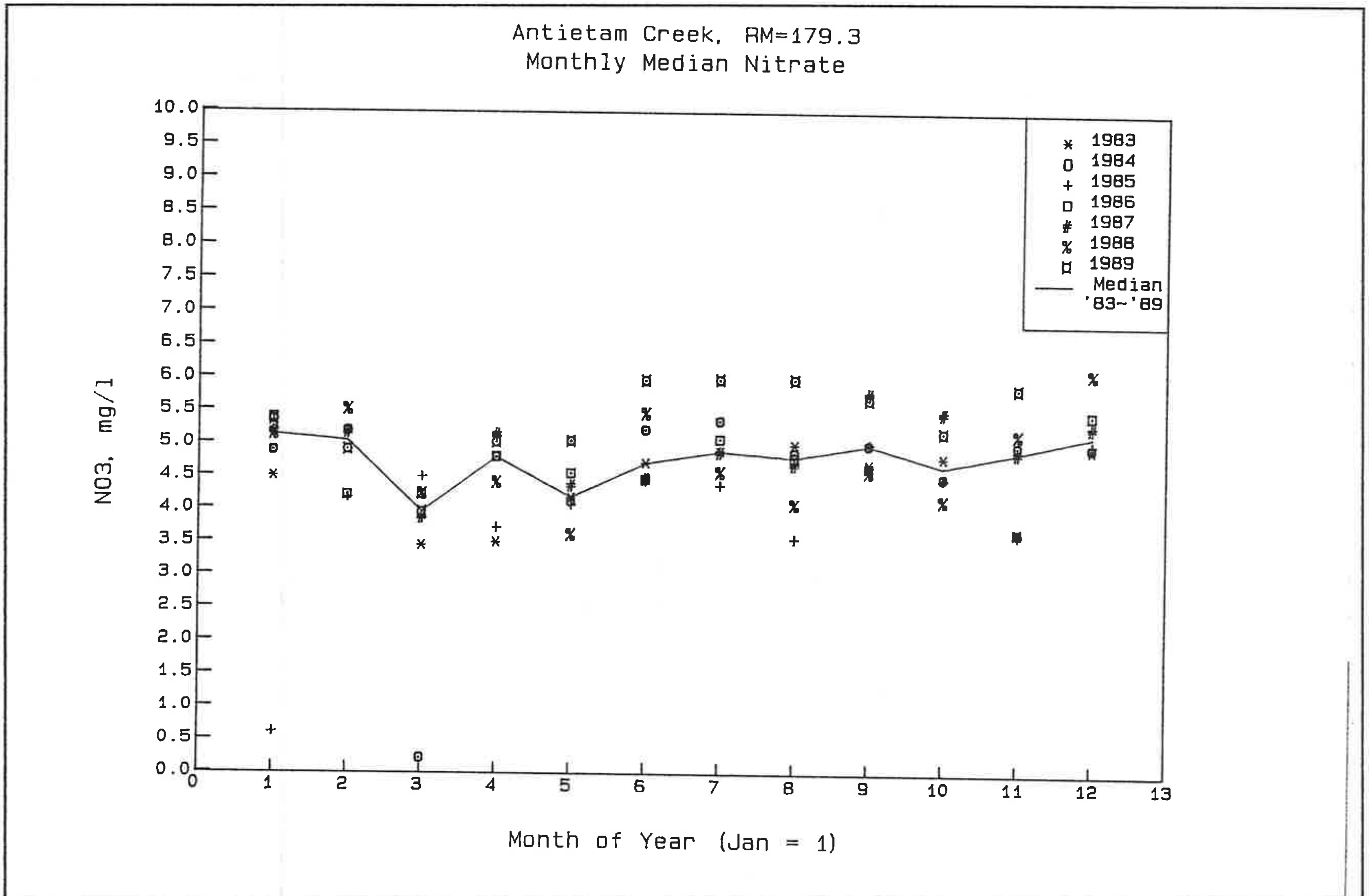

Figure 28. Monthly Median Dissolved Nitrate: Antietam Creek

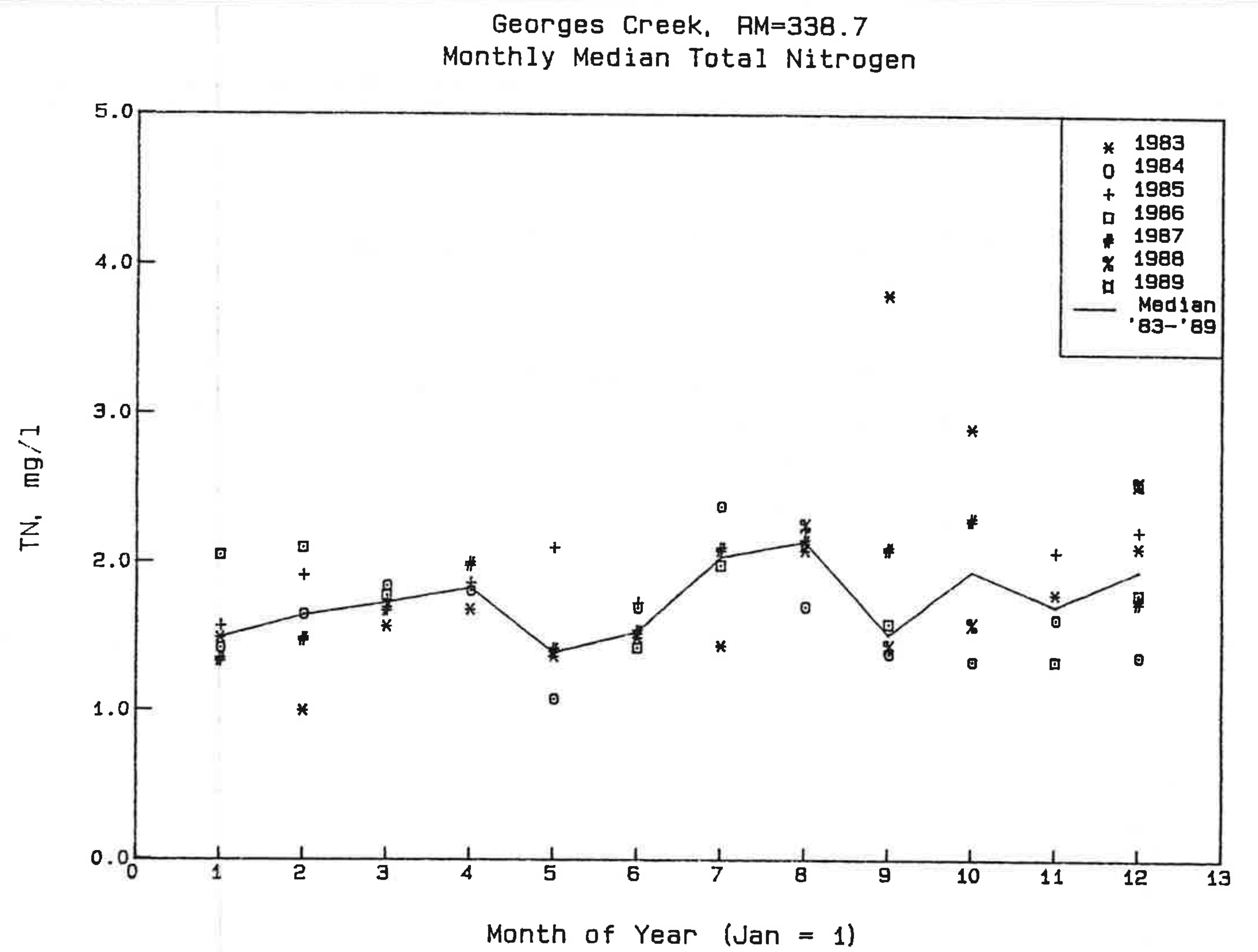

Figure 29. Monthly Median Total Nitrogen: Georges Creek

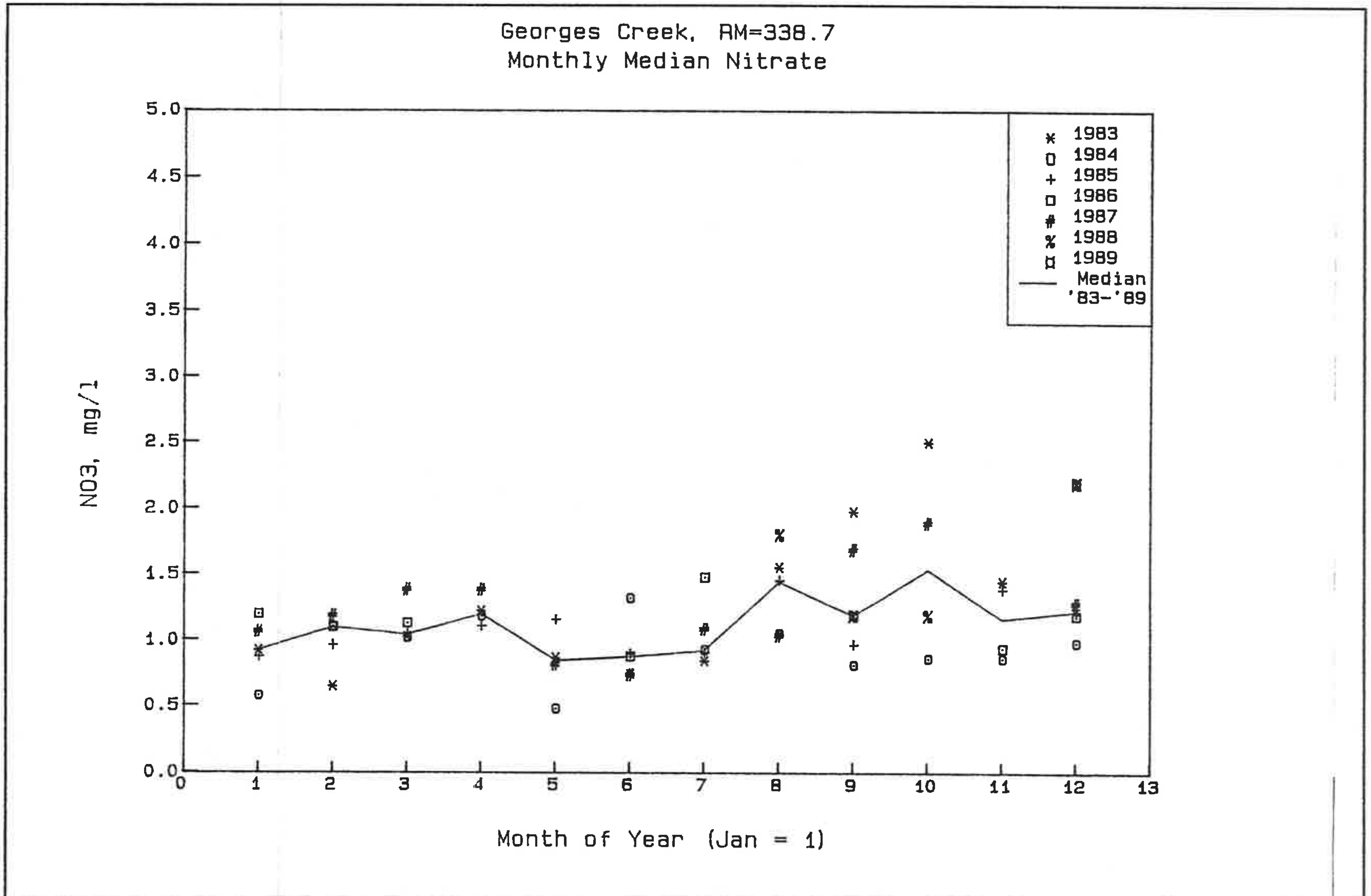

Figure 30. Monthly Median Dissolved Nitrate: Georges Creek

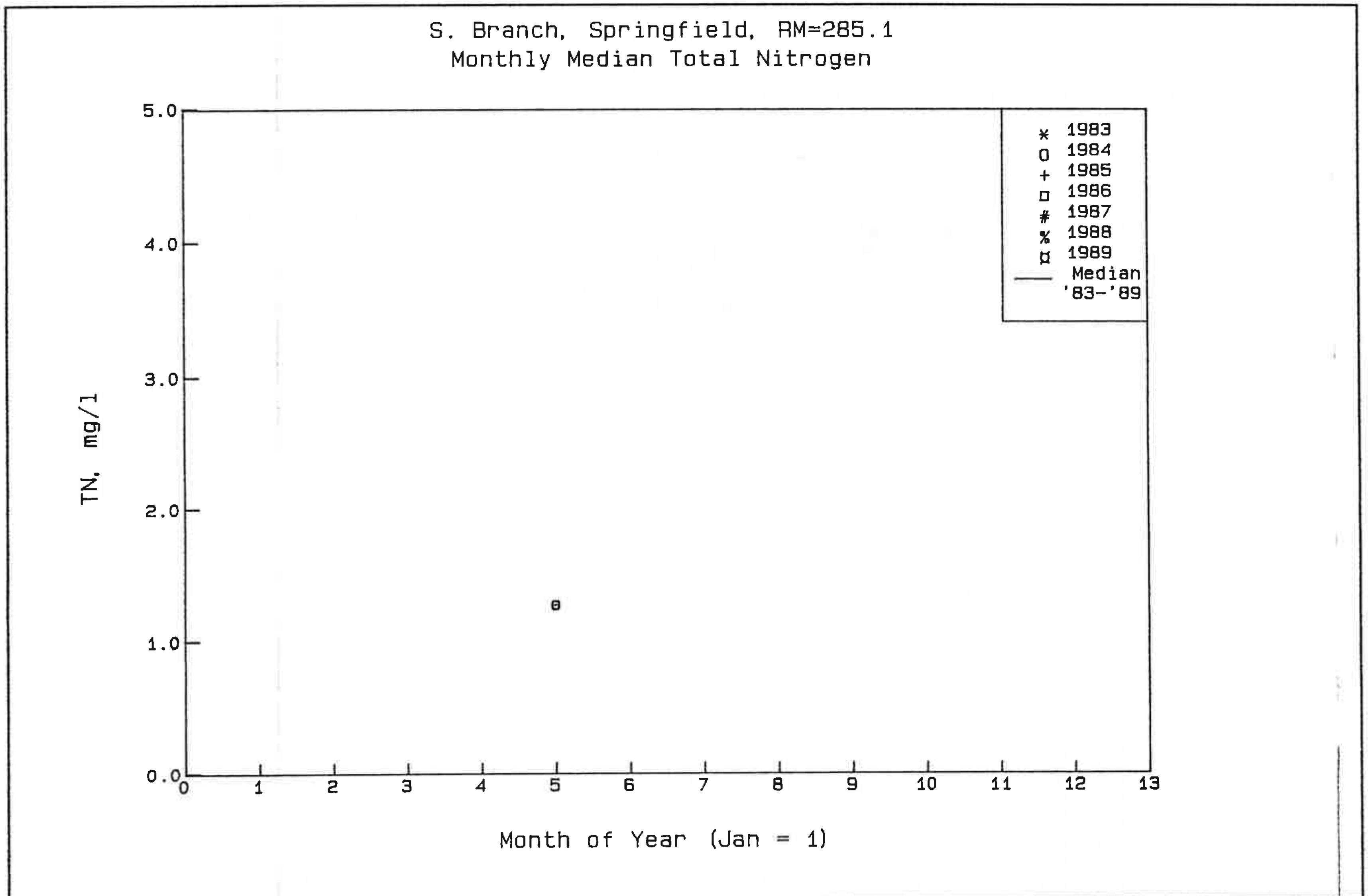

Figure 31. Monthly Median Total Nitrogen: South Branch Potomac River

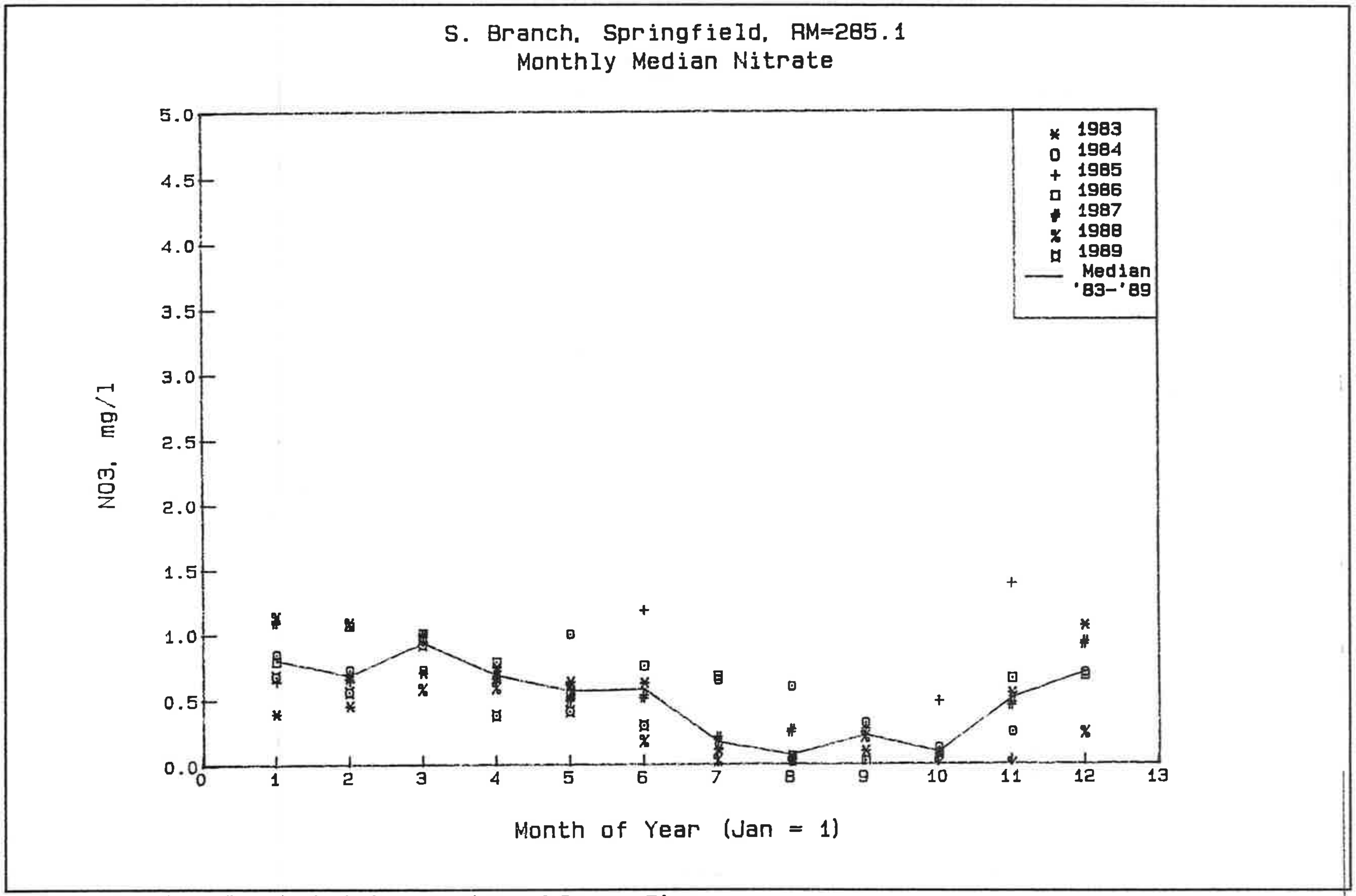

Figure 32. Monthly Median Dissolved Nitrate: South Branch Potomac River

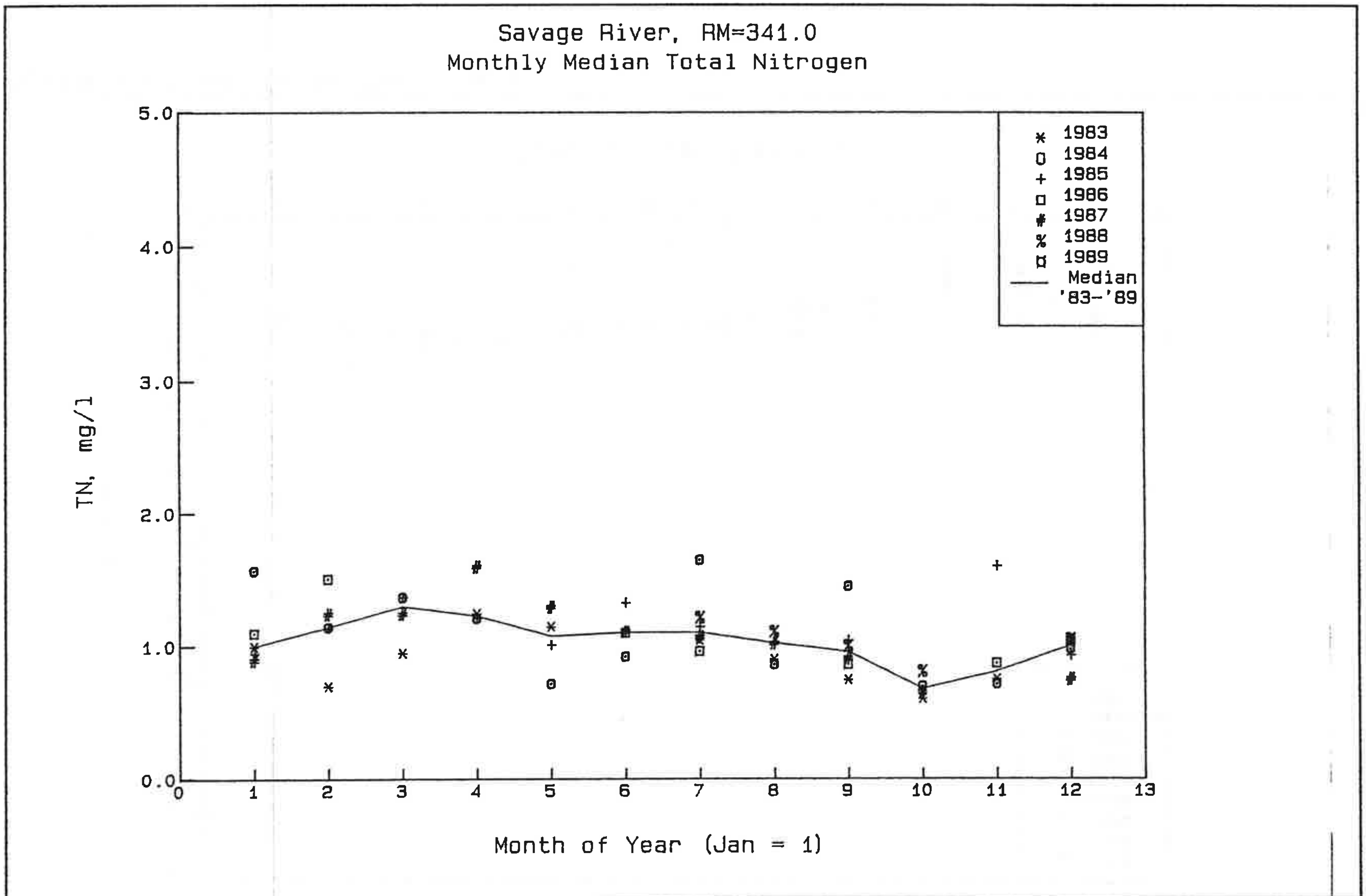

Figure 33. Monthly Median Total Nitrogen: Savage River

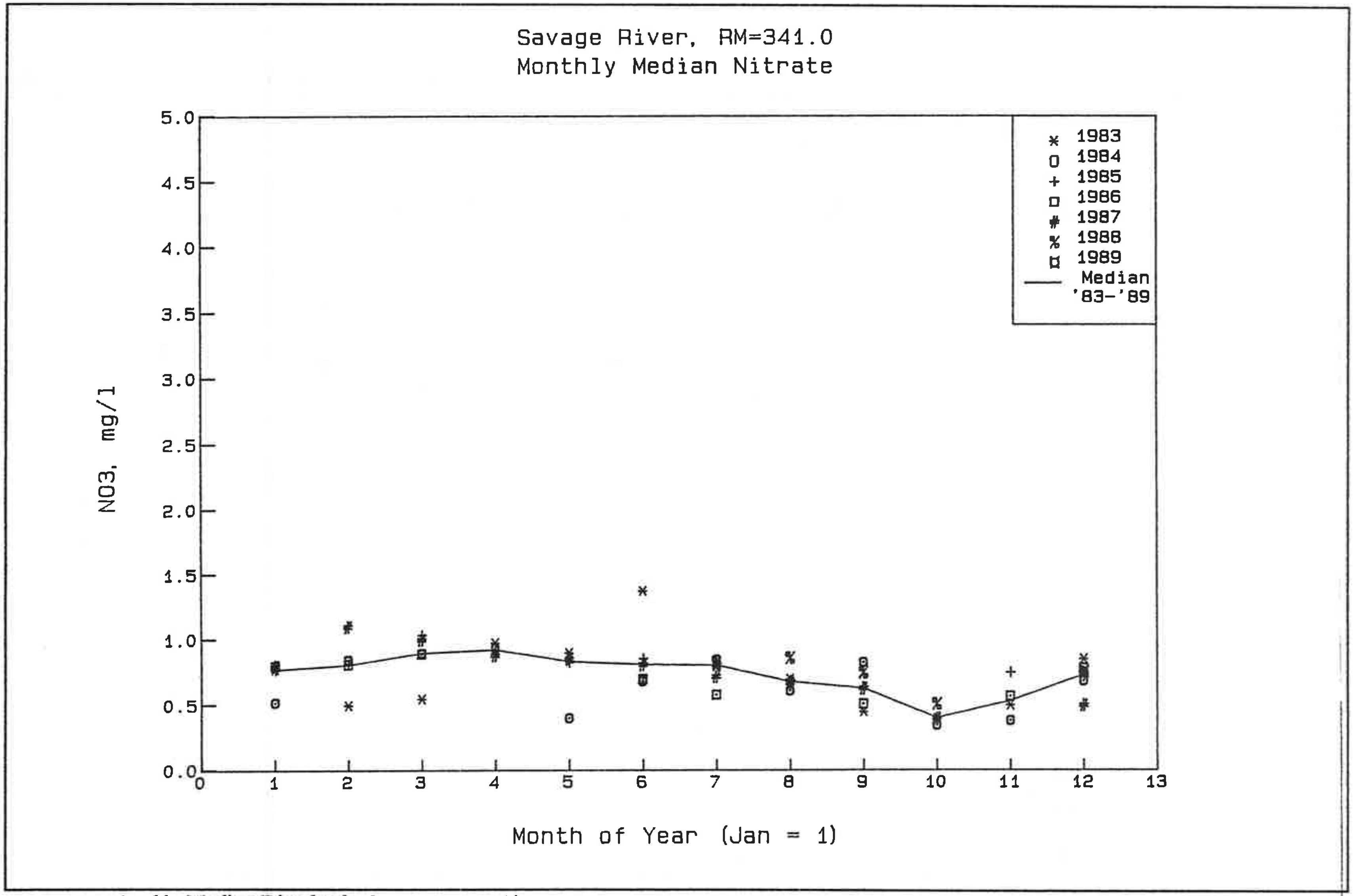

Figure 34. Monthly Median Dissolved Nitrate: Savage River

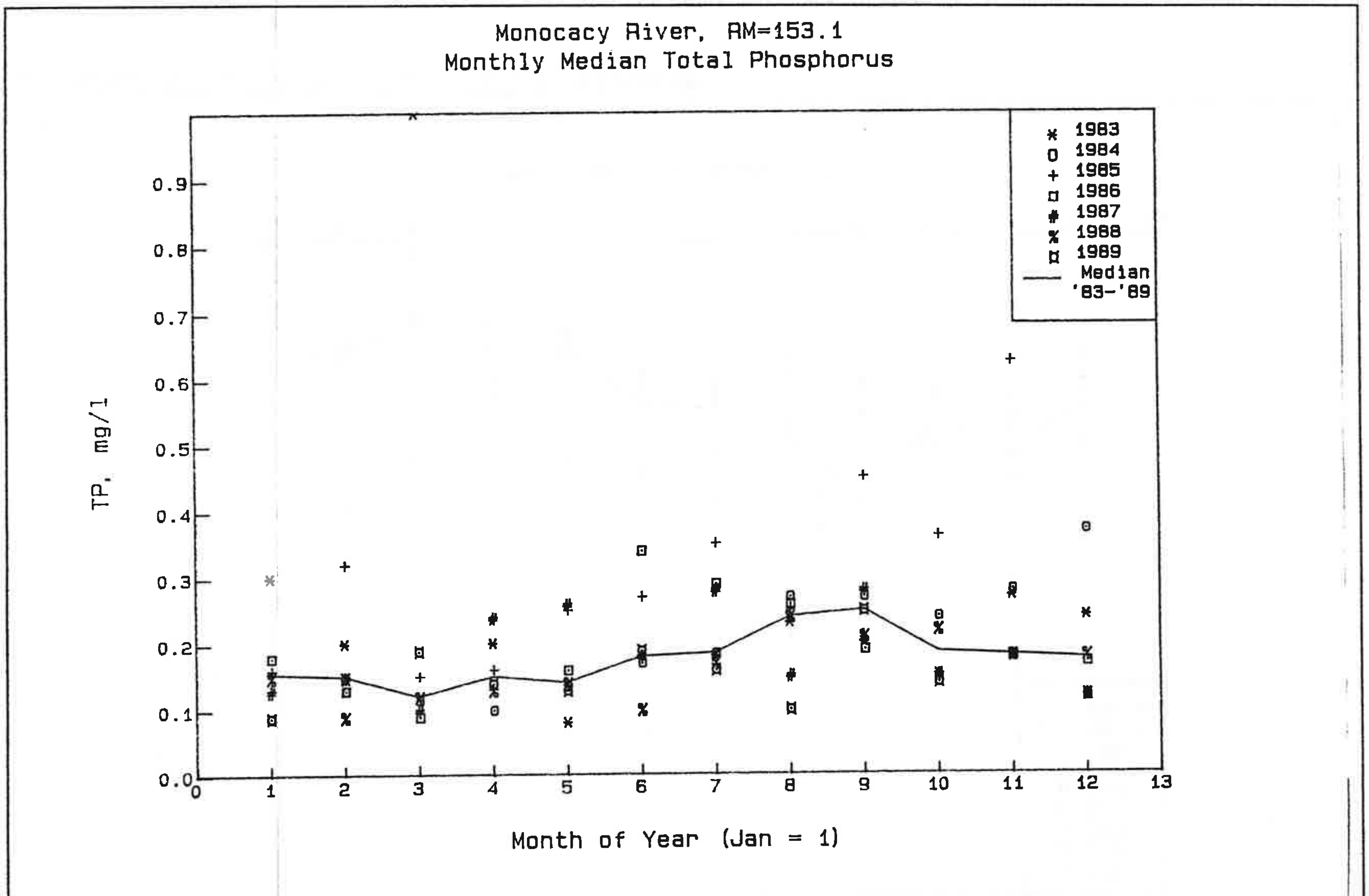

Figure 35. Monthly Median Total Phosphorus: Monocacy River

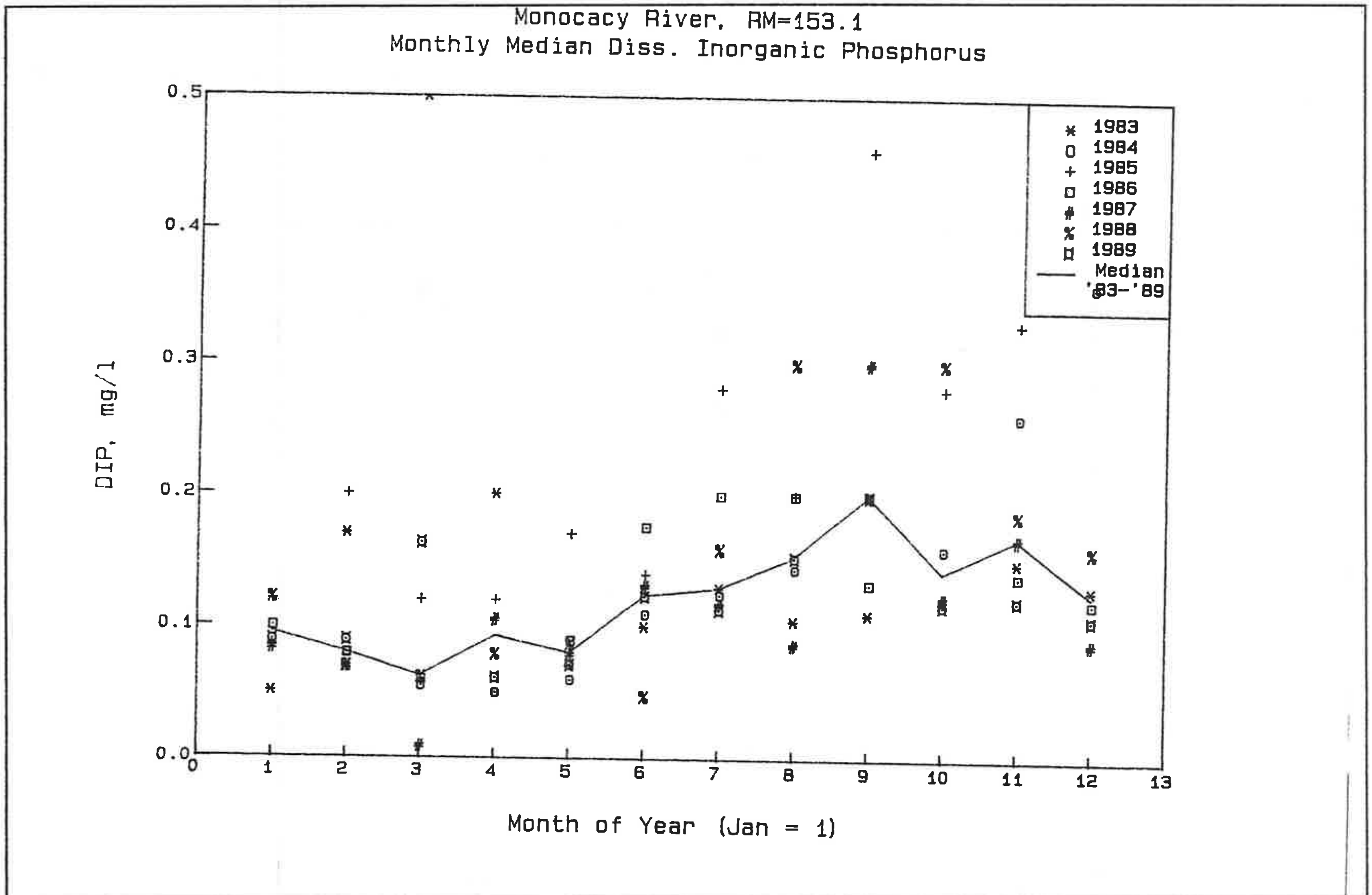

Figure 36. Monthly Median Dissolved Inorganic Phosphorus: Monocacy River

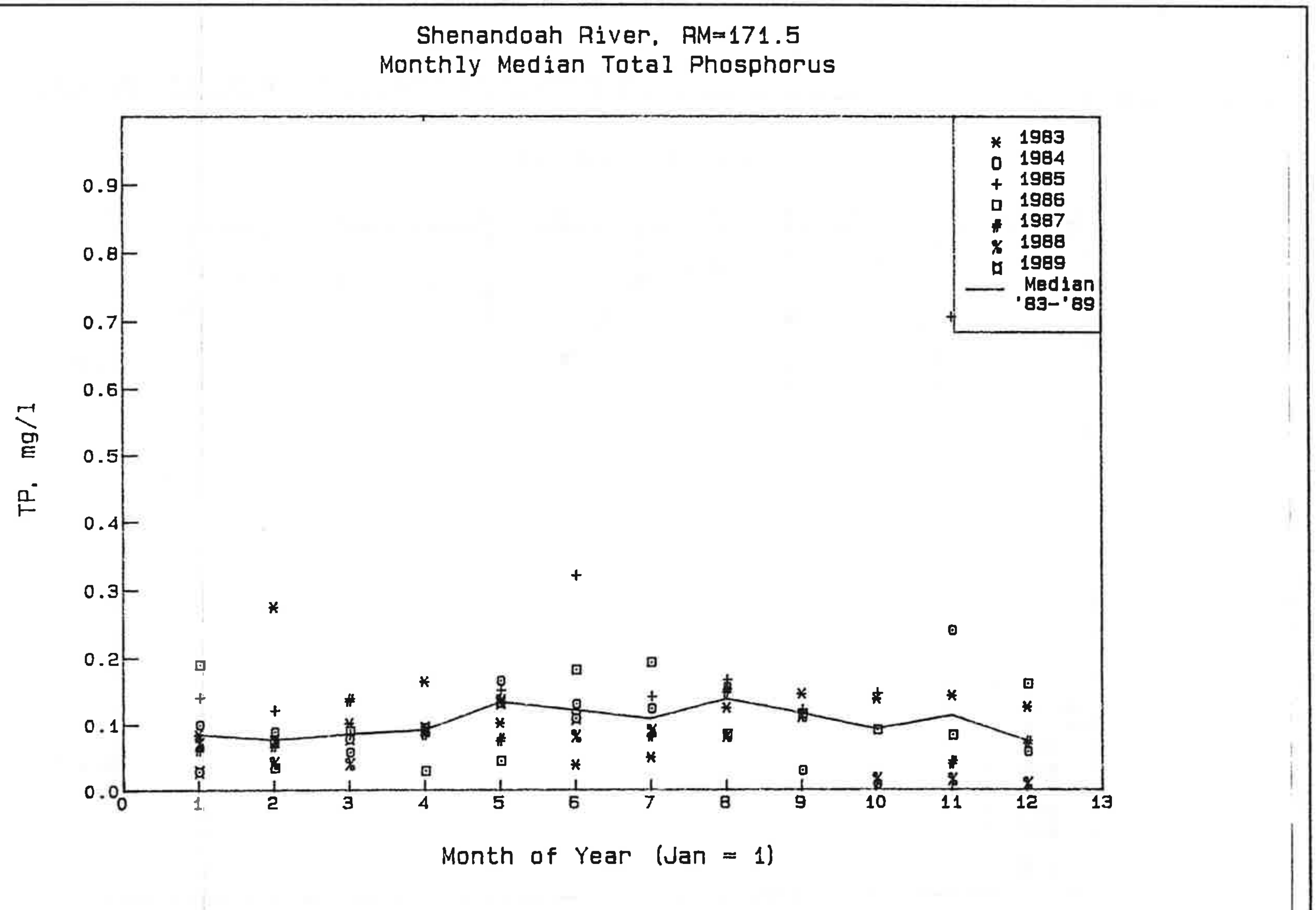

Figure 37. Monthly Median Total Phosphorus: Shenandoah River

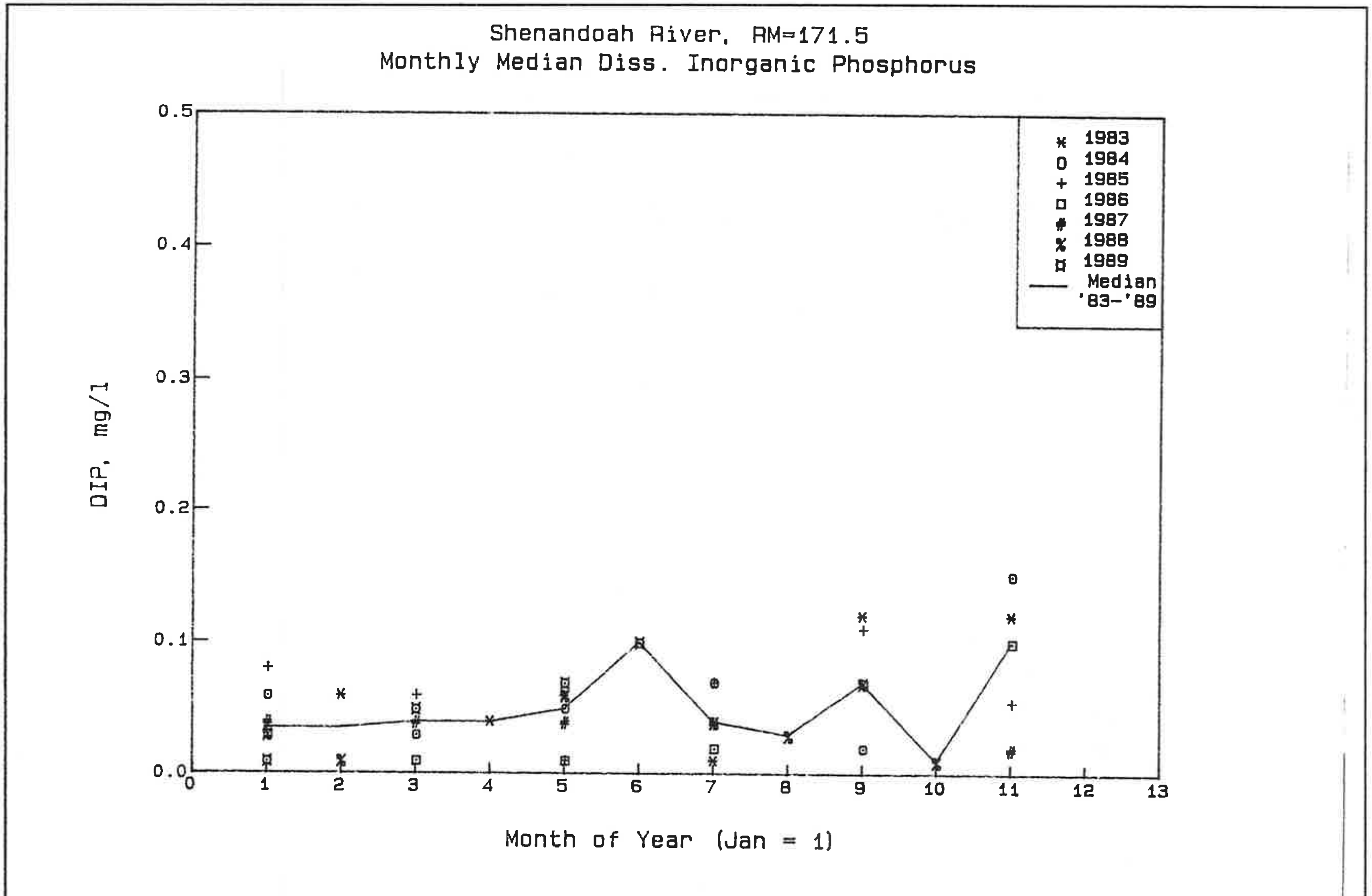

Figure 38. Monthly Median Dissolved Inorganic Phosphorus: Shenandoah River

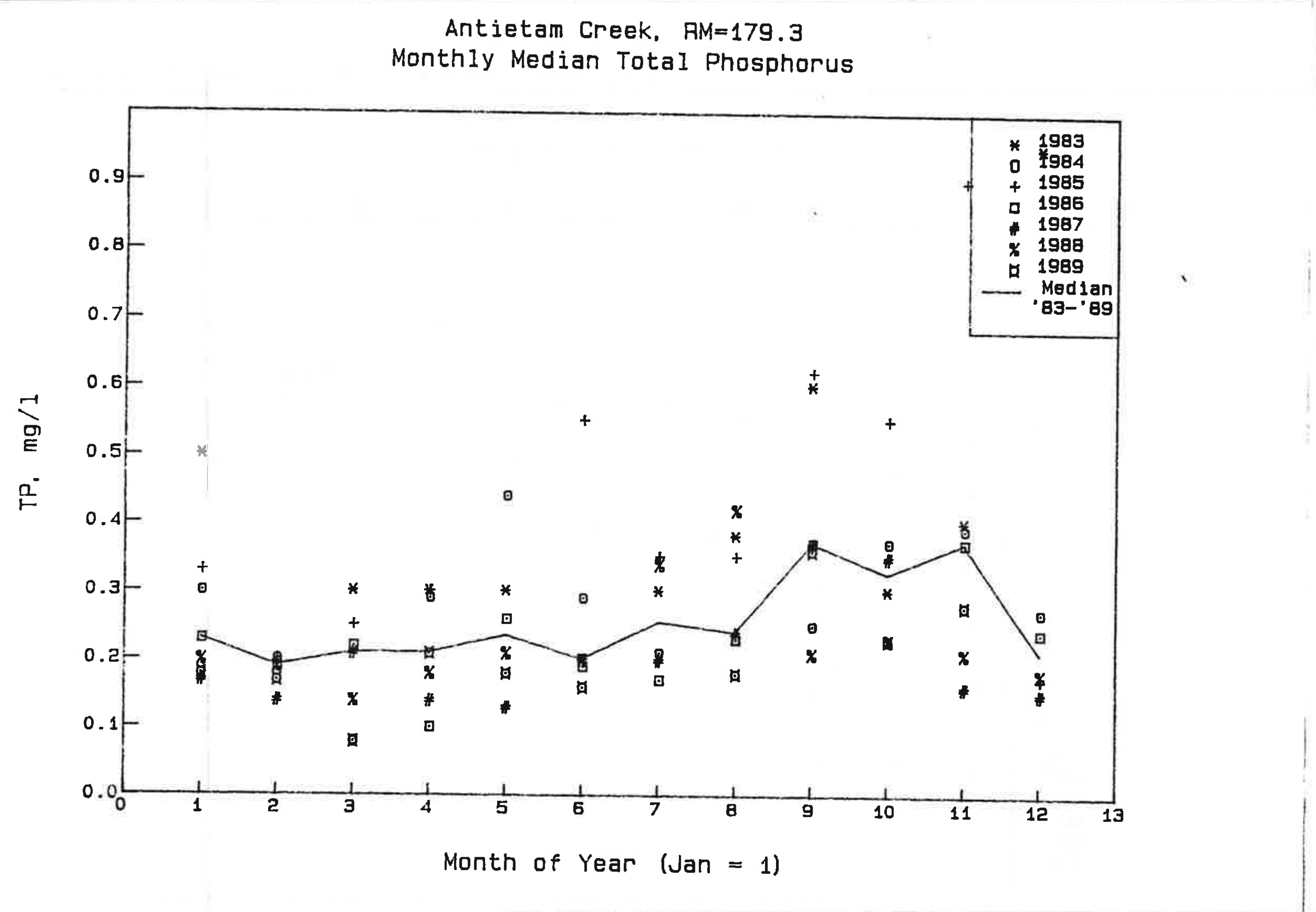

Figure 39. Monthly Median Total Phosphorus: Antietam Creek

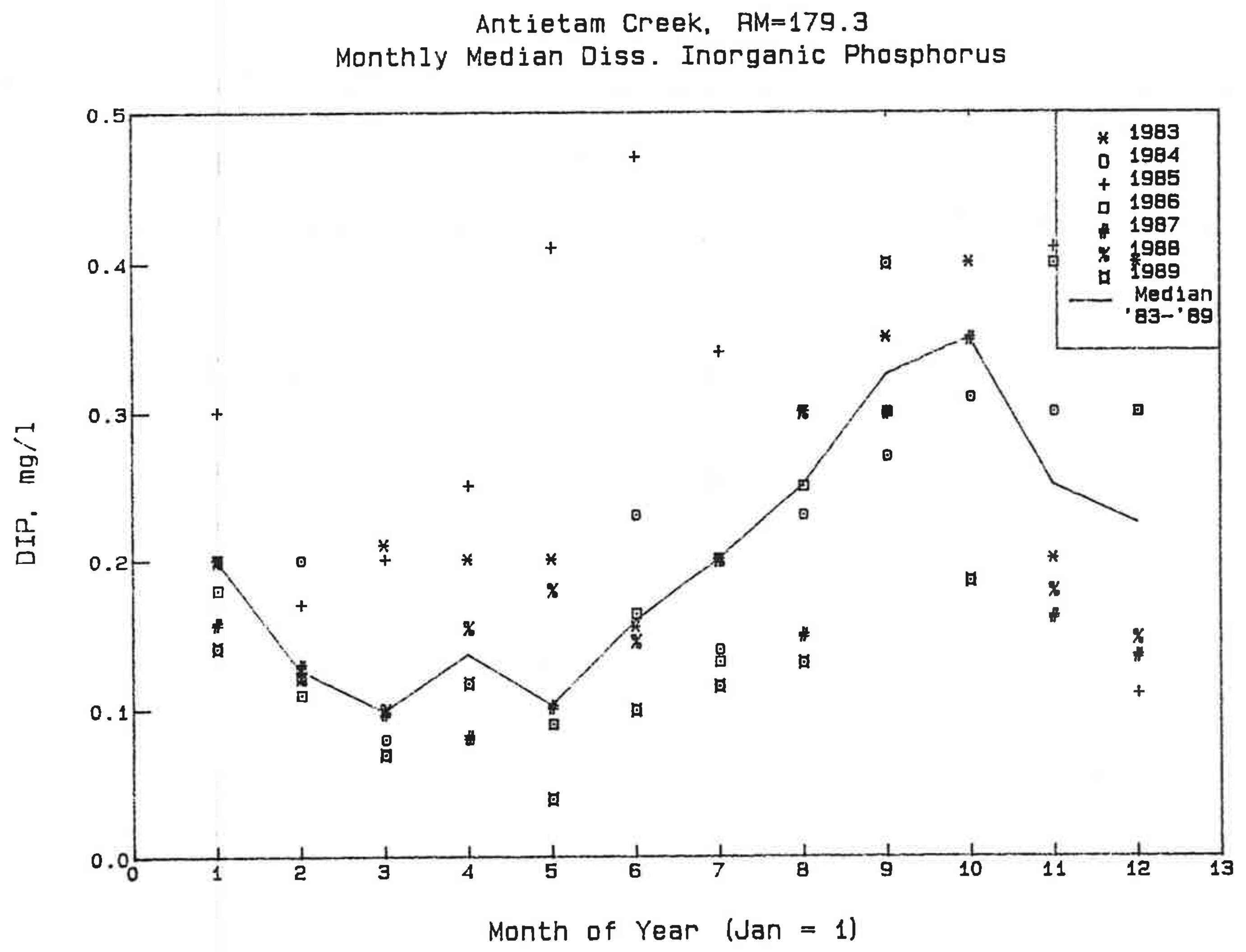

Figure 40. Monthly Median Dissolved Inorganic Phosphorus: Antietam Creek

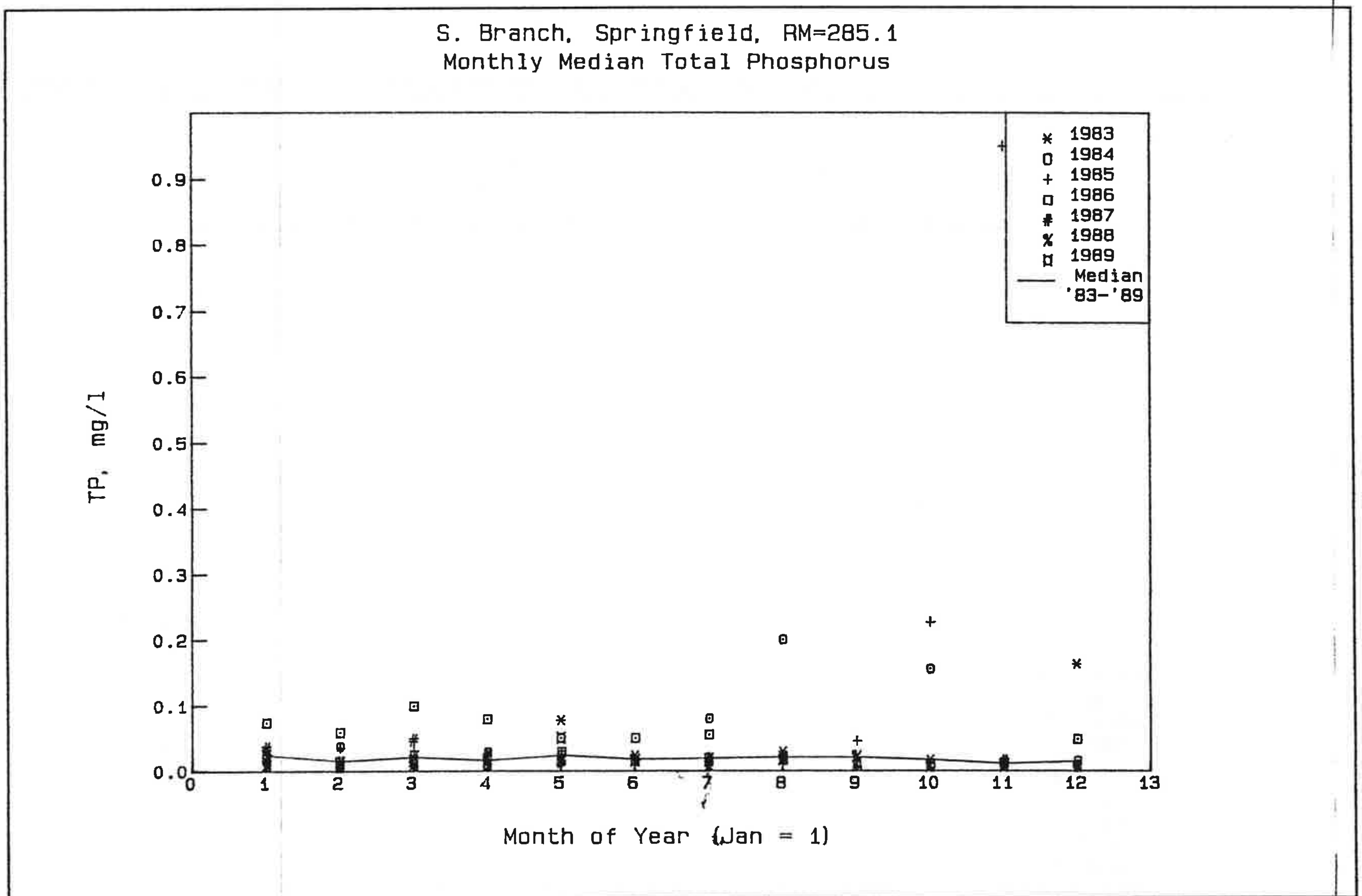

Figure 41. Monthly Median Total Phosphorus: South Branch Potomac River

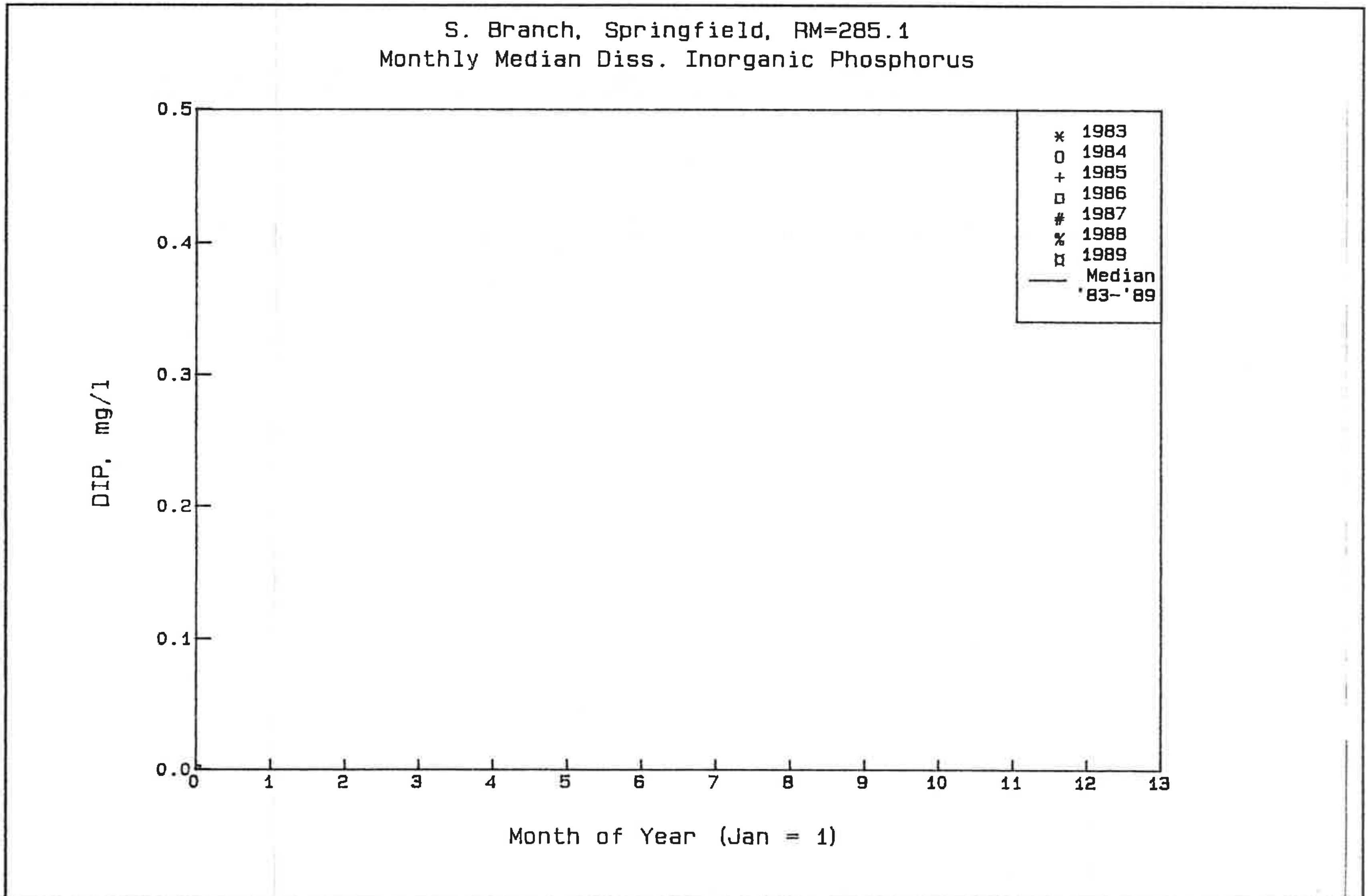

Figure 42. Monthly Median Dissolved Inorganic Phosphorus: South Branch Potomac River

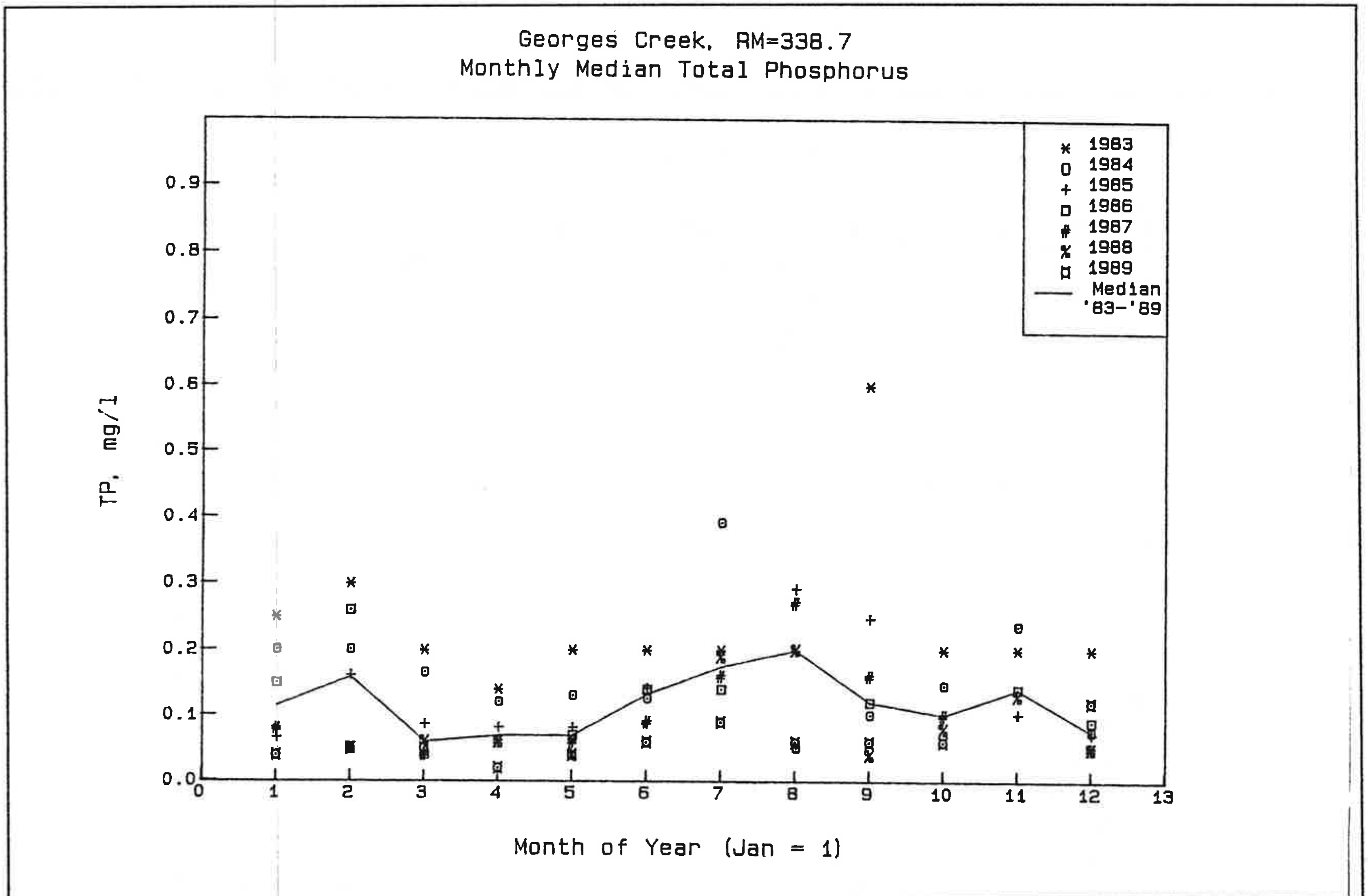

Figure 43. Monthly Median Total Phosphorus: Georges Creek

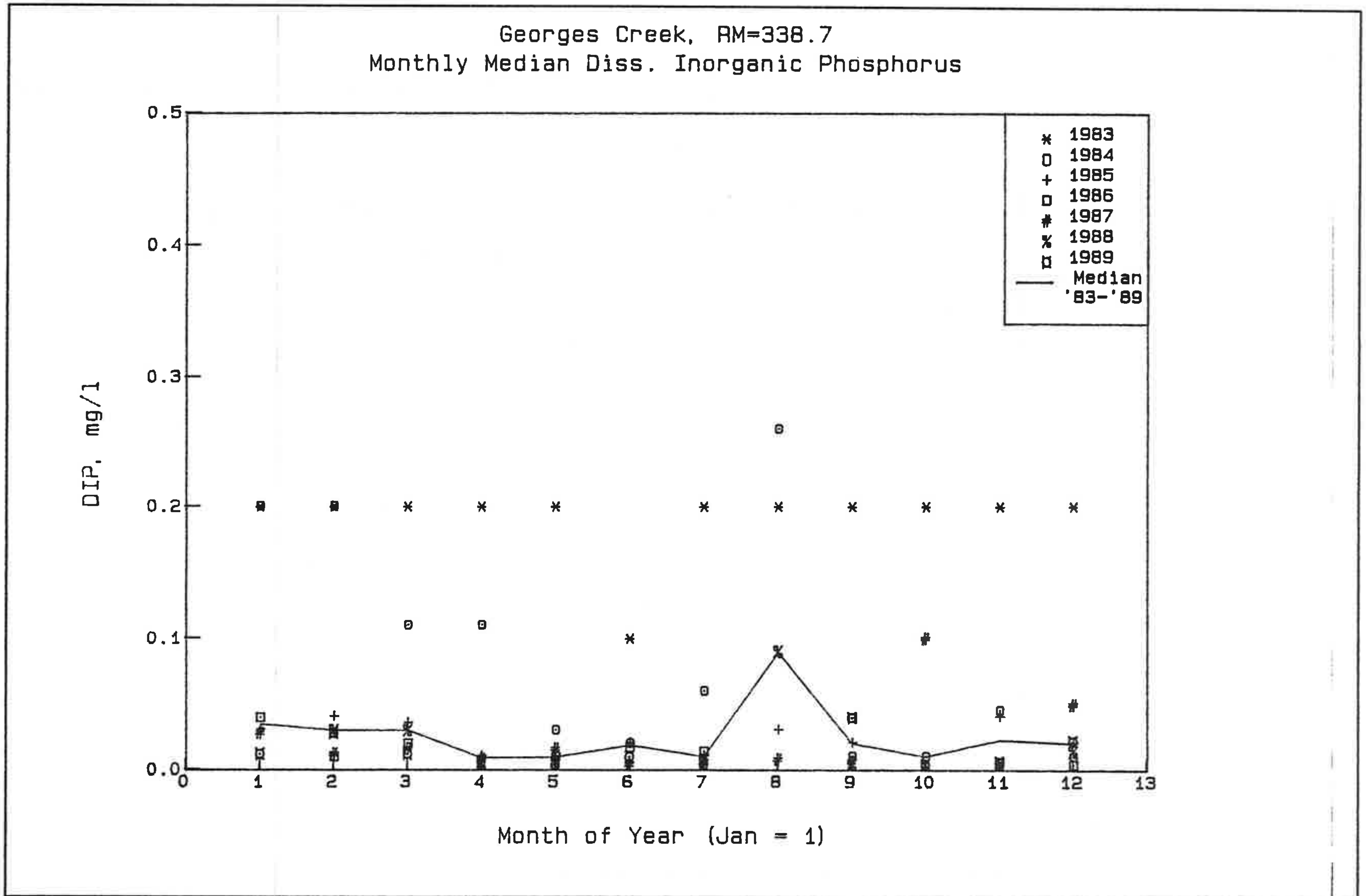

Figure 44. Monthly Median Dissolved Inorganic Phosphorus: Georges Creek

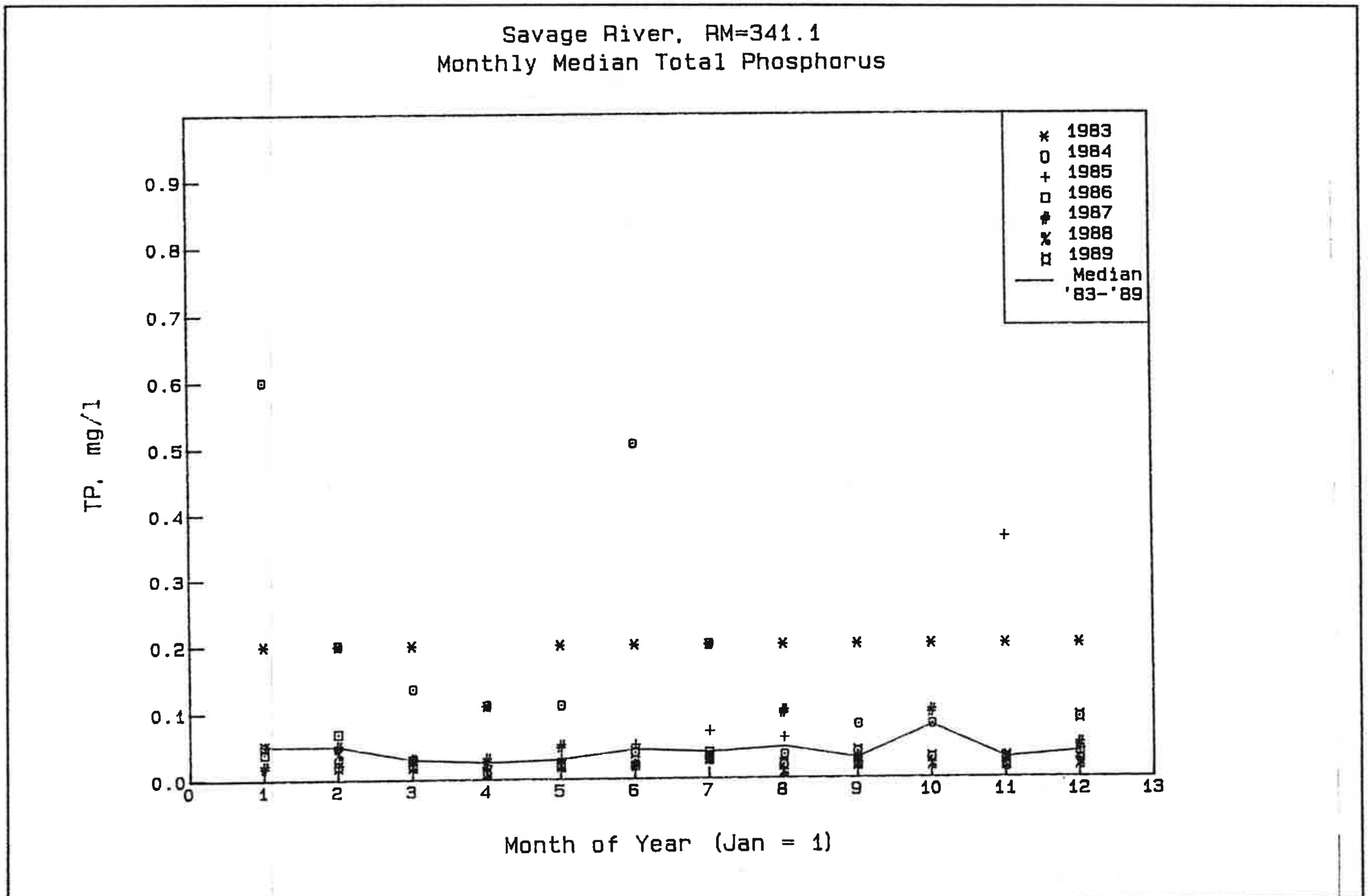

Figure 45. Monthly Median Total Phosphorus: Savage River

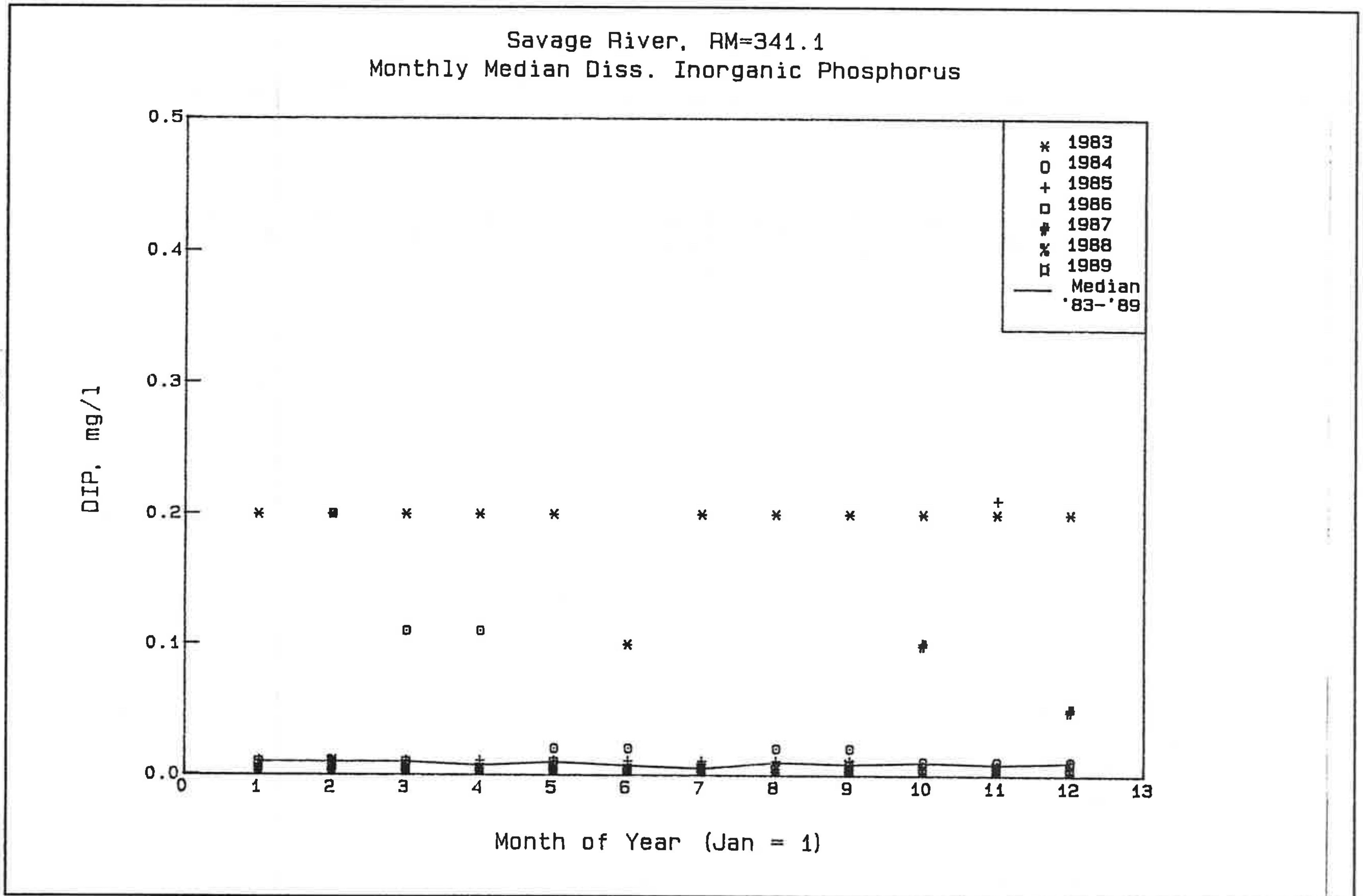

Figure 46. Monthly Median Dissolved Inorganic Phosphorus: Savage River

Chapter 3. Point Source Data Assessment

Introduction

The Potomac River Model (PRM) requires as inputs, the total loading in each segment of: dissolved oxygen (DO), carbonaceous biochemical oxygen demand (BOD_5), nitrate+nitrite (NO_3+NO_2), ammonia nitrogen (NH_3+NH_4), organic nitrogen (ON), organic phosphorus (OP), inorganic phosphorus (IP) or orthophosphate (OPO_4), and phytoplankton carbon (PHY). The nutrient load from point source inputs to the PRM are derived from municipal wastewater treatment plants (WWTP) and industrial dischargers with outfalls in the mainstem Potomac or its unmonitored tributaries. Loads from monitored tributaries are developed from monitoring data and account for upstream point sources. The first task is to identify all the point source dischargers (both municipal and industrial) contributing to these input loads. This chapter describes the process used to identify point sources and develop a "Point Source Inventory" (PSI).

Point Source Inventory

There are numerous sources of WWTP discharge data available in the literature and in various state and federal databases. These sources are frequently inconsistent. Dobler (1990) provides a detailed description of the problems associated with utilizing point source data from various sources. Information from the following sources was compiled into a "Point Source Inventory" (PSI) at ICPRB.

1. Chesapeake Bay Point Source Atlas (retrieved from Chesapeake Bay database)
2. Environmental Protection Agency (EPA) STORET Permit Compliance System (retrieved from EPA database)
3. Maryland (MD) Upper Chesapeake Bay point source report (Dobler, 1990)
4. Maryland Department of the Environment, MDE (data provided by Peter Legg, Elizabeth Dobler, and Ming L. Jiang)
5. Maryland 305(b) reports (Garrison, 1986; 1988)
6. West Virginia (WV) Potomac River Basin Plan (WVDNR, 1989)
7. Council of Government (COG) Potomac River Basin Nutrient Inventory (Lugbill, 1990)
8. Potomac River Basin water quality reports (Rasin et al., 1986; MWCOG, 1989)
9. information obtained from individual WWTP
10. Virginia Water Control Broad (VAWCB) report on effect of phosphate detergent ban (VAWCB, 1990);
11. VAWCB (personal communication with John Kennedy).
12. WV 305(b) report (WVDNR, 1988)
13. VAWCB 305(b) report (VAWCB, 1988a)

The information from these sources, including permit or design specifications, discharge monitoring reports (DMR), compliance monitoring reports (CMR), or other estimates of constituents were compiled to provide estimates of loadings for the year 1983-1989. The PSI consists of facility name, treatment process, NPDES number, PRM segment number, receiving stream, and eight water quality constituents (flow, DO, BOD_5, TKN, TN, NH_4, NO_3, and TP). These constituents are either PRM inputs or are used to compute model inputs.

From the sources listed above, a total of 350 point sources (municipal WWTP, industrial and residential) were identified that discharge directly to the Potomac or it's tributaries. The initial task was to cross reference and resolve discrepancies among the different data bases. One problem encountered in this process is that different names or NPDES numbers may be used for the same facility. Another problem is that different data sources may report different values for nutrient concentrations/loadings and design flow. For example, some sources report CMR values while others report default values. The third problem encountered is that data may not be consistent from one year to another; for example significant changes in flow or nutrient concentration may occur.

Not all of the 350 dischargers identified in the preliminary investigation need to be considered for the PRM. Only those dischargers that either directly discharge into the mainstem Potomac or are not accounted for by water quality monitoring data for tributaries need to be explicitly accounted for in the PSI. Table 6 shows the un-monitored minor tributaries in each segment. Other un-monitored tributaries which are at the head of a segment are shown in Table 7. Using geographical criteria, the number of point source dischargers included in PSI was reduced from 350 to 120. Dischargers located on monitored tributaries, or upstream from water quality monitoring stations, are excluded from the PSI except for some major WWTP such as the Poolesville and Seneca WWTPs. These major WWTPs are retained, even though they discharge above a water quality monitoring station, so that any significant between observed and computed loadings may be resolved. A comparison of the loading from the WWTPs to the tributary waste load may provide insight into the dynamics of the system.

Few industrial dischargers have nutrient loads or concentrations specified in their discharge permit or report nutrients or BOD in DMRs. Consequently, many are excluded from the PSI. Water treatment plants and power plants are assumed to have no net effect on nutrient loads and are similarly excluded from PSI (personal communication with Peter Legg and John Veil; Dobler, 1990). Although increased water temperature in power plant effluent may incrementally alter the distribution of the various forms of nutrients, data on the magnitude of temperature changes is not readily available, and is not considered here. All residential systems are excluded from the PSI because their discharge is negligible compared with the total discharge. With these deletions, the number of point source dischargers was reduced from 120 to 83. The 37 point source dischargers excluded from PSI have a combined discharge of approximately 2.5 MGD (excluding power plants and water treatment plants). Table 8 shows the 83 point source dischargers included in PSI. Average monthly data are available for 37 of these dischargers, mostly for the years 1984 to 1989. Figure 47 shows the locations of those point sources with discharges above 0.25 MGD (Table 9).

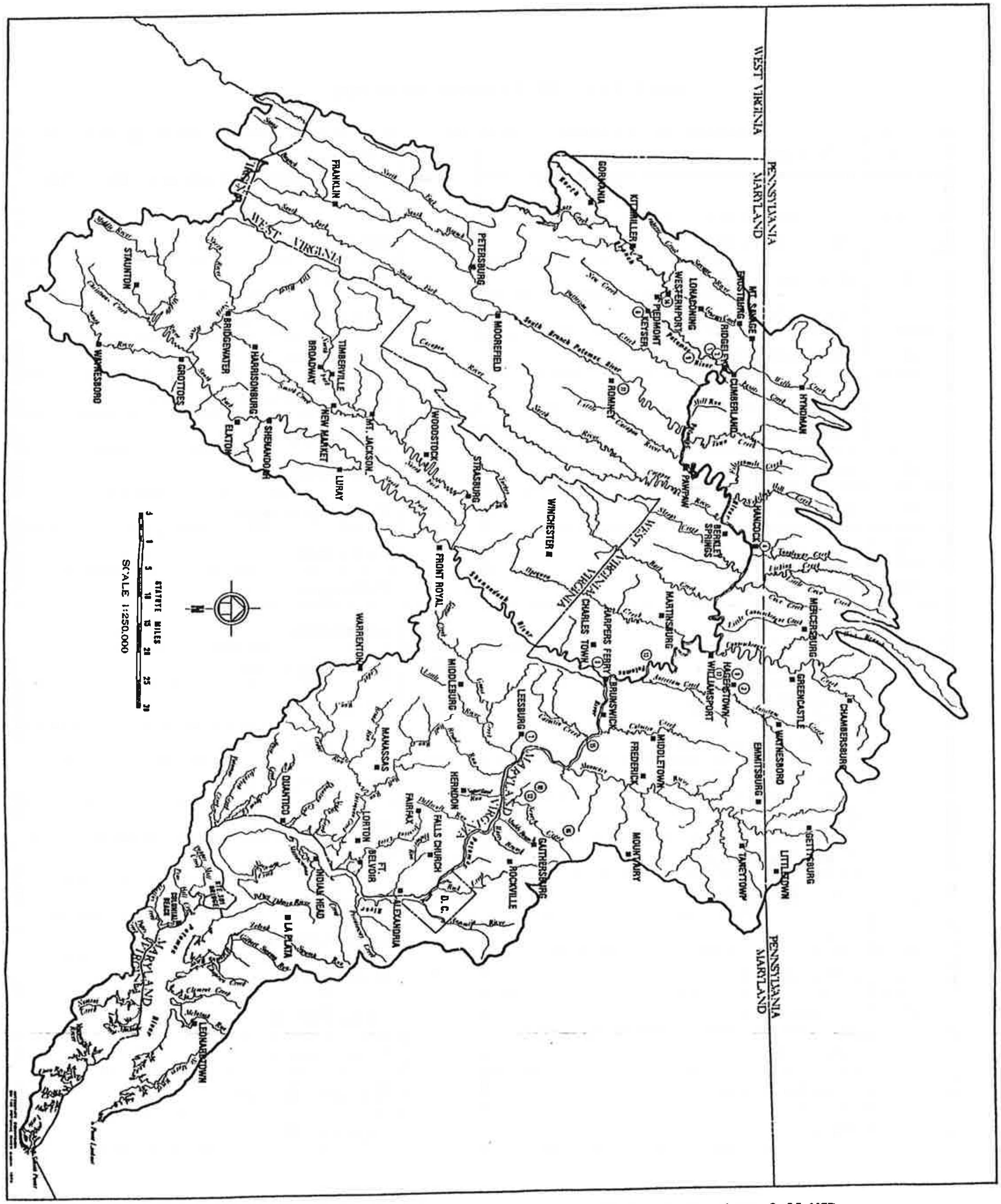

Figure 47. Location of Point Source Dischargers with Discharge above 0.25 MGD

Table 6. List of Un-Monitored Tributaries

Seg.	Tributaries	Seg.	Tributaries
1	Montgomery Run	28	Back Creek
3	Slaughterhouse Run		Harlan Run
	Powder House Run		Green Spring Run
4	Thunderbill Run		Jordan Run
5	New Creek	29	Little Conococheague Creek
	Limestone Run	31	Downey Branch
8	Ashcabin Run	32	Marsh Run
9	Mill Run		Rockymarsh Run
12	Warrior Run	33	Town Run
16	Evitts Creek		Rattlesnake Run
17	Collier Run	34	Elk Branch
18	Brice Hollow Run	36	Dutchman Creek
	Broad Hollow Run		Israel Creek
	Round Bottom Hollow		Piney Run
	Mill Run	37	Little Catoctin Creek
	Spring Run		Quarter Branch
	Green Spring Run	39	Tuscarora Creek
19	Seven Spring Run	40	Little Monocacy
	Stony Run		Limestone Branch
21	Purslane Run	42	Broad Run
22	Dawson Run		Cabin Branch
	Steer Run		Chriel Branch
	Little Steer Run		Horsepen Branch
	Big Run		Sugarland Run

Seg.	Tributaries	Seg.	Tributaries
24	Rockwell Run	43	Nichols Run
	Willett Run		Muddy Branch
25	Sir Johns Run	45	Rock Run
	Little Tonoloway Creek		Bullneck Run
26	Warm Spring Run		Difficult Run
	Dry Run		Turkey Run
	Stoney Run		Dean Run
	Ditch Run		Scott Run
	Tonoloway Creek	46	Cabin John Run
	Sleepy Creek		
27	Big Run		
	Cherry Run		

Table 7. Un-monitored Tributaries Heading a Segment

Tributary	Segment
Stony Run	4
Patterson Creek	18
Little Cacapon River	21
15 Mile Creek	23
Sideling Hill Creek	24
Cacapon River	25
Licking Creek	27
Watts Branch	44

Point Source Loading Estimation

As Table 8 shows, 29 of the PRM's point source dischargers are industrial dischargers. Of these 29 industrial dischargers, the combined discharge from UPRC WWTP, W.D. Byron, and Westvaco accounted for over 90% of the total industrial discharge. MDE (Veil, personal communication) indicated that Westvaco and W.D. Byron account for about 90% of the total industrial nutrient input to the Potomac above the fall line. Table 8 also shows that few municipal WWTPs report monthly nutrient values. Most municipal dischargers report only flow, BOD_5 and DO. MDE requires

WWTPs that are currently having their discharge permits renewed, to determine nutrient effluent concentrations (Jiang, personal communication). A review of the MDE DMR reports confirmed that most of the municipal WWTPs, especially minor dischargers (less than 0.5 MGD), do not or were not required to report nutrient concentrations.

To develop PRM input loads, observed flow and nutrient concentration are used when available. Although some average monthly flow, BOD_5, DO and nutrient data are available for 1984-1989, the availability of monthly nutrient data is insufficient for most point sources. It is therefore necessary to use published effluent concentration default values to estimate nutrient loading. Table 10 (Dobler, 1990), Table 11 (CBLO, 1990), Table 12 (NOAA, 1987) and Table 13 (Camacho, unpublished data) show four sets of default values based on either treatment process or treatment level. The default values in Table 10 are derived from the EPA "Areawide Assessment Procedures Manual". These values are based on the type of treatment process and typical concentrations measured for facilities of that type. However, the author of the EPA report has indicated that these values are no longer valid (Rathebe, personal communication). Camacho (unpublished data) has developed a set of default values based on treatment process (Table 13). He provides a range of values for a specific process rather than a single value, reflecting the differences in operation between plants. Comparing these two tables, the values presented in Table 10 are, in general, within the range provide in Table 14 except for NO_3 and NH_4. The default values for TP and TN in Table 10 have frequently been referred to in the literature and in communications with MDE (P. Legg and E. Dobler) and VAWCB (J. Kennedy) staff, and may be reasonable median default values. The default values in Table 11 and Table 12 are based on treatment type (i.e. primary or secondary). Table 11 has been developed by the EPA Chesapeake Bay Liaison Office for each state. Table 12 has been developed by NOAA for the "National Coastal Pollutant Discharge Inventory". The default values for secondary treatment compare favorably with NOAA's values, except for TN where the NOAA default value is lower. Table 11 has been developed for Chesapeake Bay point sources and may be more representative of regional WWTP efficiencies. It should be noted that WWTP effluent concentrations vary with design, as well as treatment level. The use of a single default oversimplifies the variation in WWTP effluent loads. Table 13 provides a range of values for each constituent. Considerable judgement must be exercised in selecting values from this table.

To compute the PRM nutrient loads from municipal WWTPs to the PRM, observed monthly flow, DO, BOD_5, and nutrient data will be used, when available. For those point sources with monthly flow but no nutrient data, if treatment process information is available, the default values in Table 13 will be used to estimated nutrient loads. For small WWTPs (less than 0.25 MGD), the default values for TP and TN in Table 10 will be used. To compute the concentration of the various forms of nitrogen, the ratio of ammonium, nitrate, and total organic nitrogen to TN was determined from the mean default values listed in Table 13. For phosphorus, the ratio of organic and inorganic phosphorus to TP was determined from the mean default values listed in Table 11. If no information on treatment process is available, secondary treatment default values are assumed (Table 11). For those municipal WWTPs with only average annual flow, BOD_5, DO and/or nutrient data, the average annual values will be used as the first estimate of loading for the calibration period. As indicated in Table 8, some of the WWTPs only have data (flow, BOD_5, DO, and/or nutrients) for a specific year. In that case, the values for that year (annual or monthly) will be used to approximate the loading for the calibration period even if calibration is for another year. One major drawback of this approach is that it does not reflect possible changes in treatment process at WWTPs. If data are available for more than one year but outside the calibration period, an average value is used. However, if the particular plant is known to have been upgraded during the calibration period, appropriate adjustments are made to reflect the changes. When there are no observed data of any kind but permit or design values are available, then the permit or design values will be used.

Most industrial dischargers (depending on the type of industry) do not have nutrient limits specified in their discharge permit. Nutrients are rarely reported in industrial DMR reports. Hence it is very difficult to estimate the nutrient loading for these facilities. Considerable judgement has to be used in applying the default values in Tables 10, 11, and 13. As with municipal WWTPs, industrial dischargers, are also assumed to provide secondary treatment. This assumption provides an upper bound on industrial nutrient loads, and will be reviewed on a plant-by-plant basis. For those dischargers with data for TP and TN only, secondary treatment is assumed in order to estimate the partitioning of nutrients from Table 11. For both municipal WWTPs and industrial dischargers for which no nutrient or BOD_5 data (monthly, annual or permit/design) are available, for plants in the state of Maryland, the default values of 18.5 mg/L for TN, and 7-8 mg/L for TP prior to 1985 and 3 mg/L after 1985 (to reflect the phosphorus ban in Maryland) will be used (Dobler, 1990). For plants in the state of Virginia, the default values of 18.5 mg/L for TN, and 5.3 mg/L for TP before 8/87, 3.7 mg/L between 9/87-12/87, and 3.2 mg/L after 1987 are used (VAWCB, 1990). It must be emphasized that the default value does not necessarily reflect the actual concentration. For industrial dischargers in particular, the range of nutrient discharge could vary substantially depending on the type of industry and their treatment or pretreatment requirement.

The upgrade of wastewater treatment facilities will similarly affect the selection of default values. There are several wastewater treatment plants that have been upgraded in the 1990's, e.g. Hancock WWTP in 1988, Rawlings Heights WWTP in 1988, and Ridgeley in 1990 (personal communication with Ming L. Jiang).

Using available data and default values the nitrogen and phosphorus loads for each point source can be estimated. These estimated loads cannot account for monthly variations in process efficiency, hydraulic load or influent concentration. To asses the accuracy and range of variation in estimated point source nutrient loads, default-based nutrient loads (based on TP and TN default values in Table 10) are compared to reported monthly loadings at several WWTPs above the fall line.

Assessment of Default Values

This section compares the WWTP default values with the effluent observations from several municipal sewage treatment plants in order to quantify the error introduced by estimating point source loadings using default values. Table 8 shows the type and the amount of data available for each point source. A review of this table indicates that nutrient data is not available for the majority of the point sources. For these point sources, nutrient loads must be estimated using default values. The default values will be based on treatment process or the assumption of secondary treatment. To quantify the usefulness of these default values, observed nutrient concentrations in plant effluent (average monthly) are compared with both the treatment process default values for TP and TN (Table 10), as well as the default values for secondary treatment (Table 11). Note that the WWTPs used in this discussion are major systems discharging above tributary monitoring stations. Their loads therefore enter the PRM implicitly, through the tributary loads.

Table 8. List of Point Source Dischargers

Facility Name	M/I	NPDES #	Seg.	Treatment process	Receiving Stream	Flow available	Data available
POTOMAC EDISON PAUL SMITH	I	MD0000582	30	NA	POTOMAC RIVER	85	85 BOD,TN,TP; PERMIT APPL. BOD,TN,NH3,NO3,TP
WESTVACO CORP LUKE MILL	I	MD0001422	1	LAGOON	POTOMAC RIVER	85-86; MONTHLY 84-89	PERMIT APPL. BOD,NH3,NO3,TON,TP
PPG INDUSTRIES INC	I	MD0002216	17	NA	NB POTOMAC RIVER	PERMIT	PERMIT TP
UPPER POTOMAC RIVER COMM-WASTE	I	MD0021687	3	NA	NB POTOMAC RIVER	PERMIT; 85-86; MONTHLY 84-89	PERMIT APPL BOD,NH3,TKN,NO3,PO4; MONTHLY 84-89 BOD
WEAVERTON DEVELOPMENT TRUST CO.	I	MD0023612	36	NO TREATMENT	ISRAEL CREEK	NA	85 TN,TP
W.D.BYRON & SONS,INC	I	MD0053431	30	NA	CONOCOCHEAGUE CREEK	PERMIT; MONTHLY 84-88	PERMIT BOD,NH3; MOHTHLY 84-89 BOD
CLIFTON ON THE POT.	I	MD0055557	0	ACTIVATED SLUDGE	POTOMAC RIVER	PERMIT	PERMIT BOD
MONTGOMERY CO. LEAF COMPOSTING	I	MD0062073	40	NA	LITTLE MONOCACY	PERMIT	PERMIT BOD
FIRST AMERICAN LAND COMPANY	I	NA	45	NA	POTOMAC RIVER	86	86 BOD,TKN
HARPERS FERRY CAVERNS	I	NA	34	NA	ELK BRANCH	86	86 BOD,TKN
JEFFERSON COUNTY BROAD OF EDUCATION	I	NA	8	NA	NB POTOMAC RIVER	86	86 BOD,TKN
NORTH MOUNTAIN RESORT	I	NA	28	NA	BACK CREEK	86	86 BOD,TKN
SNYDER ENTERPRISES, INC.	I	NA	34	NA	ELK BRANCH	86	86 BOD,TKN
RIVERVIEW ESTATES	I	VA0026590	45	NA	POTOMAC RIVER	NA	NA
3M MIDDLEWAY PRINTING	I	WV0005533	1	NA	TURKEY RUN	85	85 TKN,TN,NH3
HERCULES, INC.	I	WV0020371	14	NA	NB POTOMAC RIVER	86	86 BOD,TKN
VAN WYK ENTERPRISES, INC.	I	WV0023345	28	NA	POTOMAC RIVER	NA	85 TN,TP
YOGI BEARS JELLYSTONE CAMP RES.	I	WV0025976	30	NA	POTOMAC RIVER	NA	85 TN,TP
POTOMAC VALLEY PROPERTIES, INC	I	WV0041289	28	NA	UT OF BACK CREEK	NA	NA
USDA-APPALACHIAN FRUIT RES. STAT.	I	WV0042994	14	ACTIVATED SLUDGE	POTOMAC RIVER	PERMIT; 86	PERMIT, 86 BOD,TKN
BURLINGTON UNITED METHODIST	I	WV0043206	18	NA	MILL RUN	86	86 BOD,TKN
AUTOMATED PACKAGING SYSTEMS, INC.	I	WV0043800	4	NA	NB POTOMAC RIVER	NA	NA

Facility Name	M/I	NPDES #	Seg.	Treatment process	Receiving Stream	Flow available	Data available
SHERWOOD ACRES	I	WV0045012	36	NA	PINEY RUN	NA	85 TN,TP
COOLFONT RECREATION	I	WV0045128	25	NA	SIR JOHN'S RUN	86	86 BOD,TKN
BLOOMINGTON LAKE HIGH TIMBER	I	WV0054381	1	NA	NB POTOMAC RIVER	NA	85 TN,TP
KINGSFORD COMPANY	I	WV0070734	0	NA	NB POTOMAC RIVER	NA	NA
DMB ENTERPRISES	I	WV0071412	26	TRICKLING FILTER	WARM SPRINGS RUN	86	86 BOD
JEFFERSON COUNTY BROAD OF ED.	I	WV0081221	34	NA	ELK BRANCH	86	86 BOD,TKN
COOLFONT RECREATION, INC.	I	WV0081337	25	NA	SIR JOHN'S RUN	86	86 BOD,TKN
WSSC SUBDIV 1-HALFWAY WWTP	M	MD0020214	30	TRICKLING FILTER	POTOMAC RIVER	PERMIT; 84-89; MONTHLY 84-89	PERMIT BOD; 85 BOD,TKN,NH3; 84-89 TN,TP; MONTHLY 84-89 BOD
FREDERICK CO-POINT OF ROCKS ES	M	MD0020745	39	NA	UT TO POTOMAC RIVER	PERMIT; 85	85 BOD,TN,TP
FREDERICK CO METRO DIST-ARCADI	M	MD0020753	40	NA	MONOCACY RIVER	NA	85 TN,TP
POINT OF ROCKS FREDERICK CO.	M	MD0020800	39	ACTIVATED SLUDGE	POTOMAC RIVER	PERMIT; 84-87; MONTHLY 84-89	PERMIT BOD; 85 TN,TP; MONTHLY 84-89 BOD
US ARMY FORT DETRICK WWTP	M	MD0020877	34	TRICKLING FILTER	MONOCACY RIVER	PERMIT; 85; MONTHLY 83-89	PERMIT BOD,TKN; 85 TN,TP; MONTHLY 83-89 BOD,TKN(SUMMER)
BRUNSWICK SEWAGE TREATMENT PLANT	M	MD0020958	37	ACTIVATED SLUDGE	POTOMAC RIVER	PERMIT; 84-89; MONTHLY 83-89	PERMIT BOD; 85 BOD; 84-89 TN,TP; MONTHLY 83-89 BOD
WASH.SUB.SAN.COMM-DAMASCUS WWTP	M	MD0020982	43	ACTIVATED SLUDGE	MAGRUDER BRANCH	PERMIT; 84-89; MONTHLY 84-89	PERMIT BOD; 84-89 TN,TP; MONTHLY 84-89 BOD,TP,TKN
SENECA CREEK	M	MD0021491	43	EXTENDED AERATION	GREAT SENECA CREEK	PERMIT; 84-89; MONTHLY 84-89	PERMIT BOD,TKN,TP; 85 BOD,TKN; 84-89 TN,TP; MONTHLY 84-87 NH3,NO3; MONTHLY 84-89 BOD,TKN, TN,TP
CUMBERLAND,CITY OF	M	MD0021598	16	ACTIVATED SLUDGE	EVITTS CREEK	PERMIT; 84-89; MONTHLY 83-89	PERMIT BOD,TKN,TN; 84-89 TN,TP; 85 BOD,TKN; MONTHLY 83-89 BOD; 5/88-10/88, 5/89-10/89 TKN; 5/87-10/87 TN
FREDERICK CITY WWTP	M	MD0021610	40	ACTIVATED SLUDGE	CARROLL CREEK	PERMIT; 84-89; MONTHLY 84-89	PERMIT BOD,TKN,TN; 85 BOD,TKN; 84-89 TN,TP; MONTHLY 84-89 BOD; MONTHLY 88-89 TKN
HAGERSTOWN WWTP,CITY OF	M	MD0021776	34	ACTIVATED SLUDGE	ANTIETAM CREEK	PERMIT; 84-89; MONTHLY 83-89	PERMIT BOD,TKN,TN; 85 BOD,TKN; 84-89 TN,TP; MONTHLY 83-89 BOD,NH3,TKN,NO3,TP
BALLENGER CREEK	M	MD0021822	40	ACTIVATED SLUDGE	MONOCACY RIVER	PERMIT; 85-89; MONTHLY 83-89	PERMIT BOD,TKN; 85-89 TN,TP; MONTHLY 83-89 BOD; MONTHLY 89 TKN
ALLEGANY COUNTY-BOWLING GREEN	M	MD0022462	12	RBC	NB POTOMAC RIVER	PERMIT; 84-89; MONTHLY 83-89	PERMIT BOD; 84-89 TN,TP; MONTHLY 83-89 BOD

Facility Name	M/I	NPDES #	Seg.	Treatment process	Receiving Stream	Flow available	Data available
ALLEGANY COUNTY-CRESAPTOWN	M	MD0022471	12	RBC	NB POTOMAC RIVER	PERMIT; 84-89; MONTHLY 83-85,87-89	PERMIT BOD; 84-89 TN,TP; 85 BOD; MONTHLY 83-85,87-89 BOD
MEXICO FARMS	M	MD0022659	17	LAGOON	NB POTOMAC RIVER	PERMIT; 84-87; MONTHLY 84-85,88-89	PERMIT, MONTHLY 84-85,88-89 BOD
PINTO UTILITIES	M	MD0022748	10	LAGOON	UT TO POTOMAC RIVER	PERMIT; 84-87; MONTHLY 83-89	PERMIT, MONTHLY 83-89 BOD; 85 TN,TP
POOLESVILLE TOWN OF, WWTP	M	MD0023001	43	SBR	DRY SENECA CREEK	PERMIT; 84-89; MONTHLY 84-89	PERMIT, MONTHLY 84-89 BOD; 84-89 TN,TP; 5/88-10/88 TKN
RAWLINGS, TOWN OF	M	MD0023213	9	LAGOON	NB POTOMAC RIVER	PERMIT; 84-87; MONTHLY 83-89	PERMIT BOD,TKN; 85 TN,TP; MONTHLY 83-89 BOD
AT&T FAULKNER	M	MD0023361	26	TRICKLING FILTER	UT-POTOMAC RIVER	PERMIT	PERMIT BOD,TKN
HONEYWOOD	M	MD0023540	30	ACTIVATED SLUDGE	POTOMAC RIVER	PERMIT; 2,3,5,10/88 ; MONTHLY 84-85	PERMIT, MONTHLY 84-85,88-89 BOD
MD CORRECTION CTR HAGERSTOWN	M	MD0023957	34	ACTIVATED SLUDGE	ANTIETAM CREEK	PERMIT; 85; MONTHLY 83-85,87-89	PERMIT, MONTHLY 83-85,87-89 BOD; 85 BOD,TKN,TN,TP
RIVERBEND	M	MD0024236	32	OXIDATION DITCH	POTOMAC RIVER	PERMIT; MONTHLY 88-89	PERMIT, MONTHLY 88-89 BOD
HANCOCK SEWAGE TREATMENT	M	MD0024562	26	LAGOON	TONOLOWAY CREEK	PERMIT; 84-89; MONTHLY 84-89	PERMIT, MONTHLY 84-89 BOD; 84-89 TN,TP
OLDTOWN	M	MD0024759	18	EXTENDED AERATION	MILL RUN	PERMIT; 84-87; MONTHLY 83-89	PERMIT, MONTHLY 83-89 BOD
TRI TOWN PLAZA	M	MD0024937	4	EXTENDED AERATION	NB POTOMAC RIVER	PERMIT; 84-87; MONTHLY 84-85,89	PERMIT, MONTHLY 84-85,89 BOD
GREEN RIDGE FORESTRY CAMP	M	MD0024988	23	ACTIVATED SLUDGE	FIFTEEN MILE CREEK	PERMIT; 84-87; MONTHLY 87-89	MONTHLY 87-89 BOD
WHITE ROCK COMMUNITY-FREDERICK	M	MD0025089	39	ACTIVATED SLUDGE	TUSCARORA CREEK	PERMIT; MONTHLY 83-89	PERMIT BOD,TKN; MONTHLY 83-89 BOD
RIDGELEY	M	MD0050342	16	NO TREATMENT	NB POTOMAC RIVER	PERMIT; MONTHLY 87-89	PERMIT, MONTHLY 87-89 BOD; MONTHLY 88-89 TKN
FAIRVIEW BCH. SAN.	M	MD0056464	27	OXIDATION DITCH	POTOMAC RIVER	PERMIT; MONTHLY 87-89	PERMIT, MONTHLY 87-89 BOD
WOODSBORO WWTP	M	MD0058661	36	OXIDATION DITCH	ISRAEL CREEK	PERMIT; 84-87; MONTHLY 83-89	PERMIT BOD,TKN; 85 TN,TP; MONTHLY 83-89 BOD; MONTHLY 88-89 TKN
GEORGES CREEK WWTP	M	MD0060071	2	OXIDATION DITCH	GEORGES CREEK	PERMIT; 85-89; MONTHLY 85,87-89	PERMIT, MONTHLY 85,87-89 BOD; 85-89 TN,TP
BLOOMINGTON WWTP	M	MD0060933	1	ACTIVATED SLUDGE	NB POTOMAC RIVER	PERMIT; MONTHLY 87-89	PERMIT, MONTHLY 87-89 BOD
COLDSTREAM ASSOCIATION	M	NA	25	NA	CACAPON RIVER	86	86 BOD,TKN
WEST VIRGINIA DEPARTMENT OF HWYS	M	NA	18	NA	PATTERSON CREEK	86	86 BOD,TKN

Facility Name	M/I	NPDES #	Seg.	Treatment process	Receiving Stream	Flow available	Data available
LEESBURG,TOWN OF,WTR POLLUTION	M	VA0021377	39	ACTIVATED SLUDGE	TUSCARORA CREEK	PERMIT; 85; MONTHLY 84-87,87	85 BOD,TKN,NH3,NO3,TN,TP; MONTHLY 89 BOD, TKN, NH3, NO3, TP,DIP; MONTHLY 84-87 BOD, NO3, TP,TN
LOVETTSVILLE,TOWN OF	M	VA0023183	36	NA	DUTCHMAN CREEK	PERMIT; 85	85 BOD,TN,TP
MIDDLEBURG WEST WWTP	M	VA0024767	43	NA	GOOSE CREEK	PERMIT; 85	85 TN,TP
MIDDLEBURG EAST WWTP	M	VA0024775	42	NA	GOOSE CREEK	NA	85 TN,TP
HERNDON SEWAGE TREATMENT PLANT	M	VA0026336	42	NA	FOLLY LICK BRANCH	NA	85 TN,TP
BERKELEY COUNTY PSD	M	WV0020061	31	NA	OPEQUON CREEK	PERMIT; 84-86	85-86 TKN; 86 BOD
ROMNEY, CITY OF	M	WV0020699	33	NA	TOWN RUN	PERMIT; 85-86	85-86 BOD,TKN; 85 TN,TP
MARTINSBURG, CITY OF	M	WV0023167	39	NA	TUSCARORA CREEK	PERMIT; 85-86	85-86 BOD,TKN; 85 TN,TP
HONEYWOOD MOBILE HOME PARK	M	WV0023345	30	NA	POTOMAC RIVER	86	86 BOD,TKN
RIDGELEY, TOWN OF	M	WV0024376	14	NA	NB POTOMAC RIVER	86	86 BOD,TKN
KEYSER, CITY OF	M	WV0024392	5	NA	NB POTOMAC RIVER	PERMIT; 85-86	85-86 BOD,TKN; 85 TN,TP
SHEPHERDSTOWN WPCF	M	WV0024775	33	NA	POTOMAC RIVER	PERMIT; 85-86	PERMIT, 85-86 BOD,TKN; 85 TN,TP
HARPERS FERRY TOWN OF	M	WV0027162	36	NA	SHENANDOAH RIVER	PERMIT; 85	85 BOD,TN,TP
HEDGESVILLE, TOWN OF	M	WV0027189	28	NA	BACK CREEK	NA	85 TN,TP
PAW PAW, TOWN OF	M	WV0027405	22	LAGOON	POTOMAC RIVER	PERMIT; 86	PERMIT, 86 BOD; 86 TKN
WARM SPRINGS PSD	M	WV0027707	26	NA	WARM SPRINGS RUN	PERMIT; 85-86	85-86 BOD,TKN; 85 TN,TP
HARPERS FERRY-BOLIVAR PSD	M	WV0039136	36	ACTIVATED SLUDGE	SHENANDOAH RIVER	PERMIT; 85-86	PERMIT, 86, MONTHLY 88-89 BOD,TKN; 85 TKN, TN,TP
FORT ASHBY PUBIC SERVICE DIST.	M	WV0041521	18	AERATED LAGOON	PATTERSON CREEK	PERMIT; 86	PERMIT, 86 BOD,TKN
S & H SEWAGE ASSOCIATION	M	WV0045012	36	NA	PINEY RUN	86	86 BOD,TKN
SHEPHERDSTOWN WWTP	M	WV0050938	33	ACTIVATED SLUDGE	POTOMAC RIVER	MONTHLY 84,86-89	85 TN,TP; MONTHLY 84,86-89 BOD,TKN

Note. I: industrial; M: municipal.

Phosphorus

Figure 48 shows the observed TP effluent (1988-1989) for the US Army Fort Detrick WWTP and the default value for a trickling filter type of plant (Table 10). As shown in Figure 48, the default value, in general, underestimates the effluent TP concentration. The reason for the constant "observed" values for 1988 is that no DMR data are available, and the average value from a few CMR observations were used (Legg, personal communication). Figures 49 and 50 show the observed TP effluent concentration for Seneca Creek WWTP both before and after the Maryland phosphorus ban with the appropriate default value (Table 10). These two figures show that the default value overestimated the TP concentration by 50% to 100%. Again, the constant concentration for 1988 was derived from CMR data. Figures 51 (1984-1985) and 52 (1986-1988) show the observed TP concentration for the Hagerstown WWTP with the appropriate default concentrations. Figure 51 shows that before the phosphorus ban, the default value overestimated the effluent concentration. Although monthly variation in effluent concentration is significant, the default value provides a reasonable estimate of annual average effluent concentration for the post-ban period (Figure 52). Comparing these figures (Figures 48 to 51), shows that by using a single default value, we may overestimate or underestimate the effluent concentration; the error could be as high as 100%. The effluent concentration is a function of the strength of the influent, the type of treatment process, the configuration and operation of the WWTP, and whether the WWTP is required to removed phosphorus. In Virginia, all WWTPs over 1 MGD are required to meet the 2 mg/L TP limit (VAWCB, 1990). In Maryland, WWTPs discharging into nutrient enriched waters are also required to remove phosphorus (Jiang, personal communication). Operation differs between WWTPs. For example, Seneca Creek may operate more efficiently than Fort Detrick and Hagerstown explaining the lower observed TP effluent concentration. Figures 49 to 53 also show both monthly and yearly changes in effluent concentration. The use of default values will not capture this variation. The same conclusion is reached when comparing these figures with the TP default value (7-8 mg/L) based on secondary treatment (Table 11).

PRM requires the input of different forms of phosphorus. Table 11 provides the only source of default values for different forms of phosphorus based on treatment type. The variation of TP with time and WWTP suggests that the distribution of different forms of phosphorus, such as orthophosphate (inorganic phosphorus), OPO4 and organic phosphorus, OP, may also change between plants on a seasonal or yearly basis depending on the type of treatment process and its operation. The change in distribution of different forms of phosphorus cannot be quantified since only the Frederick WWTP (1990) in Maryland and the Leesburg WWTP (1989-1990) in Virginia analyze different forms of phosphorus. Their data indicated that about 90% and 60% of the total phosphorus is in the form of dissolved inorganic phosphorus, at the respective plants. The default value based on secondary treatment (Table 11) assumed that about 85% of the TP is in the form of inorganic phosphorus (assumed in dissolved form). Comparing this with the OPO4/TP ratio observed (Appendix A) in Frederick and Leesburg, the default value in Table 11 appear to be a reasonable estimate. If the default value based on treatment process (TP in Table 10) is used, the 0.85 OPO4/TP ratio computed from Table 11 appears to be a reasonable value for computing OPO4.

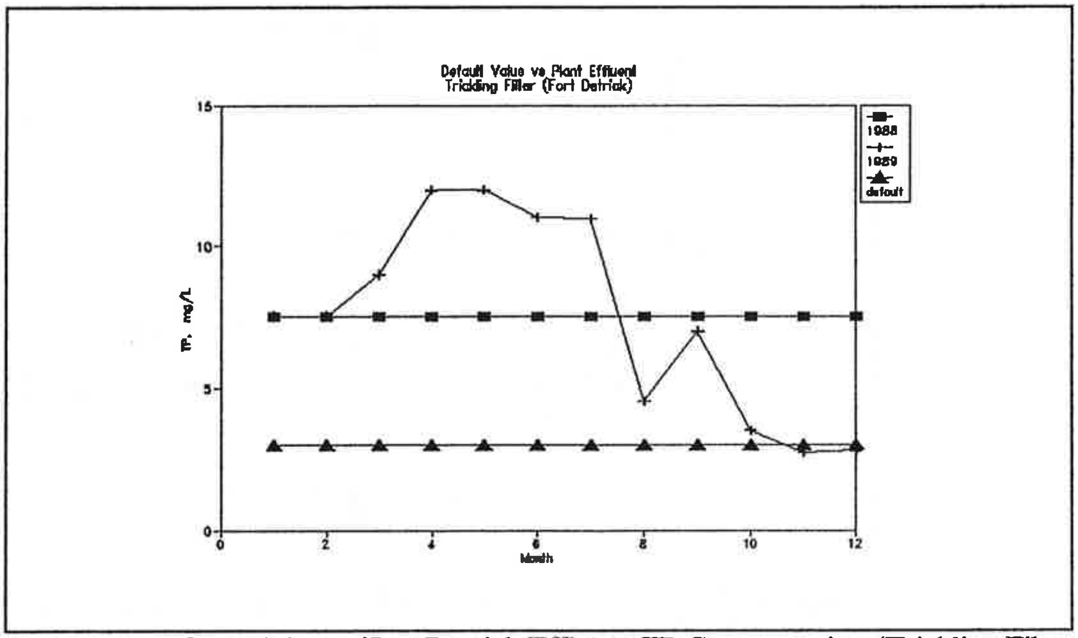

Figure 48. Default Value vs Fort Detrick Effluent TP Concentration (Trickling Filter

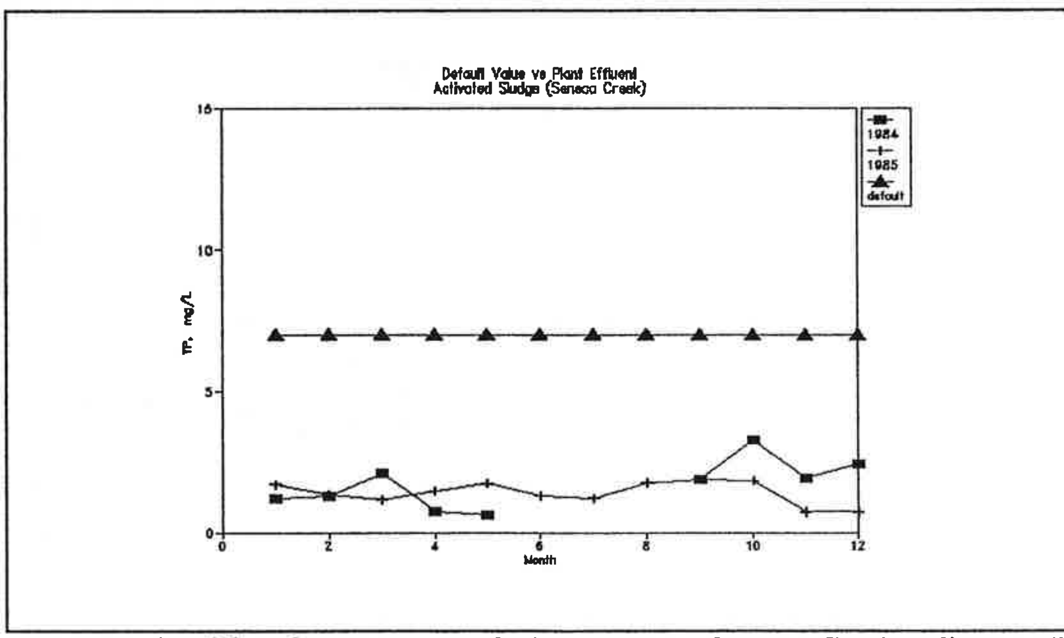

Figure 49. Pre-Phosphorus Ban Default Value vs Seneca Creek Effluent TP Concentration (Activated Sludge)

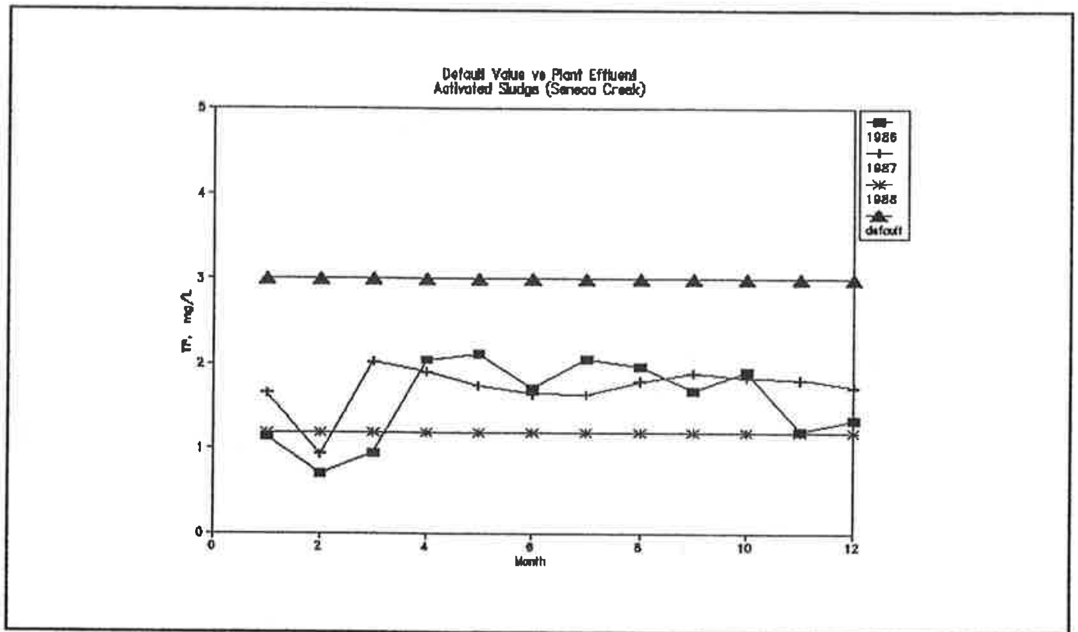

Figure 50. Post-Phosphorus Ban Default Value vs Seneca Creek Effluent TP Concentration (Activated Sludge)

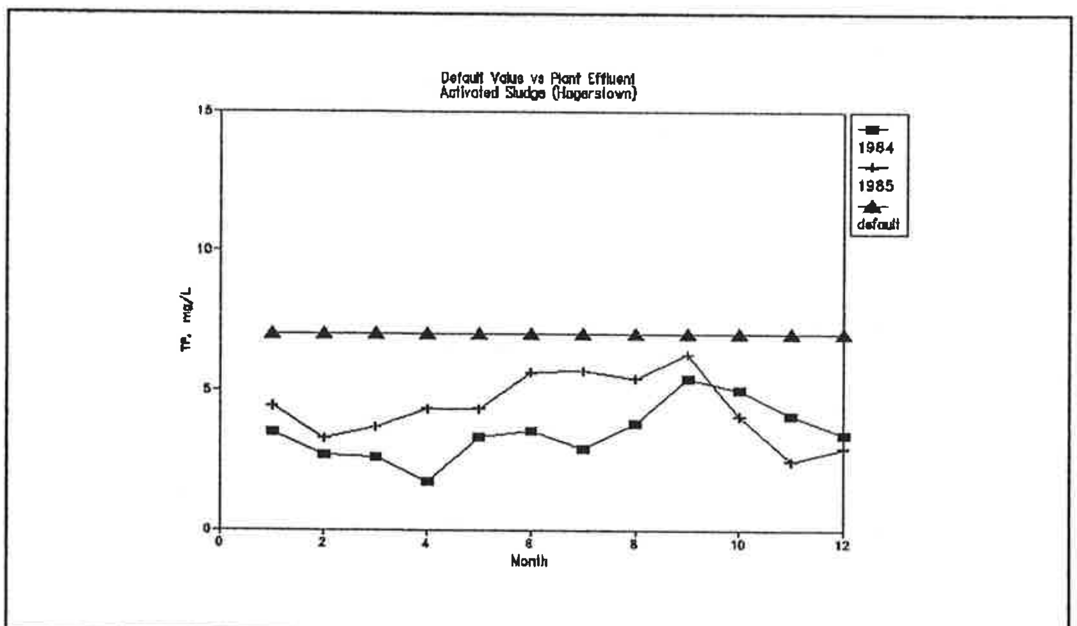

Figure 51. Pre-Phosphorus Ban Default Value vs Hagerstown Effluent TP Concentration (Activated Sludge)

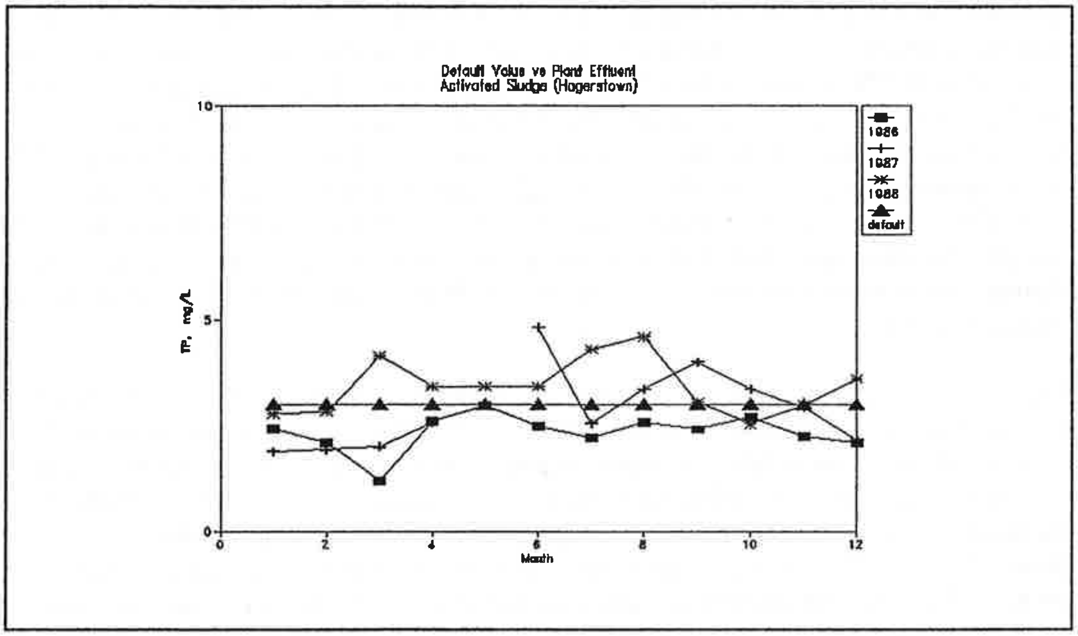

Figure 52. Post-Phosphorus Ban Default Value vs Hagerstown Effluent TP Concentration (Activated Sludge)

Nitrogen

Figures 53 to 55 show the observed effluent TN concentration for Hagerstown WWTP, Seneca Creek WWTP, and Fort Detrick WWTP with default values (Table 10) based on treatment process. These figures indicate that, in general, the effluent TN concentration is lower than the default value (overestimated by 5% to 100% depending on WWTP). In addition, these figures also show that the TN concentration varies greatly between plants on monthly and yearly time frames, as is the case for TP. This same conclusion can be reached when comparing the TN default value based on secondary treatment (Table 11).

Only a few major WWTPs (Damascus, Hagerstown, Leesburg and Seneca Creek) analyze their effluent for the distribution of various forms of nitrogen such as NH_4, NO_3 and TKN. Figures 56 through 58 show the effluent NH_4, NO_3 and TKN concentration versus default values based on secondary treatment for Damascus, Hagerstown and Seneca Creek for the year 1985. Figures 59 through 61 show respectively, the NH_4, NO_3 and TKN concentrations for Hagerstown. As shown in these figures, the concentration of these constituents varies monthly and yearly. The degree of nitrification can also vary monthly depending on the temperature and the type of treatment process. In general, the default values in Table 11 underestimate the NO_3 concentration. About 60% to 95% of the TN is in the form of NO_3; less than 1% to 50% of TN is in the form of NH_4; and about 5% to 40% of the TN is in the form of TKN. Overall, these WWTPs achieved a high degree of nitrification. However, this does not imply all plants achieved such high levels of nitrification. Some WWTPs may not be specifically designed for nitrification (M. Jiang, personal communication). Consequently, the NO_3/TN ratio may be lower for these systems. The default values based on secondary treatment shown in Table 11 suggest a low level of nitrification.

The variation in the operation of different WWTPs over time is further illustrated using the effluent data for the Hagerstown and Seneca Creek WWTPs. Figures 62 to 65 show the TN concentration and the ratios of different forms of nitrogen to TN for the Hagerstown WWTP from 1983 to 1989. The effluent TN concentrations from their Hagerstown WWTP (Figure 62) vary between 5 and 25 mg N/L with no apparent trend over the six year period. Generally, NH_4 was approximately 10% of the TN during most of the time period with the exception of early 1985 when NH_4 accounted for approximately 65% of the TN. Although there is much scatter in the data, the distribution of NO_3/TN indicates an overall downward trend from 1983 to 1987 (Figure 64). With the NH_4/TN roughly constant, the TON/TN increases slightly as shown in Figure 65. These data indicate that a change has occurred in the operation of the WWTP and that the breakdown of nitrogen in the effluent varies significantly over this period.

Figures 66 to 69 show the TN concentration, and the ratios of different forms of nitrogen with TN for the Seneca Creek WWTP from 1985 to 1990. The data in Figure 66 show that the TN effluent concentration remains fairly constant at approximately 18 mg N/L until 1989 and then decreases to 10 mg N/L by 1990. The NH_4/TN ratio gradually increases from 1985 to 1989 (Figure 67). A sharp increase occurs after 1989 although NH_4 is still a small percentage of the TN. The NO_3/TN increases from 1985 to 1986 and then stays relatively constant (Figure 68). Starting in early 1989, the ratio of NO_3 to TN gradually decreases. Correspondingly, the TON to TN ratio changes for the same time periods (Figure 69). These data indicate that a change in the operation has occurred over this time period. The data indicates a general increase in nitrification from 1985 to 1989. The decrease in TN from 1989 through 1990 indicates either a change in the concentration of TN in the influent to the plant or denitrification is occurring within the treatment process. WSSC (Hall, personal communication) indicated that denitrification was occurring at the Seneca WWTP during this time period. Nitrification is an aerobic process while denitrification is an anaerobic process. A shift towards denitrification could correspondingly slow down the nitrification process which would result in the change in the NO_3, NH_4 and TON distributions. The analysis of these two WWTPs clearly shows the variation of operation between different WWTPs, and demonstrates the limitations and assumptions encountered in choosing an appropriate default value for each WWTP.

Estimated Point Source Loading

Considering the range of default values and data availability, the point source TN, TP, and BOD5 loadings for the year 1985 were estimated using the TP and TN default values in Table 11. The resulting estimated loading by segment is shown in Table 14. The total loading of nitrogen, phosphorus, and BOD5 are estimated to be 6941.81 lbs N/day, 1890.97 lbs P/day, and 12055.46 lbs BOD/day, respectively. Industrial dischargers account for 11.5% of the total nitrogen loading and 3% of the total phosphorus loading. Of the industrial nutrient dischargers, Westvaco, UPRC and W.D. Byron collectively account for about 90% of the total industrial nutrient loading. It should be emphasized that the estimated loading is based on end-of-pipe concentration. Dobler (1990) estimated the 1985 nitrogen and phosphorus loadings for Maryland plants above the fall line to be 6167.38 lbs/d and 1522.11 lbs/day. The loads in Table 14 compare well with Dobler's estimated loadings. The difference between ICPRB estimated loads and the loads estimated by Dobler reflect differences in the use of observed and default values, and the set of plants included in the ICPRB Point Source Inventory. The ICPRB procedure is therefore judged to be reasonable, and will be used to estimate the loading to the PRM.

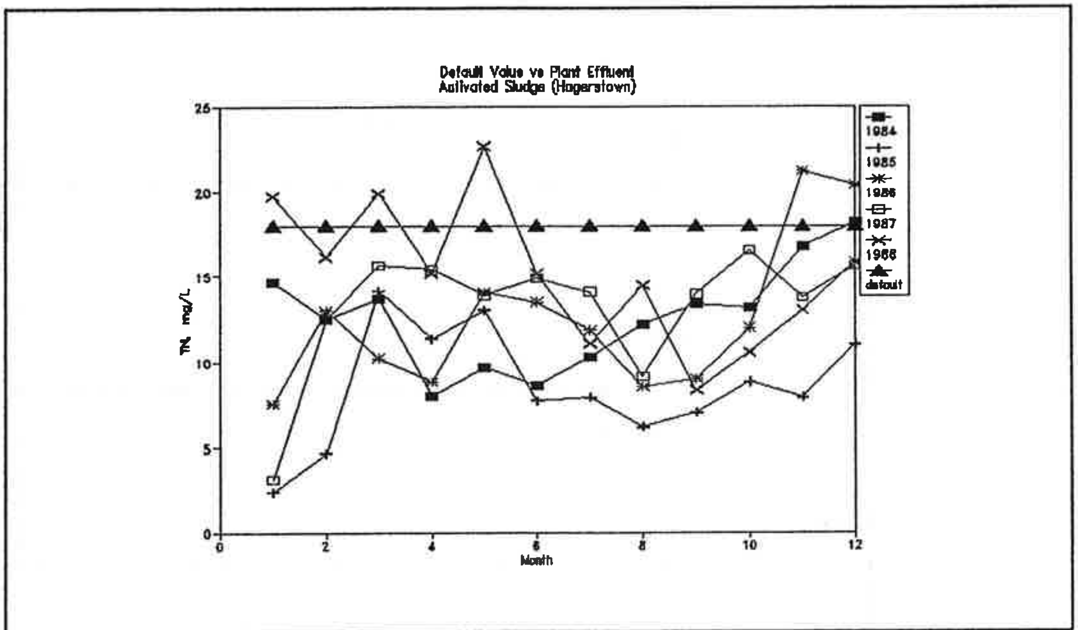

Figure 53. Default Value vs Hagerstown Effluent TN Concentration (Activated Sludge)

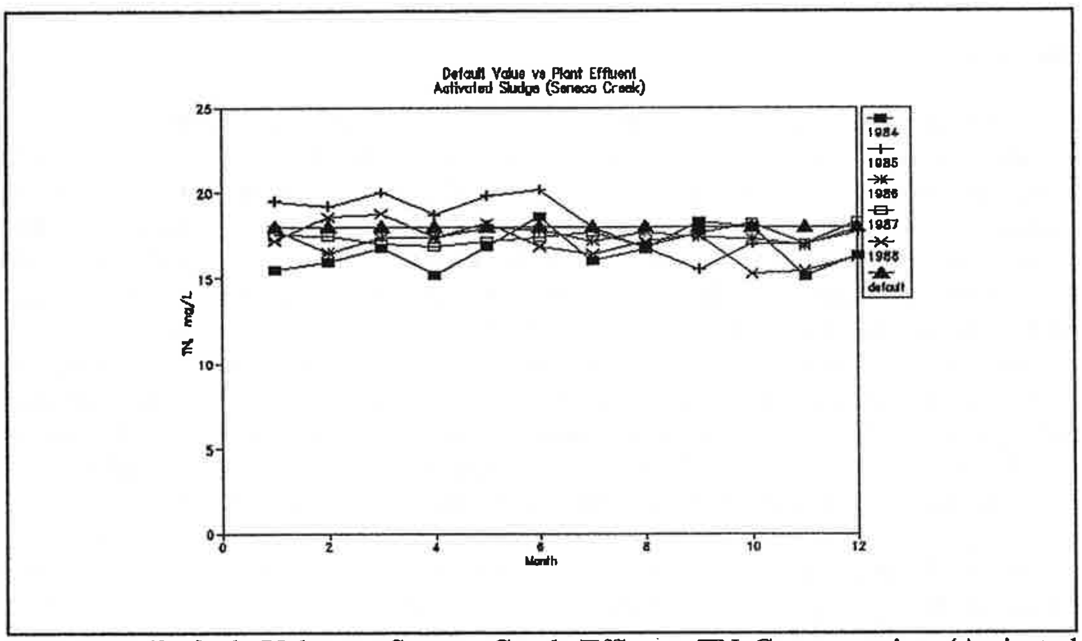

Figure 54. Default Value vs Seneca Creek Effluent TN Concentration (Activated Sludge)

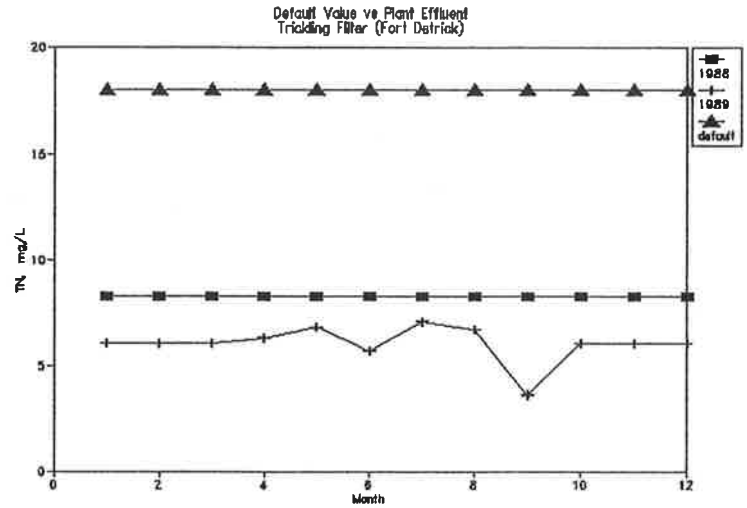

Figure 55. Default Value vs Fort Detrick Effluent TN Concentration (Trickling Filter)

Summary

The "Point Source Inventory" compiled by ICPRB contains a total of 83 point source dischargers (both municipal and industrial dischargers). Monthly observed data (flow, DO, BOD_5 and/or nutrient) are only available for 38 (3 industrial and 35 municipal) of these 83 dischargers. The majority of the remaining dischargers contain either annual average data of some sort for at least one year or permit/design specifications. Table 8 shows that the majority of the major WWTPs and major industrial dischargers included in PSI have monthly data (flow, DO, etc.) although not all of them report nutrients. Where observed data are not available, loads must be estimated using default values based on either treatment type or treatment process. Nutrient loads for 45 of the 83 dischargers listed in the PSI (Table 8), must be estimated from annual average data. 40 dischargers have no phosphorus data of any forms and require the use of default values to estimate the chemical form of the phosphorus load. TP data is available for 39 dischargers, requiring the use of default values/ratios to estimate the distribution of different forms of phosphorus. For nitrogen, 17 dischargers have no nitrogen data of any form and default values are required to estimate various forms of nitrogen loadings. 40 dischargers have TN data. For these dischargers, the loadings of each form of nitrogen (NH_4-N, NO_3-N, ON) are estimated by multiplying the observed TN by the appropriate ratio default values in Table 11. 24 dischargers have data for some form of nitrogen other than TN (mostly TKN); the loading of other forms of nitrogen must be estimated using default values/ratios.

The difference in operation between different treatment plants could significantly alter the concentration of nutrients as well as the distribution of their forms in the effluent. Although the procedure used to compute nutrient loadings is judged to be the best estimate available for the given data this estimate must nevertheless be viewed as an approximation of the unknown loads. Based on the amount and types of data available, it appears that there is sufficient information to compute or estimate the loading of the seven constituents (DO, BOD_5, NO_3, NH_4, ON, OP, IP, and OPO_4) required by PRM for eutrophication simulation. Furthermore, PRM requires the input of the dissolved fraction of each of the seven constituents. DO and BOD_5, are assumed to occur entirely in dissolved form (i.e. their dissolved fraction is equal to 1 in WASP4). For the nitrogen and phosphorus species, the derivation of their respective dissolved fraction is discussed in chapter 5.

In summary, a large portion of the nutrient loadings are derived from default values due to a lack of observed data. The point source loading (both municipal and industrial) used in PRM is an estimate based on the best available data. Considerable variation in both monthly and yearly time scales is observed in measured effluent concentration data. The variation between observed and default values has been examined and quantified. Although considerable care must be used in estimating point source loads, the available data is judged to be sufficient to allow these loads to be developed for the PRM.

The next chapter presents a simplified mass balance for the mainstem Potomac River from Luke to Chain Bridge. The mass balance provides an assessment of the overall quality and completeness of both the point source and tributary nutrient loads developed for PRM.

Table 9. Major Point Source Dischargers >0.25 MGD

No.	Facilities
1	Allegany County-Bowling Green WWTP
2	Allegany County-Cresaptown WWTP
3	Hagerstown WWTP
4	Hancock WWTP
5	Harpers Ferry-Bolivar PSD
6	Keyser
7	Lessburg WPC
8	MD Correctional Institute-Hagerstown
9	Pinto Utilities
10	Poolesville WWTP
11	Romney
12	Seneca Creek
13	Shepherdstown WWTP
14	Upper Potomac River Commission WWTP
15	Warm Springs PSD
16	WSSC-Damascus WWTP
17	WSSC-Halfway WWTP

Table 10. Default Values Based on Treatment Process
(Dobler, 1990)

Treatment Process	BOD_5 mg/L	TP * mg/L	NH_4 mg/L	NO_3 mg/L	TN mg/L
Trickling Filter	45	8	17	0	18
Activated Sludge	20	7	18	0	18
Oxidation Ditch	15	6	1	18	18
Lagoon	30	8	15		18
RBC	45	8	18	0	18
Extended Aeration **	25	8	18	0	18

* 3 mg/L after 1985
** Extended aeration is the "low rate" modification of the activated sludge process EPA, 1980)

Table 11. State Default Values for 1984 and 1985 Municipal Effluent Concentration
(computed from data provided by CBLO, 1990)

Treatment	BOD_5 mg/L*	State	TP mgP/L	PO_4 mgP/L	OP mgP/L	NH_4 mgN/L	NO_3 mgN/L	TKN mgN/L	TN mgN/L
Primary	31-45	MD	7.2-8.0	3.2-3.6	4.0-4.4	13.7	0.0	20.7	20.7
		VA	7.2	3.2	4.0	13.7	0.0	20.7	20.7
Secondary	25-30	MD	7.0-8.0 **	6.0-6.8	1.0-1.2	13.5	2.0	16.5	18.5
		VA	6.4 ***	5.4	1.0	13.5	2.0	16.5	18.5
Advanced	< 25	MD	< 2.0	< 0.9	< 1.1			< 10.0	
		VA	< 1.0	< 0.45	< 0.55			< 10.0	

* EPA 1980)
** 3 mg/L after 1985
*** 2.5 mg/L after 1987

Table 12. Default Values Based on Treatment Processes
(NOAA, 1987)

Treatment Process	BOD_5, mg/L	TP, mg/L	TN, mg/L
Primary	158.3	13.0	15.1
Secondary	23.9	7.0	11.2
Residential	113.9	10.0	14.2
Commercial	160.0	10.0	10.7

Table 13. Typical Effluent Concentration for Secondary Treatment Processes
(Camacho, 1990)

Treatment Process	BOD_5 mg/L	NH_4 mg/L	NO_3 mg/L	TN mg/L	TP * mg/L
Extended Aeration	5-50	1-10	10-25	10-30	2.5-3.2
Activated Sludge	10-40	10-25	0-5	15-30	2.5-3.2
Activated Sludge with Nitrification)	2-10	< 1	10-25	10-30	2.5-3.2
Fixed Film Trickling Filter/RBC)	5-20	1-20	0-25	10-30	2.5-3.2
Lagoon	30-100	5-15	2-20	10-30	2.5-3.2

* after phosphorus ban

Table 14. Computed Nutrient Loading for 1985

Segment	TN(lb/d)			TP(lb/d)			BOD5(lb/d)		
	Municipal	Industrial	Total	Municipal	Industrial	Total	Municipal	Industrial	Total
1	8.72	69.74	78.46	2.71	1.28	3.99	2.69	125.21	127.9
2	60.36		60.36	18.77		18.77			41.35
3		250.41	250.41		50.08	50.08	41.35	4247	4247
4	1.5		1.5	0.58		0.58	0.72		0.72
5	100.45		100.45	38.52		38.52	65.19		65.19
9	15.7		15.7	4.88		4.88	9.97		9.97
10	30.18		30.18	9.39		9.39	58		58
12	112.34		112.34	34.78		34.78	670.98		670.98
14	36.21	12.57	48.78	9.93		9.93	60.35	20.89	81.24
16	1508.81		1508.81	593.3		593.3	781.28		781.28
17	9.01		9.01	3.51	0.004	3.514	4.52		4.52
18	46.55	0.05	46.6	27.77		27.77	68.4	0.03	68.43
22	12.53		12.53	5.43		5.43	20.88		20.88
23	0.75		0.75	0.29		0.29	1.25		1.25
25	0.125	0.64	0.765	0.54		0.54	0.04	1.06	1.1
26	75.01		75.01	25.76		25.76	66.06	1.25	67.31
27	7.51		7.51	2.92		2.92	12.52		12.52
28	17.45	1.62	19.07	5.43		5.43	25.04	2.71	27.75
30	174.4	77.86	252.26	69.53	0.07	69.6	290.83	671.65	962.48
31	144.85		144.85	19.87		19.87	241.43		241.43
32	6.01		6.01	2.34		2.34	10.02		10.02
33	151.06		151.06	54.25		54.25	225.37		225.37
34	1133.38	2.41	1135.79	312.92		312.92	666.24	5.18	671.42
36	51.38	3.5	54.88	17.3	1.1	18.4	50.74		50.74
37	66.34		66.34	13.38		13.38	21.74		21.74
39	552.61		552.61	173.73		173.73	685.85		685.85
40	1018.94		1018.94	256.31		256.31	2556.73	8.35	2565.08
42	31.41		31.41	9.61		9.61	45.07		45.07
43	803.42		803.42	124.72		124.72	142.47		142.47
45		382.21	382.21			0		96.32	96.32
Total	6140.8	801.01	6941.81	1838.47	52.5	1891	6825.73	5229.73	12055.46

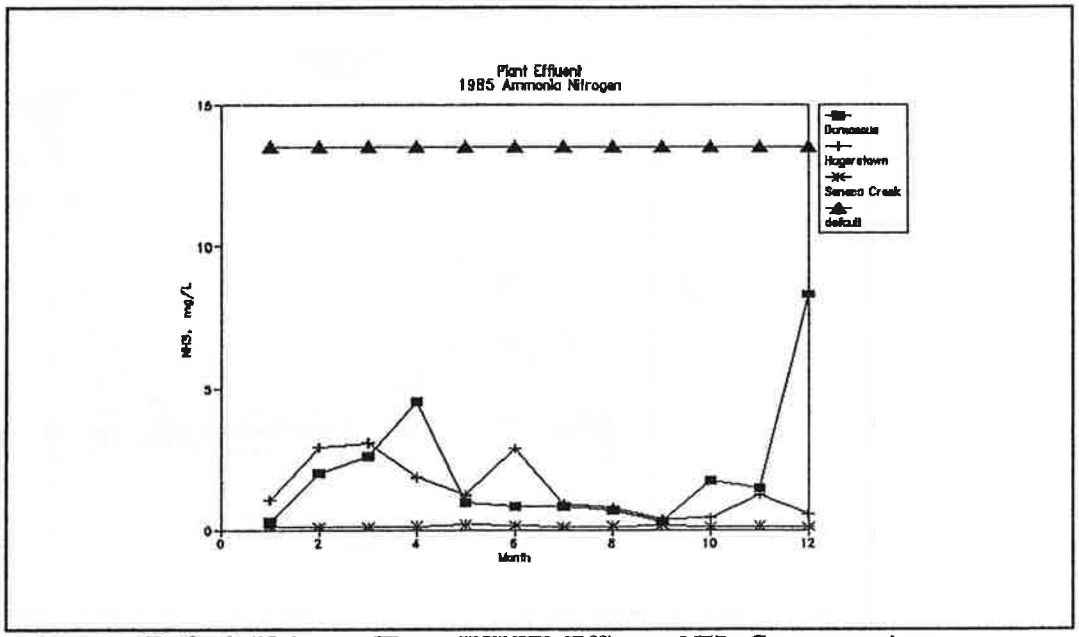

Figure 56. Default Value vs Three WWTP Effluent NH_3 Concentrations

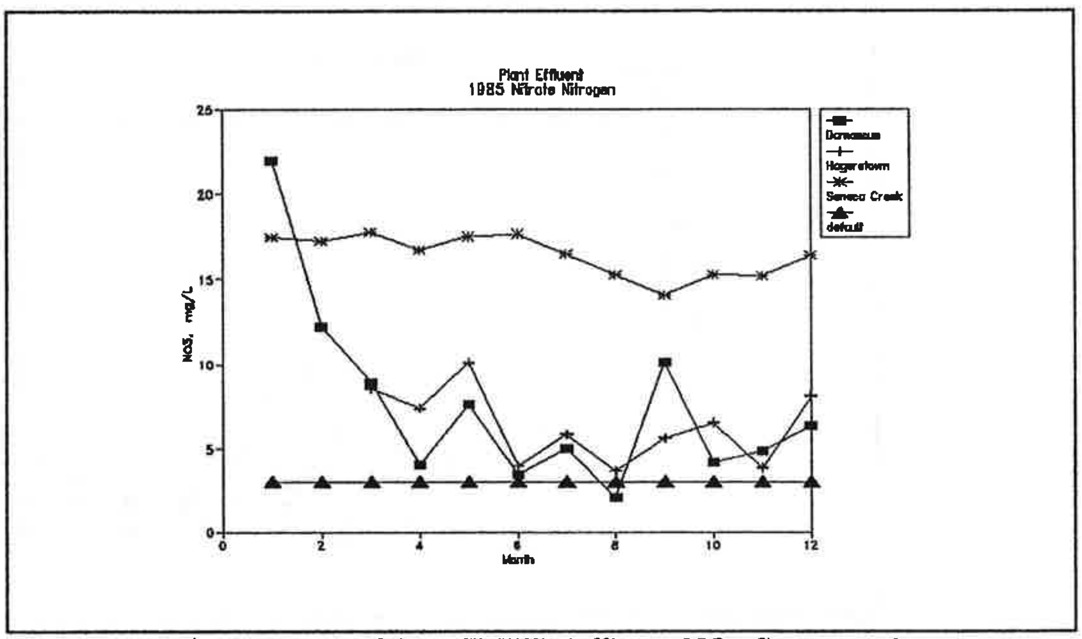

Figure 57. Default Value vs Three WWTP Effluent NO_3 Concentrations

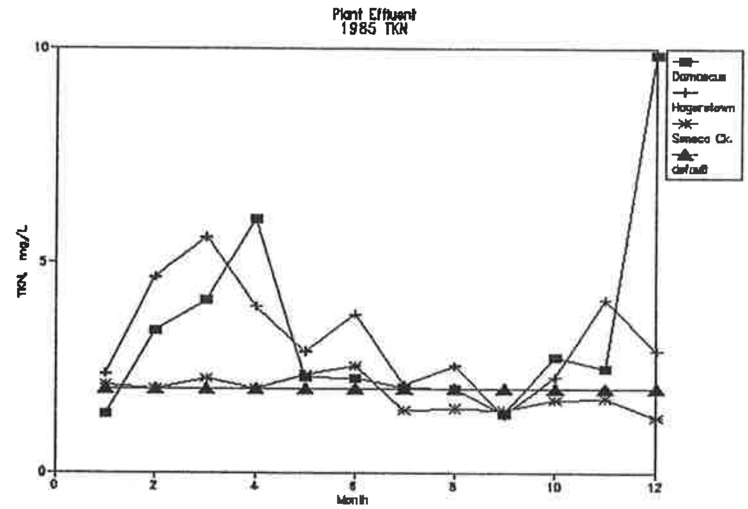

Figure 58. Default Value vs Three WWTP Effluent TKN Concentrations

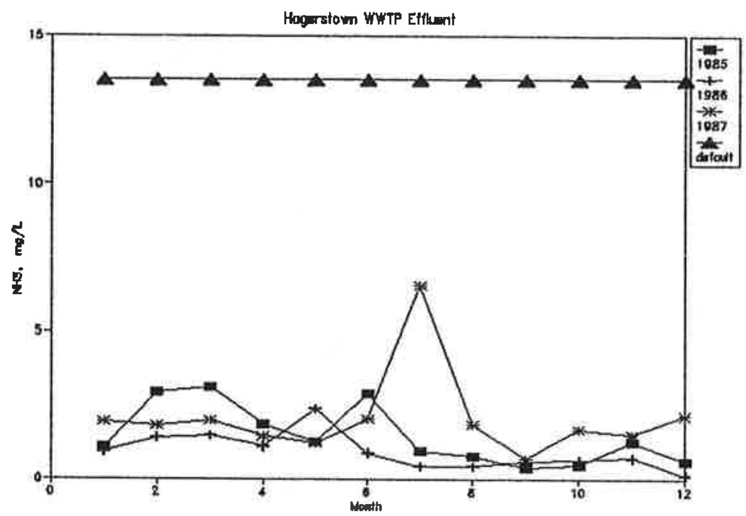

Figure 59. Hagerstown WWTP Effluent NH_3 Concentration vs Time

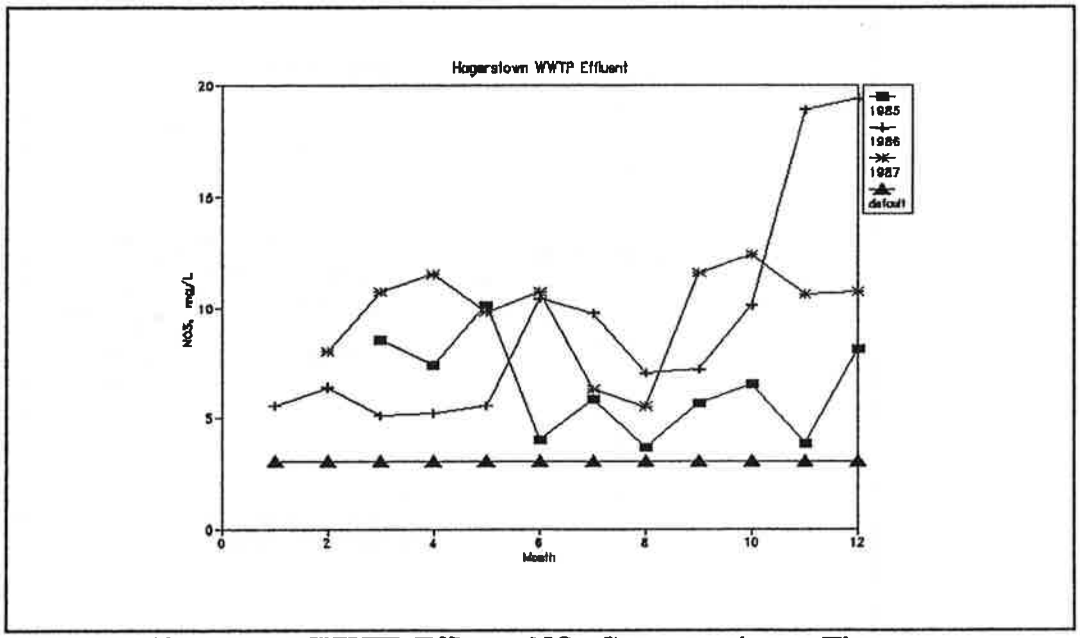

Figure 60. Hagerstown WWTP Effluent NO_3 Concentration vs Time

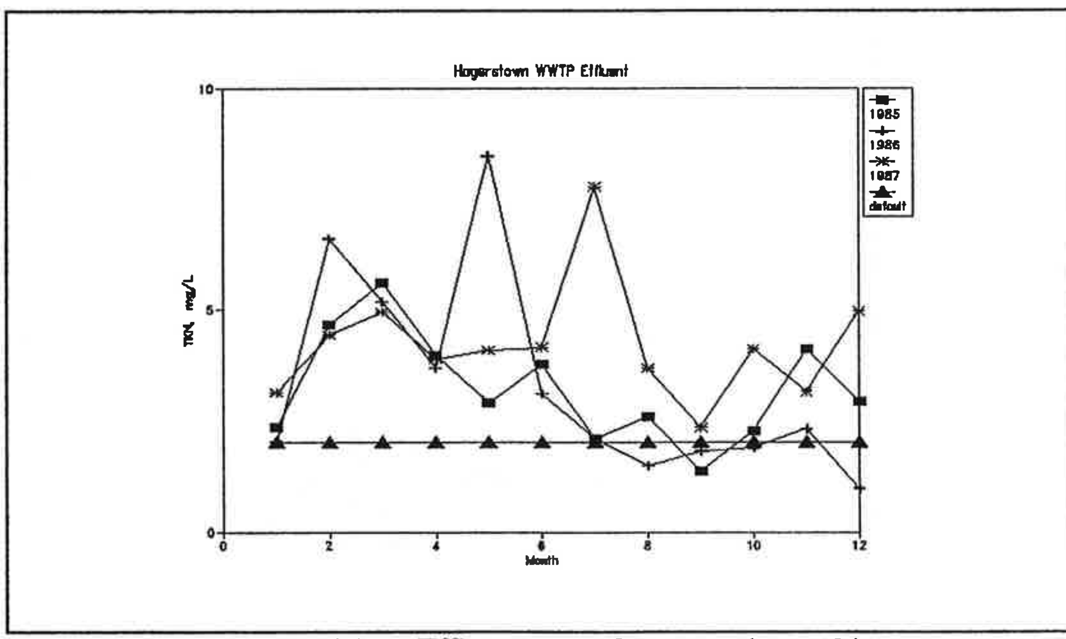

Figure 61. Hagerstown WWTP Effluent TKN Concentration vs Time

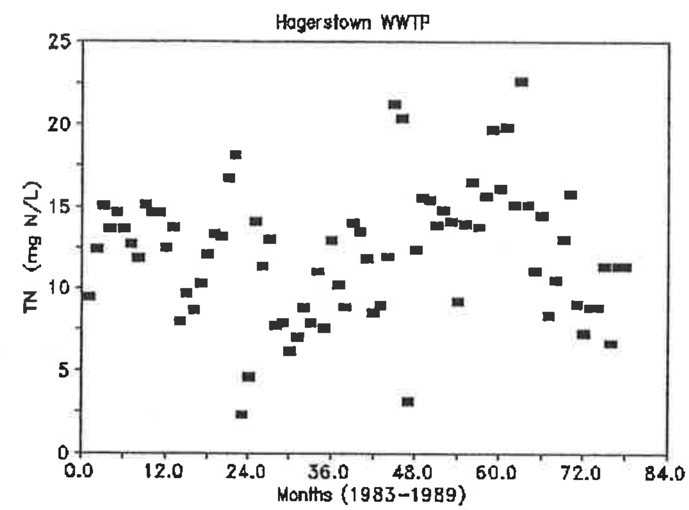

Figure 62. Hagerstown WWTP Effluent Monthly TN Concentration

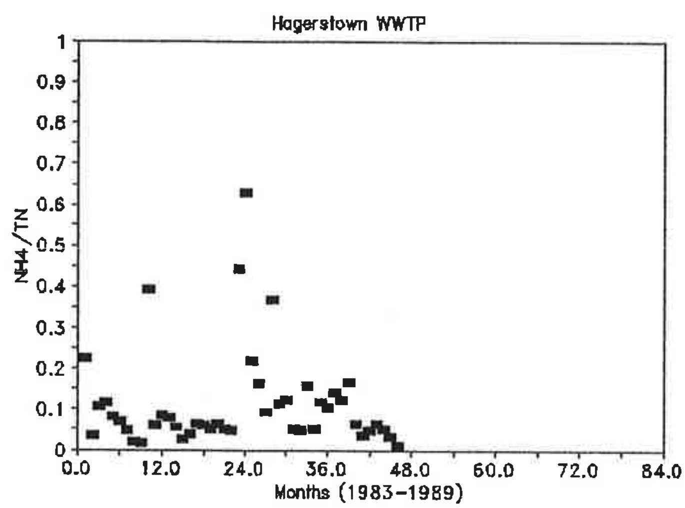

Figure 63. Hagerstown WWTP Effluent Monthly NH_4/TN Ratio

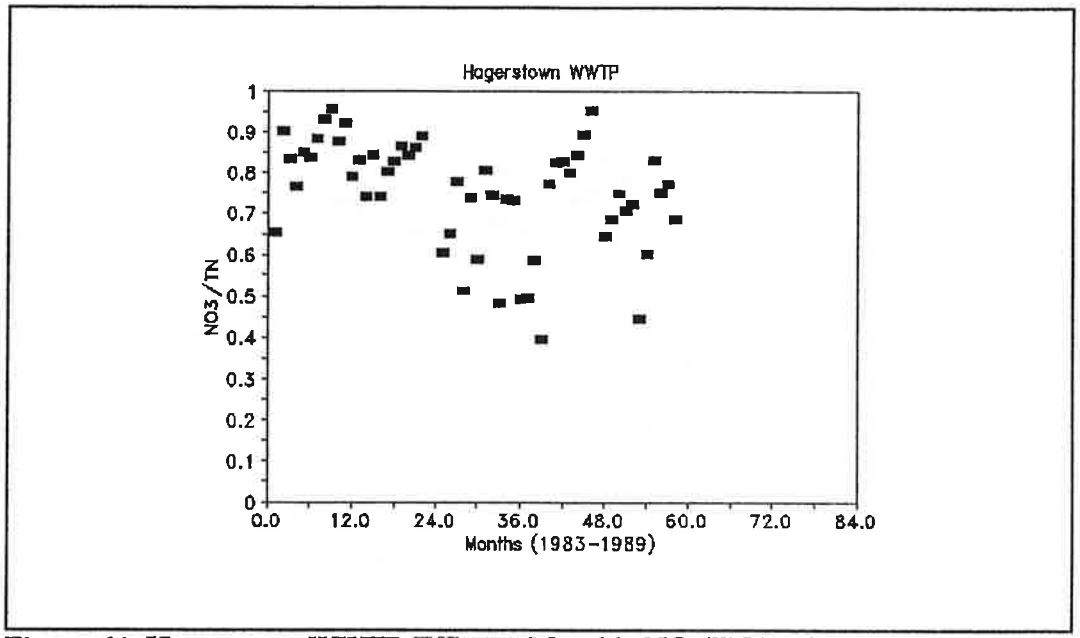

Figure 64. Hagerstown WWTP Effluent Monthly NO_3/TN Ratio

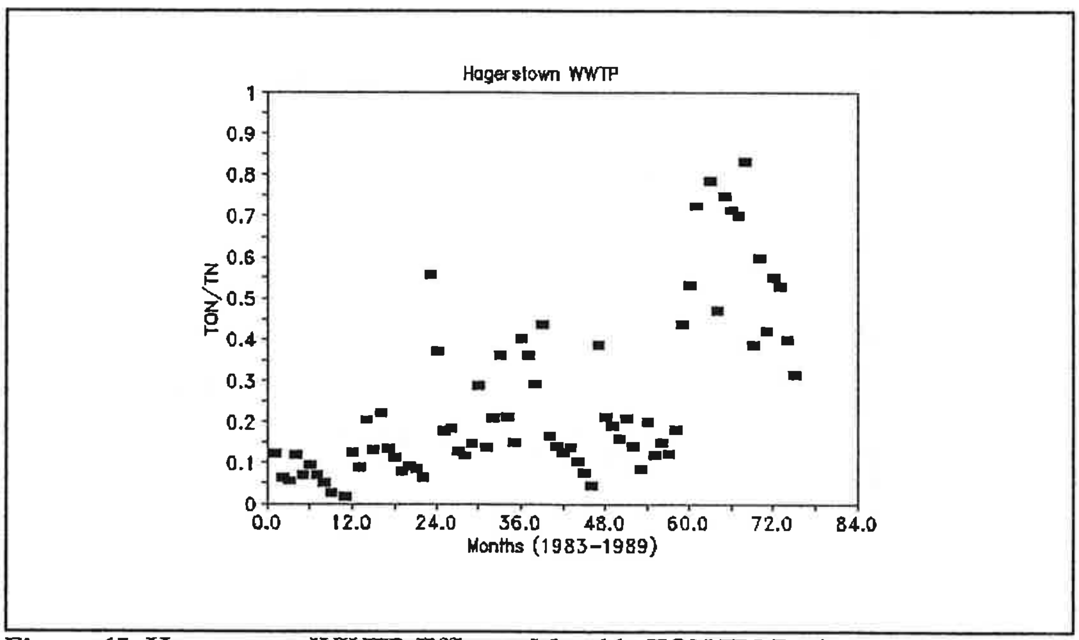

Figure 65. Hagerstown WWTP Effluent Monthly TON/TN Ratio

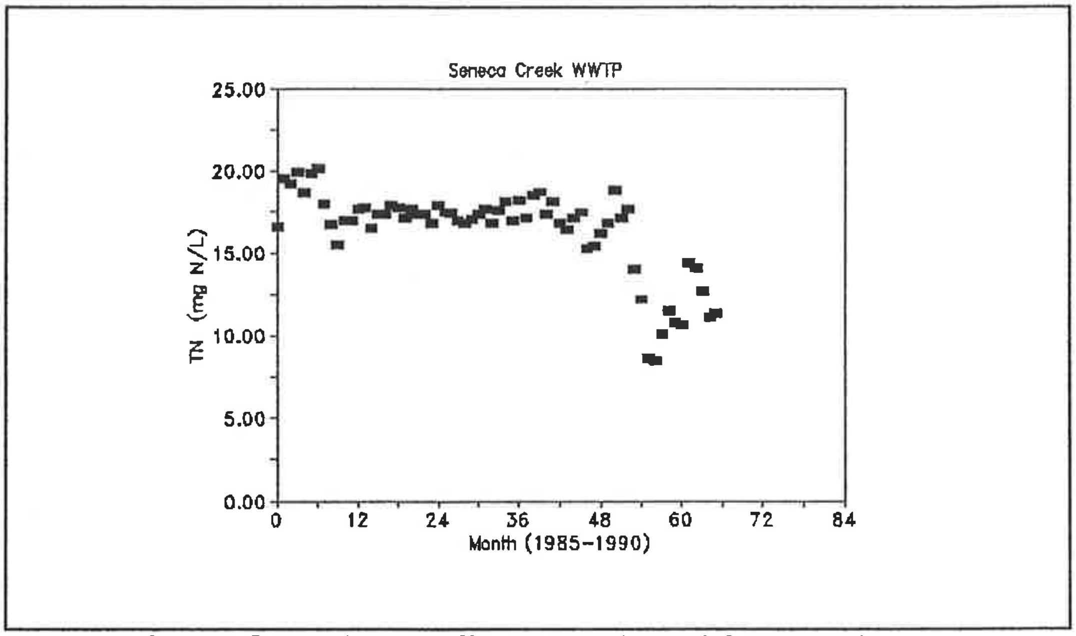

Figure 66. Seneca Creek WWTP Effluent Monthly TN Concentration

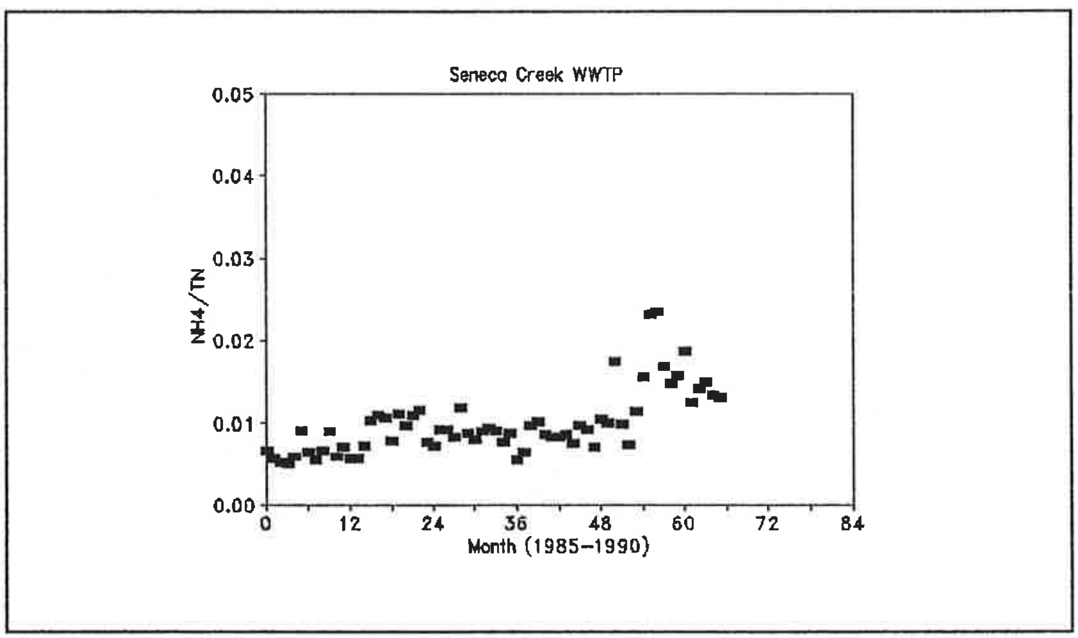

Figure 67. Seneca Creek WWTP Effluent Monthly NH_4/TN Ratio

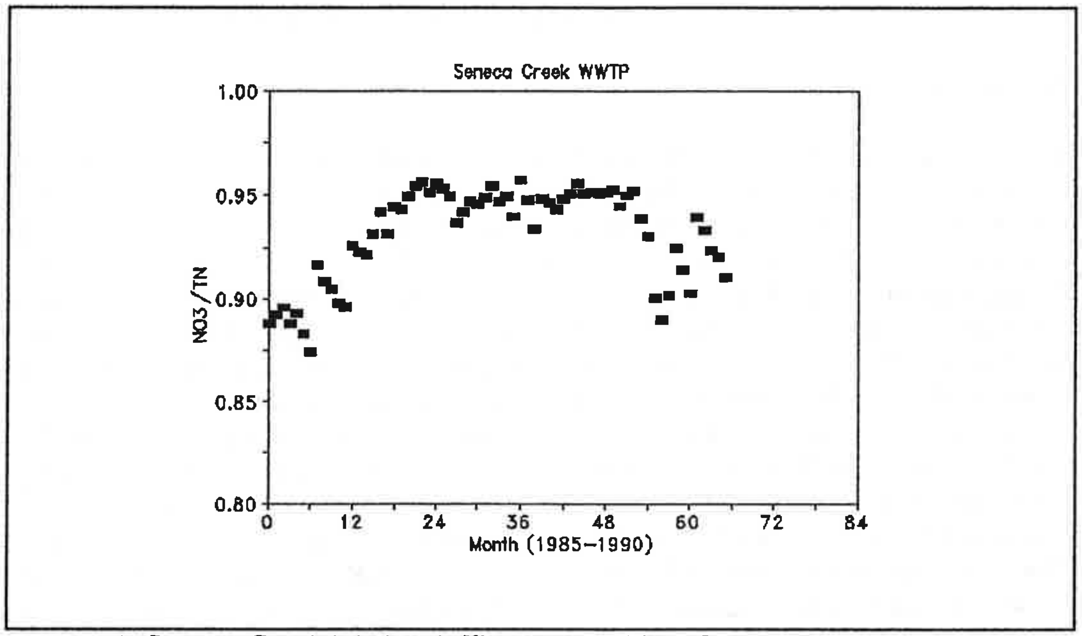

Figure 68. Seneca Creek WWTP Effluent Monthly NO_3/TN Ratio

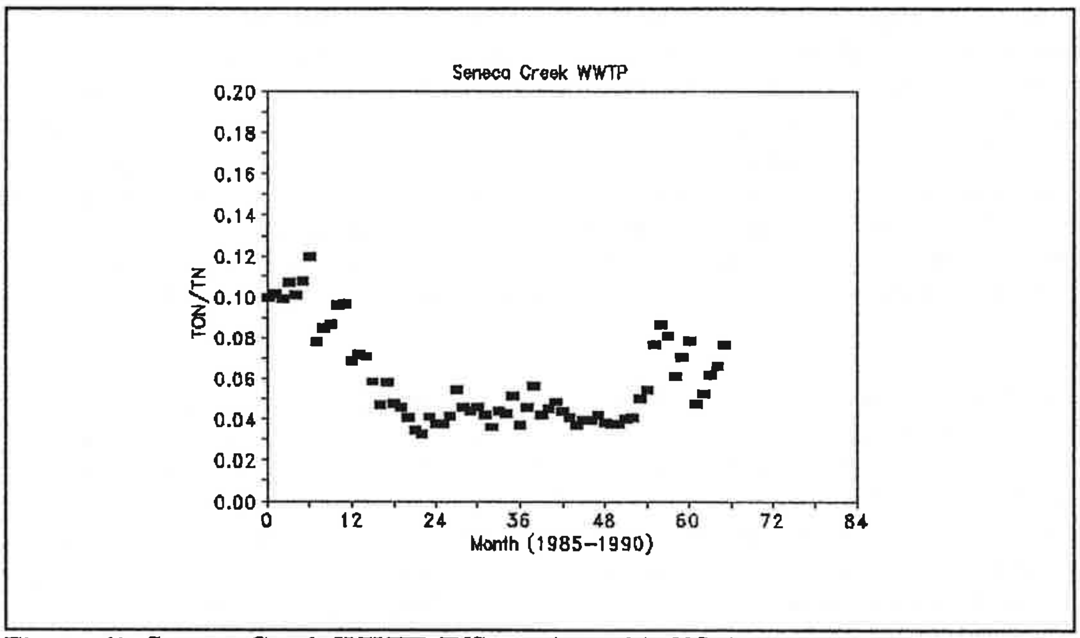

Figure 69. Seneca Creek WWTP Effluent Monthly TON/TN Ratio

Chapter 4. Nutrient Mass Balance

Introduction

The previous two chapters (Chapter 2 and 3) described the sources, quality and quantity of the nutrient data for the PRM. To assess the quality of the loadings estimated from these data, a simplified mass balance was computed for the study area. The 47 segments of the PRM were grouped into four boxes or reaches: Luke to South Branch, South Branch to Hancock, Hancock to Shepherdstown, and Shepherdstown to Chain Bridge. The four reaches were based on the distribution of the median observed total nitrogen (TN) and phosphorus (TP) concentrations along the Potomac River (Figures 2 and 3, **see Chapter 2**). As discussed in Chapter 2, there is a general trend of relatively high nutrient concentrations in the upper reach of the Potomac River (from Luke to Oldtown), followed by a decrease in the concentrations of nitrogen and phosphorus in the upper middle reach (from Oldtown to Hancock). The concentrations then increase and peak near Whites Ferry, decreasing slightly from Whites Ferry to Chain Bridge (Figure 2 and 3, Chapter 2). Hence the four reaches selected should capture the changes in the observed concentrations of total nitrogen (TN) and total phosphorus (TP) and provide an evaluation of the loads that will be used for the PRM. Throughout this discussion, TN and TP are defined as the total concentration of nitrogen and phosphorus including both particulate and dissolved forms.

TN and TP Mass Balance

To compute the mass balances in each of the four reaches, the observed TN and TP loadings from tributaries, WWTPs and industrial dischargers for summer 1985 were computed. It should be noted that tributary loadings as well as mainstem loadings are computed using observed summer (July to September) median flow and median concentrations. These concentrations are from monthly grab samples (except at Chain Bridge), and represent an instantaneous observation as discussed in chapter 2. At Chain Bridge, the data reported are a combination of grab and composite samples. A few of the tributary water quality monitoring stations are located some distance upstream from the mouth. Thus, the computed loadings are only an approximation of the loading at the mouth of the tributary. In addition, some of the water quality monitoring stations were not located near a flow gauging station. For these stations stream-flow was extrapolated using river mile-drainage area regressions.

The computed loadings from each source represent an end-of-pipe value only, and neglect sinks, such as algal consumption and subsequent deposition of particulate nitrogen and phosphorus. Other sources of nutrient loads such as unmonitored and ungauged tributaries are not included. The simplified mass balance presented here should only be used to assess the load estimate within each reach. Table 15 shows the estimated 1985 TN and TP loadings from point sources (WWTPs and industrial dischargers) and from monitored tributaries. The total loading to each reach is the sum of the point source loads, the monitored tributary loads and the "observed" loads at the upstream boundary. Using "observed" upstream loads assures that error in upstream load calculations does not propagate to downstream. For comparison, the total loads for the entire river (point sources and tributaries) from Luke to Chain Bridge were also computed. Table 16 shows the percent difference between the computed and "observed" nutrient loads, at the downstream station, for each reach. Table 17 shows the loadings from monitored tributaries. Table 18 shows the drainage areas and 1985 summer median flow, at gauging stations (mainstem and tributaries) along the river. Table 19 shows the differences in computed and reported drainage areas and flows at downstream boundary (mainstem) stations. To quantify the variability of the estimated nutrient loads, the loadings estimated from 1985 summer median flow (July to September) and 1985 summer monthly median concentration are also computed (Tables 20-21). Table 22 shows the percent difference between computed and "observed" loads (Tables 20-21) for July, August and September.

Mass Balance Assessment

Table 16 shows that the percent difference between observed and computed loads for the four reaches ranges from -25% to 47% and from 17% to 121% for TN and TP, respectively. As shown in Tables 20-21, in general, September has the lowest discharge (except at Luke), hence has the lowest loadings. In general, the TP loads were overestimated in all four river sections. The TN loads slightly underestimated the "observed" loads for the three upstream river sections. With the exception of the TP load at Oldtown, the error in the estimated loads was small compared to the variability in the monthly data. The mass balance for each of these four reaches, along with the net mass balance over the whole river, is examined in detail in the following sections.

From Luke to Oldtown

In this reach, there are three major tributaries; Georges, Wills, and Patterson Creeks, and seven "large" point source dischargers; UPRC, Keyser, Rawlings, Pinto, Cresaptown, Bowling Green and Cumberland WWTPs. As shown in Tables 15 and 17, point sources account for 52% of the TN loading and 91% of the TP loading to this reach, of which the Cumberland WWTP accounts for 68% and 75% of the TN and TP loadings, respectively. Georges Creek accounts for 40% of the TN loading and 71% of the TP loading from tributaries located in this reach (Table 17). On a monthly basis (Table 22), the computed TN loads slightly underestimated the "observed" loads in July and August and overestimated by 62% in September. On the other hand, the computed TP loads overestimated the "observed" loads by 93% to 254%. The difference between the computed and observed TP loadings at Oldtown could be related to the use of default values (7 mg/L) to compute loads for WWTPs, in particular, Cumberland WWTP. As discussed in Chapter 3, estimated WWTP loads are extremely sensitive to default effluent concentrations employed. For example, the Cumberland WWTP could have achieved lower TP effluent concentration, or have a lower TP influent load than the default values indicate. In the case of TN, the high estimate of TN loading in September could be related to the use of default values (18 mg/L) to compute loads.

The TN and TP loadings represent an end-of-pipe estimate (not delivered loads), and no internal sinks (e.g., denitrification) or sources (e.g., benthic remineralization) are considered in the mass balance. Although the flow budget (Tables 18 and 19) indicates that 45% of the flow and 43% of the drainage area at Oldtown is ungauged the estimated loads to this reach do not account for the discharge and associated nutrients from either ungauged tributaries or surface runoff. Sinks such as algal uptake of dissolved nitrogen or phosphorus and the subsequent deposition of particulate nitrogen or phosphorus are similarly not considered. Despite the significant variation in Oldtown's monthly median load computed shown in Table 20, the overall mass balance for TN is judged to be quite good. The consistent overestimate of TP load is significant and seems to be related to the use of a TP default value for the major point sources in this section of the river.

From Oldtown to Hancock

The only large point source in this reach is the Paw Paw WWTP. The major tributaries are the South Branch Potomac River and the Cacapon River. Other ungauged smaller tributaries include Town Creek, Little Cacapon River, 15 Mile Creek, and Sideling Hill Creek plus several even smaller tributaries. As shown in Table 15, the major nutrient loadings are the upstream boundary input at Oldtown which accounted for 88% of the TN loading and 87% of the TP loading. The discharge from the South Branch accounted for 31% of the total discharge at Hancock (Table 17), yet it accounted for only 11% of the TN loading and 12% of the TP loading to the reach. This is consistent with the discussion in Chapter 2, indicating that nutrient concentrations in the South Branch are significantly lower than those of the mainstem Potomac. A flow budget (Table 18-19) indicates that 2% of the flow and 33% of the drainage area are not accounted for at Hancock. Table 22 shows the differences between computed and "observed" nutrient loads for July, August, and September. The computed TN inputs overestimated the "observed" loads by 47% and 23% in July and August, respectively, while underestimating the load in September (Table 22). Monthly TP loads were overestimated by 19% to 127% Since the observed Oldtown inputs account for nearly 90% of the nutrient inputs to this reach, the overestimation of the TN and TP loadings at Hancock are most likely related to advective, and biological, processes, such as algal uptake and deposition of particulate matter, which are not considered in the mass balance. The overall error in the mass balance from Oldtown to Hancock is not significant compared to the variation in the monthly data. The loads estimated within this reach appear to be reasonable and consistent with observed monitoring data.

Table 15. Computed TN and TP loadings from WWTP and Industrial dischargers

Reach	TN lbs/d	TP lbs/d
Luke to Oldtown		
Luke (observed)	1849	52
Point Sources	2202	777
Tributaries	217	24
Total	4268	853
Oldtown to Hancock		
Oldtown (observed)	4150	386
Point Sources	14	6
Tributaries	533	53
Total	4697	445
Hancock to Shepherdstown		
Hancock (observed)	5100	380
Point Sources	192	41
Tributaries	2770	292
Total	8062	712
Shepherdstown to Chain Bridge		
Shepherdstown (observed)	10721	596
Point Sources	1255	274
Tributaries	10829	1075
Total	22804	1944
Chain Bridge (observed)	15470	1350
Net Total (from Luke to Chain Bridge)	19860	2593

Table 16. Percent Difference Between Computed and Observed N an P Loadings.

Station	Percent Difference	
	TN	TP
Oldtown	- 3	+ 121
Hancock	- 8	+ 17
Shepherdstown	- 25	+ 20
Chain Bridge	+ 47	+ 44
Net at Chain Bridge	+ 22	+ 92

Table 17. TN and TP Loadings From Monitored Mainstem Tributaries

Tributary/Mainstem	Q MGD	TN lbs/d	TP lbs/d
Georges Creek	7	87	17
Wills Creek	30	130	7
South Branch Potomac	196	533	53
Conococheague Creek	83	2279	193
Opequon Creek	37	491	98
Antietam Creek	87	3558	255
Shenandoah River	426	3911	427
Catoctin Creek, MD	10	99	26
Catoctin Creek, VA	10	45	8
Monocacy River	98	2217	287
Goose Creek	3	120	16
Seneca Creek	20	878	57
Luke	207	1849	52
Oldtown	440	4150	386
Hancock	650	5100	380
Shepherdstown	892	10721	596
Chain Bridge	1470	15464	1350

Table 18. Drainage Area and Flow at the Gaging Station

Gaging Station	Drainage Area mi^2	Flow MGD
Luke to Oldtown		
Luke	404	207
Georges Creek	72	7
Wills Creek	247	30
Total	723	243
Oldtown to Hancock		
Oldtown	* 1274	** 440
South Branch	1471	196
Total	2745	636
Hancock to Shepherdstown		
Hancock	4073	650
Conococheague Creek	494	83
Opequon Creek	272	37
Total	4839	770
Shepherdstown to Chain Bridge		
Shepherdstown	5936	892
Antietam Creek	281	87
Shenandoah River	3040	426
Catoctin Creek, MD	67	10
Catoctin Creek, VA	90	10
Monocacy River	817	98
Goose Creek	332	3
Seneca Creek	101	20
Total	10664	1546
Chain Bridge	11570	1470

* estimated by river mile-drainage area regression
** estimated from discharge at Paw Paw and South Branch

Table 19. Percent difference of Drainage Area and Flow at Mainstem Station

Station	Percent Difference	
	Drainage Area	Flow
Oldtown	- 43	- 45
Hancock	- 33	- 2
Shepherdstown	- 19	- 14
Chain Bridge	- 8	+ 5

\- denotes unaccounted for area or flow
\+ denotes loss of flow

Table 20. Mainstem 1985 Summer Monthly Median Flow and Median Nutrient Loads

Mainstem Station	Month	Q MGD	TN lbs/d	TP lbs/d
Luke	July	298	2612	174
	August	191	1212	96
	September	207	1866	35
Oldtown	July	543	6345	544
	August	429	3867	430
	September	310	2588	233
Hancock	July	821	5962	274
	August	672	4151	393
	September	406	3626	237
Shepherdstown	July	1183	20440	790
	August	963	10289	804
	September	598	6788	449
Chain Bridge	July	1642	17543	1507
	August	1609	20817	1813
	September	1018	10876	935

Table 21. Tributary 1985 Summer Monthly Median Flow and Median Nutrient Loads

Tributary	Month	Q MGD	TN lb/d	TP lb/d
Georges Creek	July	13.6	149.5	30.6
	August	7.1	131.1	17.2
	September	3.9	45.6	8.1
Wills Creek	July	60.1	702.1	35.1
	August	29.7	148.8	7.4
	September	15.5	66.0	3.9
South Branch Potomac *	July	264.9	1437.0	44.2
	August	217.1	1177.7	54.4
	September	91.1	494.2	38.0
Conococheague Creek	July	89.2	3162.5	163.7
	August	87.2	2030.9	211.1
	September	66.5	1821.7	155.5
Opequon Creek *	July	56.8	759.2	151.8
	August	36.18	483.1	96.6
	September	29.72	396.9	79.4
Antietam Creek	July	95.0	4161.4	277.4
	August	91.1	3071.6	266.1
	September	71.1	3458.0	355.9
Shenandoah River *	July	453.5	3028.4	605.6
	August	430.2	10163.0	610.5
	September	366.28	2751.6	366.9
Catoctin Creek, MD	July	10.3	148.4	41.4
	August	14.2	204.0	56.9
	September	5.8	32.0	7.3
Catoctin Creek, VA	July	16.7	75.4	14.0
	August	6.1	27.9	5.1

Tributary	Month	Q MGD	TN lb/d	TP lb/d
	September	3.3	15.1	2.7
Monocacy River	July	102.1	2061.7	298.2
	August	107.4	2488.4	223.8
	September	80.1	1805.3	300.9
Goose Creek	July	7.8	259.5	32.4
	August	3.2	128.9	16.2
	September	0.7	30.0	3.8
Seneca Creek	July	25.2	1017.8	48.4
	August	20.0	880.9	56.8
	September	14.2	682.1	42.7

From Hancock to Shepherdstown

There are two major tributaries in this reach, Conococheague and Opequon Creeks. In addition, two large point sources, the Hancock WWTP and W.D. Byron, discharge directly to the Potomac. In addition, there are two dams located within the reach; Dam #5 located upstream from Conococheague Creek and Dam #4 located downstream from Opequon Creek. As shown in Table 16, the computed TN load underestimated the "observed" load, while the computed TP load overestimated the "observed" load at Shepherdstown. Table 15 shows that tributaries account for only 34% of the TN load and 41% of the TP load, with Conococheague Creek accounting for 82% and 66% of the tributary TN and TP loads, respectively. The nutrient inputs "observed" at Hancock account for 63% and 53% of the TN and TP loads calculated at Shepherdstown. The combined flows from Conococheague and Opequon Creeks account for only 50% of the increase in flow from Hancock to Shepherdstown. A flow budget (Table 18-19) indicates that 19% of the drainage area and 14% of the discharge at Shepherdstown are not accounted for. The combined municipal diversions (e.g., Williamsport, Hagerstown and Halfway) were not included in the mass balance calculation. The backwater created behind Dams #4 and #5 should result in longer residence times in this section of the river, contributing to biological uptake and enhanced settling of particulate material under low flow conditions. In some areas of this reach, extensive macrophyte growth has been observed in slack water pools. This observation suggests that conditions support biological uptake that may be represented in PRM as chlorophyll a concentrations substantially higher than those observed in monthly monitoring data.

Table 22 shows the percent difference between computed and "observed" nutrient loads for July, August, and September. The computed TN load consistently underestimated the observed load at Shepherdstown, although the error of only 9% in September cannot be considered a significant difference. The monthly TP load estimates were all within 20% of the observed load. Overall the mass balance calculated at Shepherdstown was acceptable considering the variability of the inputs. The magnitude of the error in the mass balance is small compared to the variation in the monthly data. The nutrient inputs estimated within this reach are judged to be reasonable for PRM and consistent with observed monitoring data, although non-point sources of nitrogen may need to be considered at higher flow levels.

From Shepherdstown to Chain Bridge

In this reach three major tributaries , Antietam Creek, Shenandoah River, and Monocacy River, and two large point sources, Brunswick and Shepherdstown WWTPs, discharge to the mainstem Potomac River. In addition, three dams are located within the reach: Pleasantville Dam, Great Falls Dam, and Little Falls Dam. The three major tributaries accounted for 42% of the total flow, 42% of the TN, and 50% of the TP loads at Chain Bridge. The "observed" load at Shepherdstown accounts for 47% of the TN and 31% of the TP observed at Chain Bridge. A flow budget at Chain Bridge (Table 18-19) showed that there is a net loss (about 75 MGD) of flow between Shepherdstown and Chain Bridge. It should be noted that the flow budget did not account for the drinking water diversions within the reach which could withdraw over 400 MGD from the river.

The mass balance overestimates both TN and TP observed at Chain Bridge by about 45%. The observed tributary loads account for more than half of the input to the reach, suggesting the overestimate is more likely due to physical and kinetic processes that are not accounted for in the mass balance, rather than the use of default nutrient concentrations in estimating point source inputs.

While the TN tributary input for this reach is roughly equal to the upstream input at Shepherdstown, it should be noted that on a flow adjusted basis, the TN contributions of Goose Creek and Seneca Creek are significantly higher than the load from the Monocacy.

Nutrient loss through water supply withdrawals are similarly not considered in the mass balance. The significance of water supply withdrawals is suggested in Table 19. In sharp contrast to the other three reaches, Chain Bridge shows a net loss of streamflow, despite the contribution of ungauged drainage areas. Considering the variation in the observed Chain Bridge data, as well as the magnitude of water supply withdrawals, the 45% difference between estimated inputs and the observed load at Chain Bridge is not unreasonable.

The TN and TP load estimates are judged to be reasonable inputs for PRM. The mass balance indicates that accounting for nutrient kinetics, algal uptake and water supply withdrawals in PRM will be especially important for this section of the river.

Net Mass Balance

The net mass balance from Luke to Chain Bridge is calculated as the sum of the observed load at Luke plus all of the point source and tributary loads that will be input to PRM. The results summarized in Table 15 and Table 16 show that the calculated nutrient inputs exceed the "observed" load at Chain Bridge. The difference in TN load is small compared to the observed variation in the Chain Bridge data. Considering the mass balance for each of the reaches, it is clear that the relatively small difference in the TN mass balance masks the longitudinal variation of nutrient inputs and losses, emphasizing the value of the finer spatial resolution used in the PRM segmentation.

The difference between the estimated and observed TP load at Chain Bridge indicates that even without diffuse non-point sources inputs, point source and monitored tributary inputs overestimate the observed load at Chain Bridge by nearly a factor of 2. This difference similarly emphasizes the importance of the physical and biological processes included in PRM in accurately accounting for the transport and transformation of nutrient inputs to the mainstem Potomac River.

Summary and Discussion

It should be kept in mind that this exercise is intended to provide an assessment of the quality and completeness of the estimated nutrient loads for the PRM. The flow and nutrient loading from unmonitored tributaries, ungauged drainage areas and drinking water diversions were not considered. A segment-by-segment mass balance could provide a better picture of the sources and magnitude of the unaccounted flow and nutrient loads.

The errors in the mass balance calculation must be judged in comparison to the overall variation in the observed data. To quantify this relative error, the relative standard deviation (RSD) was calculated for the monthly data in Table 20. The RSD presented in Table 23 expresses the standard deviation of the monthly loads as a percentage of the mean. Overall, the RSD varied from 20% to 65% for both TN and TP loadings. The quality of the nutrient inputs that have been developed for PRM can be evaluated by comparing the RSD calculated in Table 23 to the differences in the mass balance in Table 16. The values in Table 23 can also be considered as a first estimate of the range of variability that can be expected in PRM results, based on the variation in the available calibration data. For example, considerable variation can be expected between daily observations and the monthly grab samples that are available at most monitoring sites throughout the basin.

The mass balance for most of the reaches is quite reasonable. The magnitude of most of the differences is generally consistent with the range of variation in the monthly data. Estimated TP inputs are consistently greater than the observed downstream values suggesting the importance of particulate transport and settling which was not considered in the mass balance. The TP overestimate at Oldtown appears to be significant. Since the point source inputs to this reach are so large, the point source default effluent concentration used for TP should be reexamined. Although the difference in the TN mass balance at Shepherdstown is small compared to the variation observed in Shepherdstown monitoring data, the low estimate of TN suggests that additional TN sources need to be considered in PRM. The monthly observations indicate that the underestimation of TN is most significant for discharges over 1,000 MGD. For the September low flows, the error in the TN mass balance is less than 10%.

With the possible exception of Shepherdstown TN at higher flows, diffuse non-point sources do not appear to provide significant nutrient inputs under the summer flow conditions considered here. The largest tributary nutrient loads are provided by the Shenandoah, Antietam Creek, the Conococheague, and the Monocacy, in order of TN load. Despite their smaller drainage areas, Seneca Creek, Goose Creek, the Antietam and the Conococheague contributed a disproportionate share of the summer 1985 mainstem nutrient load on a flow adjusted basis.

In conclusion, the mass balance indicates that the PRM nutrient inputs appear to be reasonable and complete. Two areas that require further examination are point source TP inputs on the North Branch, and non-point source TN inputs between Hancock and Shepherdstown under higher flow conditions. In order to provide the detailed description of Potomac River water quality necessary for permitting and management decisions, the finer spatial resolution, including the representation of physical and biological processes and transformations of the PRM will be required.

Table 23. Percent Relative Standard Derivation (%RSD)

Mainstem Station	%RSD (mean±std)	
	TN	TP
Luke	37% (1897±700)	69% (102±70)
Oldtown	44% (4267±1878)	39% (402±157)
Hancock	26% (4580±1168)	27% (301±82)
Shepherdstown	55% (12506±6826)	30% (681±201)
Chain Bridge	31% (16412±5667)	32% (1413±445)

Chapter 5. Derived Nutrient Systems

Introduction

The forms of nitrogen and phosphorus that the model requires for input are listed in Table 2 (**see Chapter 2**). Also shown are nutrient ratios that are specified in input files and are used by the model to partition nutrients into dissolved and particulate organic and inorganic fractions. Some of the required nutrient forms are not routinely monitored and therefore the observed data must be transformed.

This section describes how nutrient data, both for water quality monitoring stations and point sources, were transformed to PRM state variables. For example, the PRM program needs, as a data input, the concentration or loading of total ammonium (dissolved+particulate) as well as the ratio of dissolved ammonium to total ammonium. This enables the PRM to distinguish between a pool of ammonium that is available for algal growth and a pool of ammonium that is bound to particulate material and unavailable for algal growth. These transformations were derived from limited observations at various stations along the Potomac River over the past ten years and published information.

Nutrient Forms

The PRM requires the concentrations of the different chemical forms of inorganic and organic nitrogen and phosphorus. Along with these concentrations, the ratios between dissolved and total inorganic and organic nitrogen and phosphorus must be specified (Table 2; **see Chapter 2**).

Data provided by the Maryland Department of the Environment (MDE) and obtained through STORET (used for VA, WV USGS stations) provide a reasonable data base for the concentrations of the major **dissolved** chemical forms of nitrogen and phosphorus for the tributaries and mainstem of the Potomac River (**see Water Quality Section; Chapter 2**). These forms include dissolved ammonium, nitrate and orthophosphate as well as total phosphorus, nitrogen and kjeldahl nitrogen (total kjeldahl nitrogen = total organic nitrogen + total ammonium; Table 2). Chemical forms such as total ammonium, total nitrate, dissolved organic nitrogen and total inorganic and organic phosphorus are rarely determined. For example, the water quality monitoring station (WQMS) at Chain Bridge (Sta. ID: 01646580) has approximately 350 observations for the major nutrient forms from 1983 to 1989 (OWML, 1990). While this is one of the most thorough data sets, it does not contain the concentrations of total ammonium (dissolved+particulate), total dissolved phosphorus or particulate phosphorus (either particulate inorganic or organic forms). However, the Chain Bridge data set does contain a six year record of the concentrations of DON and TON. Also, assuming that particulate inorganic phosphorus (PIP) is equal to zero (Thomann and Fitzpatrick, 1982), DOP and TOP can also be derived from the Chain Bridge data set. The WQMS at Shepherdstown (Sta. ID: POT1830), has limited data for total and dissolved organic nitrogen (5 matching observations between 1980 and 1981) and dissolved and total ammonium data (17 matching observations between 1980 and 1989). Information from water quality monitoring stations that contain sufficient data was used to determine the missing chemical forms of nitrogen and phosphorus. Factors were derived and applied to stations that do not report data needed for the PRM (Tables 2 and 24).

Wastewater treatment plants (WWTPs) usually do not determine or report the effluent concentrations of the different forms of nitrogen and phosphorus, although some may report TP, TN or TKN. This is especially true for pre-1988 WWTP data (Dobler, 1990;). Once the concentrations of nitrogen and phosphorus, and their chemical forms, are specified (**see Chapter 3 for details**), the ratio of dissolved to total (Tables 2 and 24) nitrogen and phosphorus can be determined.

Wastewater Treatment Plants

Data pertaining to the effluent concentrations of the different forms of nitrogen and phosphorus have been obtained and compiled from various wastewater treatment plants that discharge to the Potomac River or its tributaries and literature values. These plants (**described in Chapter 3**) encompass a variety of treatment processes (i.e., activated sludge, trickling filtration and oxidation ditch) which make any generalities between plants tenuous at best. Unfortunately, not all wastewater treatment plants determine or report the concentrations of the different forms of nitrogen or phosphorus. In fact, many wastewater treatment plants do not report any nitrogen or phosphorus concentrations at all. Certain wastewater treatment plants, usually the smaller ones ($<<1$ mgd), report only ammonium and/or TKN concentrations; without the concentrations of nitrate, total nitrogen (TN) can not be calculated. Similarly, many WWTP report only TP concentrations and do not determine the concentration of dissolved phosphate or total dissolved phosphorus. To estimate effluent concentrations for nitrogen and phosphorus and their different chemical forms, WWTPs that do not report TN and/or TP are assigned concentrations based on specific criteria (**see Chapter 3**). Once the plant has been assigned effluent concentrations for the different chemical forms of nitrogen and phosphorus they must be broken into dissolved and total fractions (Tables 2).

As shown in Table 2, the total concentration as well as the dissolved to total ratio need to be specified both for both nitrogen and phosphorus. Since no data exist as to the dissolved to total ratio in WWTP effluents, certain assumptions are made. For phosphorus, it was assumed that particulate inorganic phosphorus (PIP) is zero (Thomann and Fitzpatrick, 1982). This means that all of the inorganic phosphorus is in the dissolved form (i.e., total inorganic phosphorus (TIP) is equal to dissolved inorganic phosphorus (DIP)). A second assumption, due to a lack of data from WWTP's, was that the average ratio of dissolved organic phosphorus (DOP) to total organic phosphorus (TOP) from water quality stations is similar to the effluent of WWTP's. To determine this ratio, the average ratio between DOP and TOP from water quality data taken at the Chain Bridge (Table 24; OWML, 1990) was calculated to be 0.37. With these assumptions, the phosphorus data were estimated as follows:

PIP = 0 (assumption), so
TIP = DIP,
DOP = 0.37 x TOP.

In estimating the dissolved to total ratios for nitrogen, certain assumptions were also made. As with phosphorus, there are no dissolved and total data from WWTP's. Therefore, in stream water quality data were used to estimate the ratio of dissolved to total nitrogen (Tables 2 and 24). The average ratio of dissolved ammonium to total ammonium for all locations is 0.90, while the ratio of dissolved to total organic nitrogen is, on average, 0.60 (Tables 24). It was assumed that all the nitrate is in the dissolved form (i.e., particulate nitrate is zero). In summary:

PNO_3^- = 0 (assumption), therefore:
$DNO_3^- = TNO_3^-$
$DNH_4^+ = 0.90 \times TNH_4^+$
DON = 0.60 x TON.

From the above relationships, the dissolved to total ratio (Table 2) for WWTP's of the PRM can be obtained.

Water Quality Monitoring Stations

Most Maryland water quality stations, in conjunction with the STORET database, provide sufficient nutrient concentration data for the different chemical forms of dissolved nitrogen and phosphorus as well as TP, TN and TKN. Except for the organic forms of phosphorus (i.e., DOP or POP), particulate inorganic phosphorus (PIP) and dissolved organic nitrogen (DON), most nitrogen and phosphorus forms are determined directly (i.e., direct chemical analysis) or can be calculated directly (e.g., TON = TKN-NH_4^+). These chemical forms include dissolved ammonium, nitrate, phosphate, TKN, TON, TP, and TN. These chemical forms still need to be broken down into dissolved and total fractions for input to the model (Tables 2 and 24).

Table 24 lists the concentration ratios for ammonium, organic nitrogen and phosphorus from stations located on the Potomac River. These ratios were obtained from the STORET database and the Occoquan Watershed Monitoring Laboratory (OWML) for Chain Bridge. The Chain Bridge data base (OWML, 1990), provides the most thorough temporal record of the ambient nutrient levels in the Potomac River. From the STORET and OWML data bases, the average ratios between DON and TON, between DOP and TOP (again, assuming PIP = 0) and dissolved ammonium and total ammonium were calculated (Tables 2 and 24). These ratios were applied to both MDE and STORET data bases when needed. For example, a DOP/TOP six-year average of 0.37 for Chain Bridge was calculated. Overall, the phosphorus data were estimated with assumptions similar to those used for WWTP's and are as follows:

PIP = 0 (assumption), therefore:
TIP = DIP
DOP = 0.37 x TOP.

For the nitrogen system, similar assumptions were made as for the WWTP's. However, the MDE data set and some STORET data reported TKN concentrations. Therefore, total ammonium, calculated from the relationship given below, needed to be subtracted from TKN to obtain TON (i.e., TON = TKN - TNH_4^+). The following relationships were used to calculate the various missing forms of the nitrogen system:

PNO_3^- = 0 (assumption), therefore:
DNO_3^- = TNO_3^-,
DON = 0.6 x TON,
TNH_4^+ = 1.11 x DNH_4^+, therefore,
TON = TKN-TNH_4^+

From the above relationships, the input data for the nitrogen and phosphorus systems from water quality stations were obtained for the PRM.

Limitations and Implications of Nutrient Transformations

In using these ratios certain assumptions and caveats must be mentioned and understood. First, in assuming that PIP and particulate nitrate are zero, all nitrate and inorganic phosphorus will be available for algal uptake. The concentration of particulate nitrate is most likely small because most salts of nitrate are soluble. In fact Hickman (1986) reported that the ratio of dissolved nitrate to total nitrate was 1 for three tributaries of the Potomac River. Also, various researchers have shown that a certain, amount of inorganic phosphorus is in the particulate form (Froelich et al., 1982; Fox et al., 1985; Froelich, 1988). These forms could be either phosphorus adsorbed to iron oxides or as the mineral phase apatite.

Froelich (1988) estimated that approximately 90% of the TP carried by rivers is associated with suspended solids, some fraction of which is "desorbable" and thus potentially bioavailable. Using an average concentration of sorbed P of 0.15 mg P/g (particulate material), Froelich (1988) estimated a global average particulate reactive phosphorus concentration of 0.06 mg/l (or 15% of the TP). This concentration is a global average and large differences can be expected from one river system to another. As part of the calibration and verification of the Potomac estuary model, Thomann and Fitzpatrick (1982), derived the amount of PIP using limited field data taken at Chain Bridge. The calculated data along with the field data indicated that between 2 and 8% of the total phosphorus (TP) is as PIP. Although these data show that some fraction of TP exists as sorbed P, it is unclear as to how and to what extent the phosphorus "buffering" mechanism would affect the concentration of dissolved phosphorus in the Potomac River system. Complex interactions between pH, concentration of dissolved and particulate phosphorus, suspended sediment type and concentrations and exchange kinetics all must be accounted for in a more realistic phosphorus model. Overall, the assumptions that PIP and particulate nitrate are zero would yield a maximum amount of inorganic phosphorus and nitrogen available for algal uptake.

Second, constant dissolved to total nutrient ratios imply that all the WWTP's operate by similar processes and do not allow for process changes overtime at specific plants. While most WWTP's use secondary treatment, not all will have the same efficiencies and variations over time can be expected. Given the many assumptions required to develop point source nutrient loads, including partitioning of nutrients, the model input loads can be expected to only approximate point source loads. The effect of these assumptions is somewhat mitigated by the small portion of the total input derived from the point sources in most segments.

Third, the ratios could change at different points along the river due to various hydrologic and biogeochemical processes. For example, the DON/TON value varies significantly at Chain Bridge (Figure 70). For flow less than 5000 cfs, which is closer to the base flow of the Potomac River, no relationship exists between DON/TON and either flow or season. Figure 70 suggests a possible relationship between DON/TON and flow at flows greater than 50000 cfs at Chain Bridge. However, Hickman (1986) showed that the ratio of dissolved to total concentration of organic nitrogen (and ammonium) was not significantly correlated with either suspended sediment or flow in three urban tributaries of the Potomac River. More research needs to be done to investigate nutrient-flow dynamics in the Potomac River. Overall, the dissolved form of organic nitrogen accounted for between 0.5 and 0.8 of the total organic nitrogen. Using an average ratio of 0.67, neglects any flow or suspended sediment variations. Therefore, the use of one ratio as a system parameter for the entire PRM might hinder data interpretations. With extensive calibration and verification of the model, these ratios may be modified.

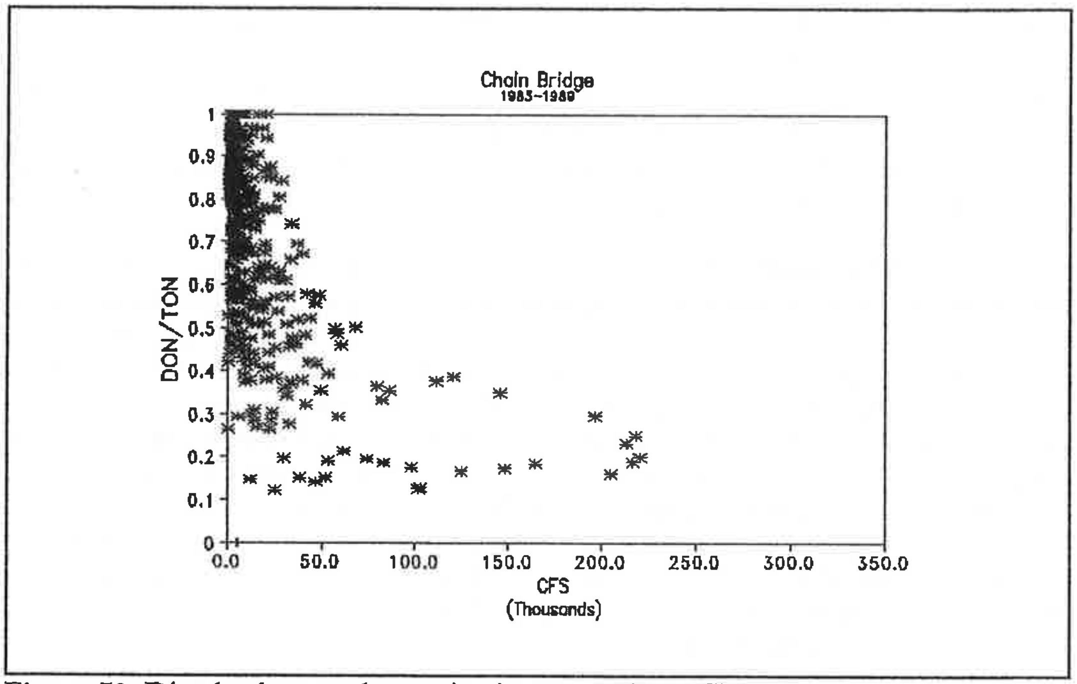

Figure 70. Dissolved to total organic nitrogen ratio at Chain Bridge, MD

Table 24. Dissolved to total ratios for N and P chemical forms taken from WQMS along the Potomac River (Shepherdstown, Shenandoah River, Monocacy River and Chain Bridge).

Year	DNH4/TNH4	n	DON/TON	n	DOP/TOP	n
Chain Bridge						
1980	0.59 ± 0.30	26	0.60 ± 0.25	29		
1981	0.81 ± 0.19	19				
1982			0.42 ± 0.24	9		
1983						
1984						
1985	0.82	1				
1986	0.94 ± 0.09	3				
1987	0.98 ± 0.03	3				
1988						
1989	1.0	1				
1983-1989			0.67 ± 0.23	370	0.37 ± 0.25	370
Monocacy River						
1980-1981	1.0	11				
Shepherdstown						
1980	1.0	1	0.69 ± 0.30	5		
1981	0.95	1				
1986	0.82	1				
1987	0.84 ± 0.24	4				
1988	1.0	6				
1989	0.83 ± 0.19	4				
Shenandoah Riv.						
1980	0.86 ± 0.31	5	0.67 ± 0.24	8		
1981	0.98 ± 0.03	3				
1986	0.70	2				
1987	0.83 ± 0.24	5				
1988	0.97 ± 0.08	6				

n = number of observations

Chapter 6. Miscellaneous Functions

Hydrologic Data

Streamflow

In WASP4, the inflows and outflows of a segment can be specified as constant or time-variable across segment boundaries. For each time-variable inflow, a piecewise linear function of flow versus time is specified. The require flow information can be obtained from USGS streamflow gauging stations along the mainstem Potomac and tributaries. Table 25 is a listing of the USGS gauging station used in this study. It should be noted that the reported streamflow is a daily average value, consequently, the finest resolution which can be used to define time-variable flow is one day. For steady state simulation, it is assume that the flows during the simulation period remain constant. Therefore, the average flow within that period is used. Since there are fewer gauging stations than model segments, it is necessary to interpret flow between two adjacent stations. To account for ungauged surface runoff and flow from ungauged tributaries, a linear drainage area-river mile regression is used to computed the ungauged flow.

Table 25. Mainstem and Tributary Gauging Stations

Gauge	Location
01598500	North Branch Potomac at Luke, MD
01603000	North Branch Potomac at Cumberland, MD
01610000	Potomac River at Paw Paw, WV
01613000	Potomac River at Hancock, MD
01618000	Potomac River at Shepherdstown, WV
01638500	Potomac River at Point of Rocks, MD
01646500	Potomac River near Washington D.C.
01597500	Savage River near Bloomington, MD
01599000	Georges Creek at Franklin, MD
01601500	Wills Creek near Cumberland, MD
01608500	South Branch Potomac near Springfield, WV
01609000	Town Creek near Oldtown, MD
01619500	Antietam Creek near Sharpsburg, MD
01636500	Shenandoah River at Millville, WV
01637500	Catoctin Creek near Middletown, MD
01643000	Monocacy River at Jug Bridge near Frederick, MD
01645000	Seneca Creek at Dawsonville, MD
01614500	Conococheague Creek at Fairview, MD
01638480	Catoctin Creek at Taylorstown, VA
01644000	Goose Creek near Leesburg, VA
01616500	Opequon Creek at Martinsburg, WV

Design Low Flow

The choice of design flows for waste load allocation decisions has traditionally provided an implicit frequency based approach for limiting the adverse water quality impacts of waste loadings to streams. Under design flow conditions steady state water quality modeling is most commonly used to transform waste loads into ambient concentrations in natural receiving waters. The recurrence interval of the design low flow therefore suggests the recurrence interval with which stream standards may be violated. The choice of a design flow provides the link between a waste load allocation decision and the resulting frequency with which an ambient water quality standard will be satisfied in natural receiving waters. For this reason the choice of design flow should reflect the basis upon which ambient water quality standards have been set.

Evolving standards for ambient water quality are increasingly based on toxicity and exposure effects in the stream biota. Although the deleterious ecological effects of waste loadings are cumulative, the use of design flows based on an annual recurrence interval fails to incorporate the full biological impacts of low flow events. Following acute and chronic exposure biological communities need an unstressed recovery period in order to return to a healthy condition. Standards to limit the stress on stream biota must consider the duration as well as the frequency of ambient conditions in addition to ambient concentrations.

The development of water quality-based toxics control has led to biologically-based water quality criteria that explicitly incorporate the impact on aquatic life of the intensity, frequency and duration of exposure. To incorporate ecological and toxicological considerations in ambient water quality standards, aquatic life criteria are specified as two concentrations. The Criterion Continuous Concentration (CCC) is the 4-day average ambient concentration that, on average, should not be exceeded more than once in three years. The 1 hour and 4 day averaging periods reflect concerns for acute and chronic exposure, respectively. The average exceedance of once in three years reflects the time needed for a stressed ecosystem to recover. Biologically based water quality standards can be incorporated in waste load allocation decisions through the use of a biologically-based design flow. This is achieved by basing permit decisions on a design flow for which the frequency and duration of ambient concentrations is biologically acceptable.

Current guidance from EPA recommends the use of both hydrologically-based and biologically-based design flows. Hydrologically based methods derive the design flow from the quantile function of n-day annual low flows. Biologically based design flows explicitly limit both the duration and frequency with which low flow excursions are realized. The 7-day 10-year low flow, ${}_7Q_{10}$ is an example of a hydrologically based design flow for which the annual series of 7 day average low flows is used to estimate the discharge with a 10 year recurrence interval. The annual series of low flows is typically used to estimate the parameters of a log pearson III distribution and the design flow is taken from the resulting quantile function. The use of hydrologically-based design flows is in part supported by long standing practice; ${}_7Q_{10}$ is used as the design flow in roughly half of the states and procedures to calculate low flows using the log pearson III distribution are both familiar and readily available. One criticism of the hydrologically-based design flow for waste load allocation is that it fails to consider the cumulative stress to a biological system from low flow events of long duration.

The second approach to specifying design low flows is the biologically based design flow method. This approach empirically identifies a flow value from the historical record that explicitly satisfies a priori constraints on both the frequency and duration of low flow excursions, reflecting the averaging periods and durations used to express CCC and CMC concentrations. Biologically based design flows are intended to result in water quality exceedances that are small enough and far enough apart that the resulting stresses would not cause unacceptable effects on aquatic organisms. Like aquatic-life water quality criteria, biologically-based design flows acknowledge that there will be significant violations at low flows. These standards and design low flows provide an explicit level of protection for aquatic organisms except when severe drought conditions would result in degradation anyway.

Biologically-based design flows have the advantage of explicitly establishing the frequency and duration of ambient criteria exceedances. The heuristic use of the historical flow record avoids problems associated with identification and parameter estimation of appropriate low flow probability distributions. Dependence on the historical record however limits the frequency of events that can be specified. For streams with short records it may not be possible to develop a biologically-based design flow.

For waste load allocations based on steady state modeling the U.S. EPA recommends the use of the biologically-based 1-day 3-year and 4-day 3-year events as the CMC and CCC design flows, respectively. This notation corresponds to the flow over the specified averaging period for which "flow excursions" in the historical record occur, on average, once in a three year period. For example, based on an historical record of 60 years no more than 20 flow excursions would occur within the period of analysis. Prior to the development of biologically-based design flow procedures, the U.S. EPA recommended the interim use of the hydrologically-based ${}_1Q_{10}$ and ${}_7Q_{10}$ low flows as the CMC and the CCC design flows respectively.

The EPA (1986) compared the hydrologically-based and biologically-based CCC and CMC design flows for 60 streams nationwide. For the CMC design flow the differences between the 1-day 3-year low flow and the ${}_1Q_{10}$ ranged from -50.0% to 20.8% with a mean of -4.9% and a median difference of -3.1%. Similarly the 4-day 3-year CCC design flow was compared to the ${}_7Q_{10}$ with differences ranging from -44% to 6% with a mean difference of -7.0% and a median difference of only 4.4%. This comparison suggests that the biologically-design flows are generally similar to the more familiar hydrologically-based design flows. Three Potomac river streamflow records were included in the 60 stream comparison. The alternate design low flows for Bull Run near Manassas, Va., North Branch Potomac River at Pinto, and the mainstem Potomac River at Paw Paw, W.Va are compared in Table 26.

Although the use of biologically-based design flows is increasingly encouraged, particularly in waste load allocations for toxic discharges, the current EPA recommended design low flow for use in waste load allocations for oxygen demanding pollutants is the traditional ${}_7Q_{10}$. Tables 27 and 28 show the ${}_7Q_{10}$ flows for the mainstem Potomac River and its principal tributaries. These values were calculated with the EPA DFLOW program for the current period of record in the EPA STORET database. In referring to ${}_7Q_{10}$ values, care must be exercised in identifying the period of record over which this value applies. As an example, for the mainstem Potomac River below Cumberland, the ${}_7Q_{10}$ values reported in Table 27 are approximately 10-20% higher than ${}_7Q_{10}$ values calculated in 1971. The differences largely reflect different periods of record. The 1971 values used streamflow data through water year 1967. This record included the severe drought of 1966 as well as droughts in the 40's and 50's. In addition, observed low flows on the mainstem of the Potomac have been augmented since 1981 by water quality releases from Jennings Randolph reservoir on the North Branch. Since changes in calculated values of ${}_7Q_{10}$ will affect permitting decisions, both the length of gauging records, as well as consumptive withdrawals and ongoing river regulating activities must be considered in choosing a design low flow value for steady state water quality modeling in support of waste load decisions.

Table 26. Comparsion of Biologically-based and Hydrologically-based design flows, (cfs)

	Bull Run near Manassas, VA.	North Branch Potomac River at Pinto, MD.	Potomac River at Paw Paw, WV.
USGS Gage ID	01657000	01600000	01610000
State	VA.	MD.	WV.
Drainage Area	148	596	3109
Period of Record	1951-1982	1939-1982	1939-1983
Coefficient of Variation	4.48	1.42	1.48
1-day 3-year	0.2	42.9	202.2
${}_1Q_{10}$	0.3	54.7	209.6
4-day 3-year	0.4	49.0	219.6
${}_7Q_{10}$	0.4	61.6	220.7

Table 27. $_7Q_{10}$ Mainstem Potomac River

Segment	River Mile	Gauge	Period of Record	$_7Q_{10}$ (cfs)	Location
2	338.3	01598500	1901-1988	42.18	North Branch at Luke, Md.
16	304.6	01603000	1930-1988	65.26	North Branch at Cumberland, Md.
22	277	01610000	1939-1988	225.40	Paw Paw, W.Va.
26	238.6	01613000	1933-1988	273.48	Hancock, Md.
29	210.8	01618000	1929-1988	414.51	Shepherdstown, Md.
39	159.5	01638500	1901-1988	869.80	Point of Rocks, Md.
47	117.4	01646500	1930-1988	627.99	Washington, D.C. nr. Little Falls
47		01646580	1980-1981	1109.37	Chain Bridge

Table 28. $_7Q_{10}$ Potomac River Tributaries

Segment	River Mile	Gauge	Period of Record	$_7Q_{10}$ (cfs)	Location
1	340	01597500	1949-1988	5.59	Savage River
2	338.7	01599000	1930-1988	3.04	Georges Creek, Franklin, Md.
14	307.2	01601500	1930-1988	13.68	Wills Creek, Cumberland, Md.
19	285.1	01608500	1901-1987	73.13	South Branch, Springfield, W.Va.
20	282.6	01609000	1929-1981	2.28	Town Creek, Oldtown, Md.
34	179.3	01619500	1901-1988	66.81	Antietam Creek, Sharpsburg, Md.
36	171.5	01636500	1901-1987	364.27	Shenandoah River, Millville, W.Va.
38	163.4	01637500	1948-1988	1.03	Catoctin Creek, Middletown, Md.
40	153.1	01643000	1930-1988	51.45	Monocacy River at Jug Bridge, Md.
43	133.9	01645000	1931-1988	8.37	Seneca Creek, Dawsonville, Md.
		01614500	1929-1988	53.90	Conococheague Creek, Fairview, Md.
		01638480	1972-1989	1.41	Catoctin Creek, Taylorstown, Va.
		01616500	1948-1987	34.46	Opequon Creek, Martinsburg, W.Va.
		01645000	1944-1989	1.48	Opequon Creek, Berryville, Va.

Solar Radiation

Total daily solar radiation, is one of the miscellaneous time functions (parameter name: ITOT) for WASP4. Solar radiation drives the kinetics of photosynthesis. Only one value for ITOT, is used for all segments in the model.

Long term records of solar radiation are available at only one location in the Potomac River basin, at Sterling, VA (Dulles Airport); and then only for the period 1948 - 1980. The National Weather Service's (NWS) network of solar radiation observation stations does not include other stations that publish data within the Potomac River basin.

Without actual measurements of solar radiation, a method must be used to estimate solar radiation (ITOT). It should be pointed out that even if actual measurements were available, applying those data to all segments in the model would be an approximation given the geographic scope of the Potomac River Basin. The NWS has developed methods for estimating solar radiation based on regressions with cloud cover, sky condition, and percent sunshine values for some weather stations (NOAA, 1978), and similar methods are described in Ryan and Harleman (1973). Cloud cover and percent sunshine values are measures of 'cloudiness', during daylight hours, that are recorded daily for the NWS's Local Climatological Data network of weather stations. Cloud cover takes integer values from 0 to 10 with 0 referring to the least cloudiness. Percent sunshine takes integer values from 0 to 100, with 100 referring to the least cloudiness. Haywood (1984), using Sterling, VA solar radiation data, found no significant difference between NWS cloud cover and percent sunshine values as a predictor of daily solar radiation.

The general method for estimating daily solar radiation received on the ground is to compute the clear sky solar radiation (CS) received at the edge of the earth's atmosphere, then apply a reduction factor to account for scattering, absorption, and reflection by the atmosphere. Clear sky solar radiation (DS) is a function of latitude and day of year, which determine the intensity of solar radiation and the fraction of a day that the sun is above the horizon. The calculations are

$$LAT=\tan\left(\frac{38.85\pi}{180}\right)$$

$$J(I)=\left(\frac{2\pi}{365}\right)(284+I)$$

$$DEL(I)=(\frac{23.45\pi}{180})\sin(J(I))$$

$$F(I)=(\frac{2}{15\times24})(\frac{180}{\pi})\arccos(-LAT\times\tan(DEL(I))) \quad (1)$$

$$DS(I)=2\times\frac{SN(I)}{\pi}\times F(I)\times1440 \quad (2)$$

where π = 3.14159
I = Julian days (Jan. 1 = 1)
LAT= tangent of latitude of Washington DC, 38.85°, expressed in radians
J = factor which expresses a Julian days as an offset in a sine wave in which the maximum is June 21.
DEL= intermediate calculation.
F = fraction of day I that sun is above horizon
SN = solar noon clear sky radiation for day I in cal/cm^2. (These values, for Washington DC, were provided by the NWS).
DS = total daily clear sky radiation in langleys/day (cal/cm^2/day)2.

Daily clear sky solar radiation is shown in Figure 71.

Next, to estimate an appropriate reduction factor to calculate incident net solar radiation, the NWS solar radiation data for Sterling (VA) along with cloud cover data from Washington National Airport for the period between 1977 and 1980 were examined. Table 29 lists median %CS values and variances for each possible value of cloud cover. Figure 72 is a Box & Whisker type plot showing, for each possible cloud cover value, the median, minimum, maximum, and standard deviation of percent Clear Sky Radiation (%CS). %CS was determined by dividing the radiation received by the Clear Sky radiation calculated for that day of year. Examination of Figure 72 and Table 29 shows that %CS varies non linearly with cloud cover, and that variance is non uniform with variance increasing as cloudiness increases. Given these characteristics, and the fact that cloud cover takes only a few discrete values, it was decided to use the median %CS for each cloud cover value as the reduction factor for calculating net solar radiation received on the ground.

The equation for estimating net daily solar radiation then becomes

$$R = DS(1 - 0.65C^2) \qquad (3)$$

where R = daily global solar radiation ($cal/cm^2/day$).
DS = calculated clear sky radiation ($cal/cm^2/day$).
C = fraction of sky covered by clouds.

Table 29. Median calculated clear sky radiation (%CS) actually received on the ground for each possible value of NWS cloud cover.

Cloud Cover	no. of obs.	median % Clear sky	Std. Dev.
0	38	98	4.6
1	41	97	7.9
2	36	90	5.1
3	42	89	6.6
4	43	88	11.0
5	27	79	9.8
6	38	79	13.4
7	50	70	13.8
8	33	58	15.6
9	77	52	17.2
10	162	28	19.9

In summary, to calculate the solar radiation flux to the basin equations (1 and 2) are used for the time period in question. Next, the clear sky radiation is corrected for cloud cover with equation (3) using NOAA cloud cover data for National Airport. A major assumption in this calculation is that the cloud cover estimated at National Airport is representative for the entire basin, in this regard WASP4 only needs one value for the basin. Sensitivity tests will be performed to estimate the error in using one value for the entire basin and to assess the effect of solar radiation on the distributions of nitrogen and phosphorus.

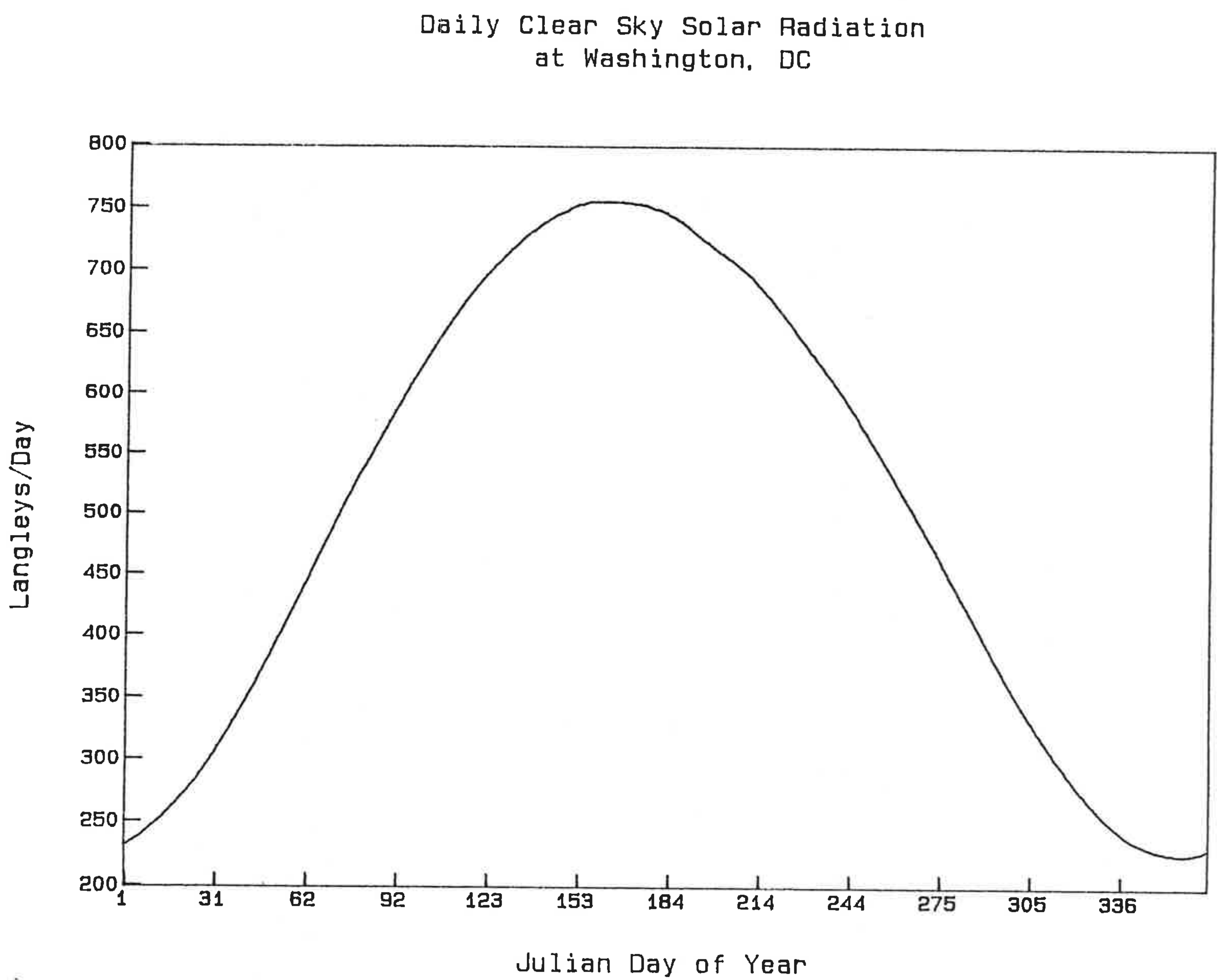

Figure 71. Daily Clear Sky Solar Radiation at Washington, D.C..

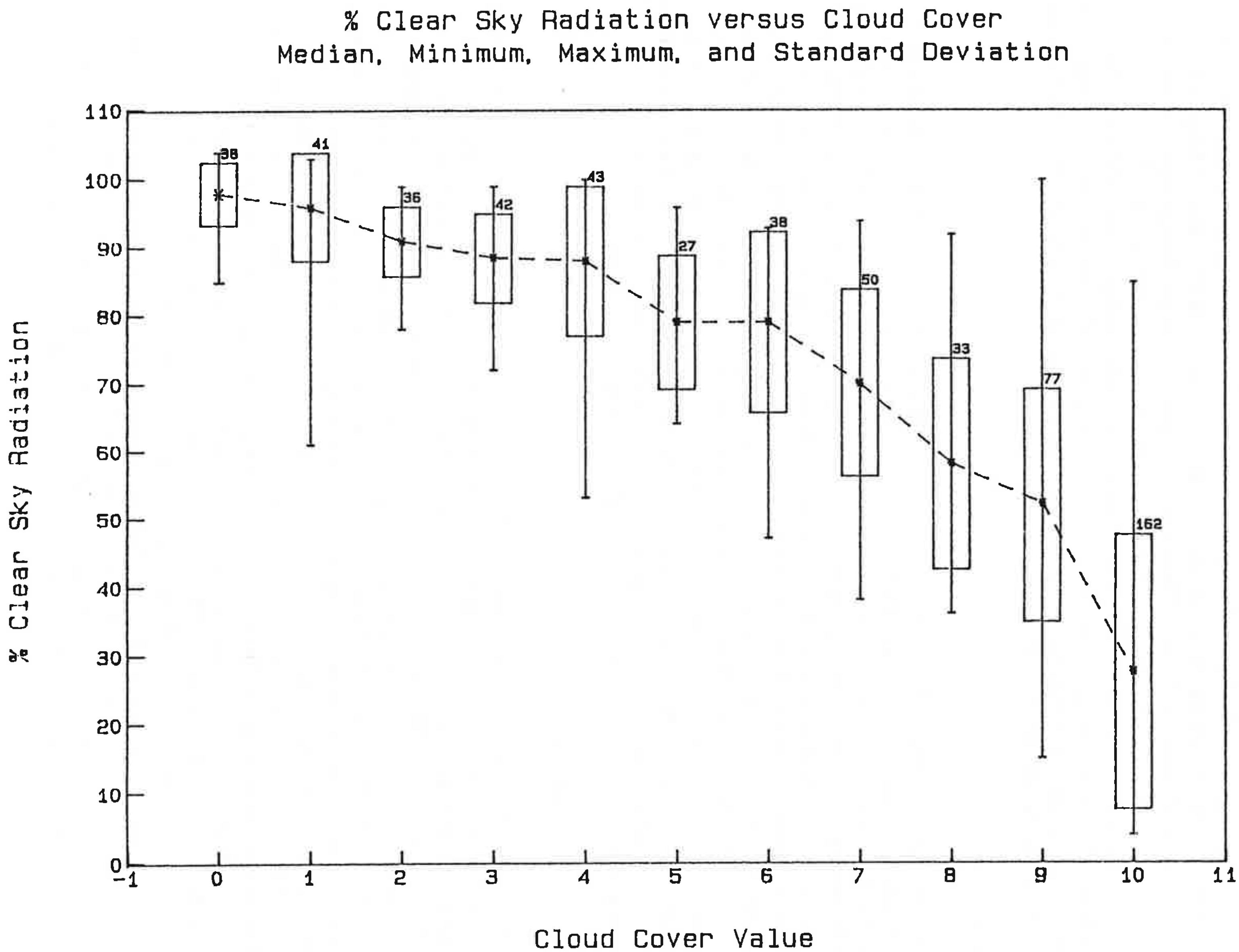

Figure 72. Percent Clear Sky Radiation vs Cloud Cover, Median, Mimimum, Maximum and Standard Deviation.

Ambient Water Temperature

Water temperature affects the rates of virtually all the kinetic reactions in the model. In the WASP4 model framework, up to four temperature functions can be included in the input deck to permit different temperature patterns in different model segments. Daily water temperature data, generally consisting of single observations per day, are available from several water supply intakes on the Potomac and hourly observations are available from a US Army Corps of Engineers station. These intakes are at Pinto, Williamsport, Sharpsburg, and in Montgomery County for the Rockville and WSSC treatment plants. The intakes are located at river miles 317.3, 211., 179., 130., and 128. respectively. These data will be used to construct temperature time series for model runs. Daily water temperature time series for the year 1985 were examined to evaluate the importance of variations in temperature along the length of the river. The results of that analysis are described in the following section.

Analysis

Two non-parametric statistical tests were performed to determine if daily water temperatures in the Potomac river show statistically significant longitudinal variation. The first test, a sign test, tallies the differences in temperatures between two time series. If the variation between the two series is random, the number of positive and negative differences should be approximately equal over the record. Significant deviations from this expected result suggests a systematic temperature difference between locations. The sign test is most appropriate in analyzing two time series in which one temperature series is consistently higher (or lower) than the other. The second test employed was the Kolmogorov-Smirnoff test for the difference between two distributions. This procedure tests the likelihood that two samples have been drawn from the same distribution by comparing the cumulative distribution functions from the two samples. The Kolmogorov-Smirnoff test can detect differences in the underlying distribution of data, and is therefore sensitive to differences that may be masked in considering only pair-wise comparisons.

Williamsport vs Rockville

Since the spatial distribution of daily water temperature data is extremely limited, the temperature records at Williamsport were compared to those at the Rockville intake to see if there was **any** significant longitudinal difference in ambient water temperature. Figure 73 shows daily temperature for the year 1985 at both locations. The daily temperature at Rockville consistently tends to be higher than that at Williamsport. Applying the sign test to these data, there are 320 days on which the Rockville temperature is greater than that at Williamsport, while 43 days have a higher temperature at Williamsport. If these temperature differences were randomly distributed, one would expect no more than 181.5 positive differences. The probability of observing 320 positive differences from a random sample of this size is less than 10^{-6}, indicating that daily temperature at Rockville is significantly higher than that at Williamsport. Figure 74 shows the daily temperature difference between Rockville and Williamsport. In addition to showing the significant temperature difference, the figure also indicates that this difference is greater during the summer months than in the winter. Thus the temperatures are not only significantly different throughout the year, but the magnitude of the difference varies seasonally. Figure 75 shows the cumulative distribution function (cdf) for temperature at both sites. The Kolmogorov-Smirnoff test evaluates the significance of the maximum difference between the two functions over all temperatures. If the two samples were drawn from the same distribution, the probability of realizing a maximum difference in cumulative probability as large as the observed difference of 0.152 is less than 0.0004. The KS test confirms the highly significant difference between the two time series.

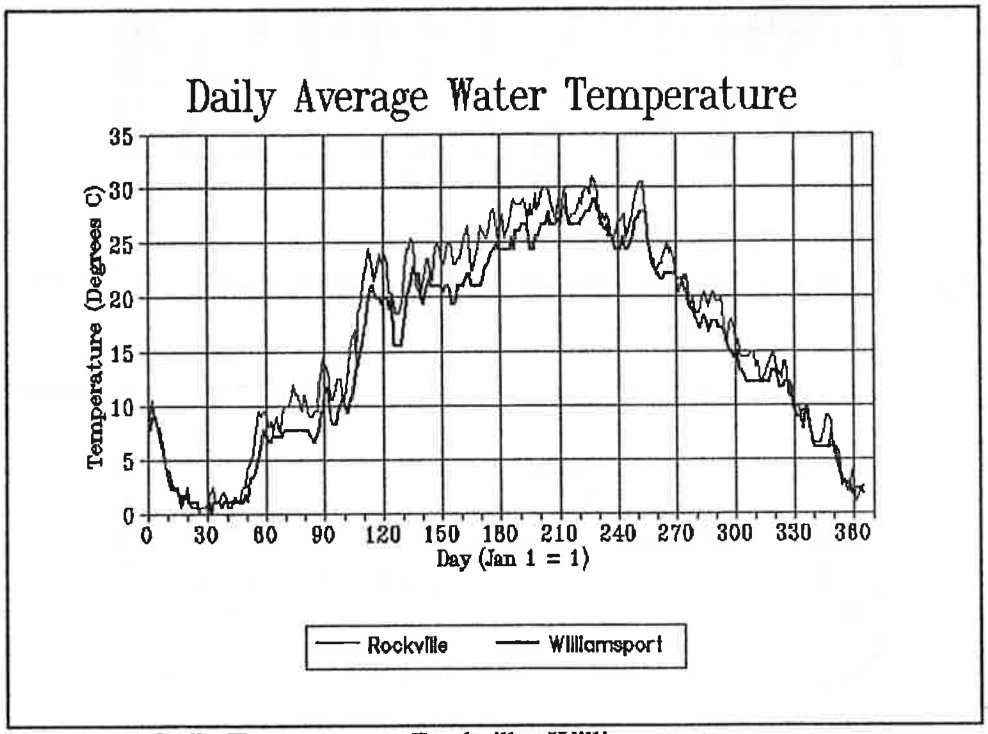

Figure 73. Daily Temperature: Rockville, Williamsport

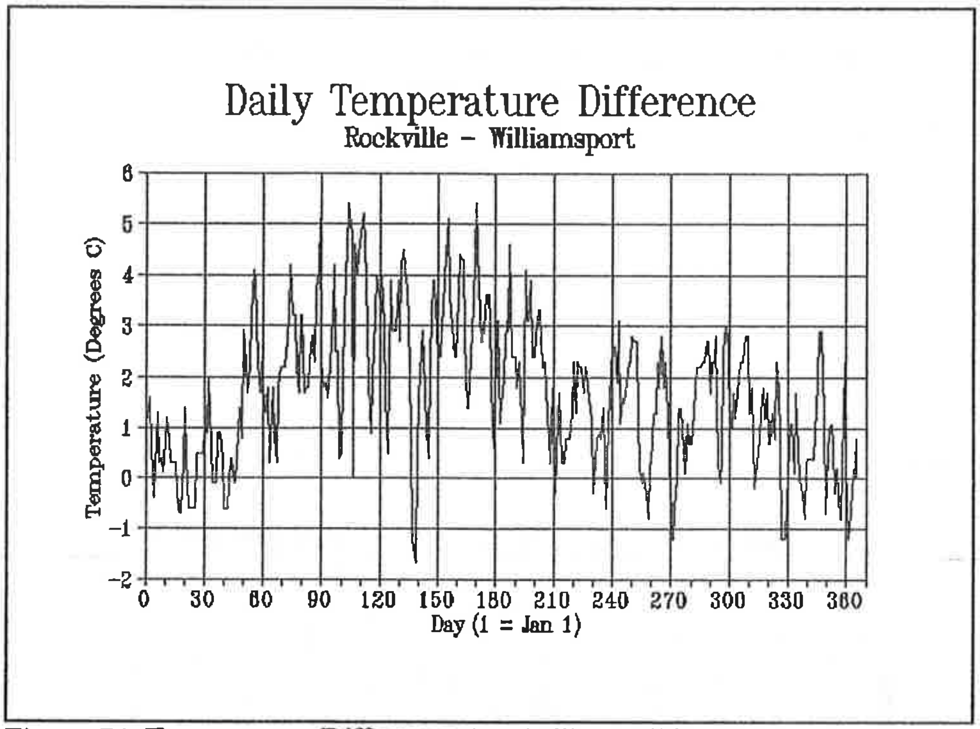

Figure 74. Temperature Difference: Rockville - Williamsport

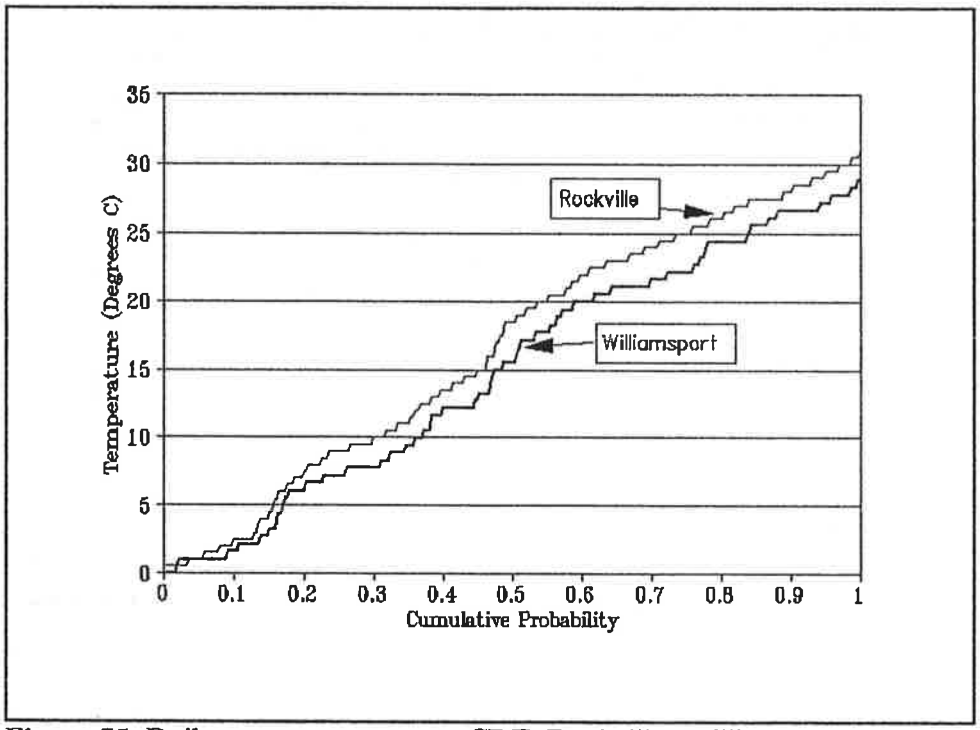

Figure 75. Daily water temperature CDF: Rockville, Williamsport

Williamsport vs Sharpsburg

Given the highly significant difference between daily water temperature in the middle Potomac observed at Williamsport and the lower Potomac observed at Rockville, the daily record at the Sharpsburg treatment plant in Washington County, also in the middle Potomac, was similarly analyzed. The daily record at Sharpsburg is largely complete, but values on weekends are frequently missing.

Figure 76 compares the daily temperatures at Williamsport and Sharpsburg. There again appears to be a systematic, though more complex, difference between temperature at the two locations. Compared to Williamsport, Sharpsburg temperatures are consistently higher in the summer and lower in the winter. This seasonal change in temperature difference shown in Figure 77, causes the number of positive and negative differences in temperature to be relatively close on an annual basis. The sign test is just barely significant, with the probability of observing the 175 positive differences and 139 negative differences, (compared to an expected number of 157) estimated at 0.48. The sign test is most powerful in detecting a consistent difference between all pairs of observations. The test is less sensitive to systematic changes in the pattern of temperature differences. The Kolmogorov-Smirnoff test, performed on the cumulative density functions for the two time series shown in Figure 78 indicates a difference between the two temperature records at the .003 significance level.

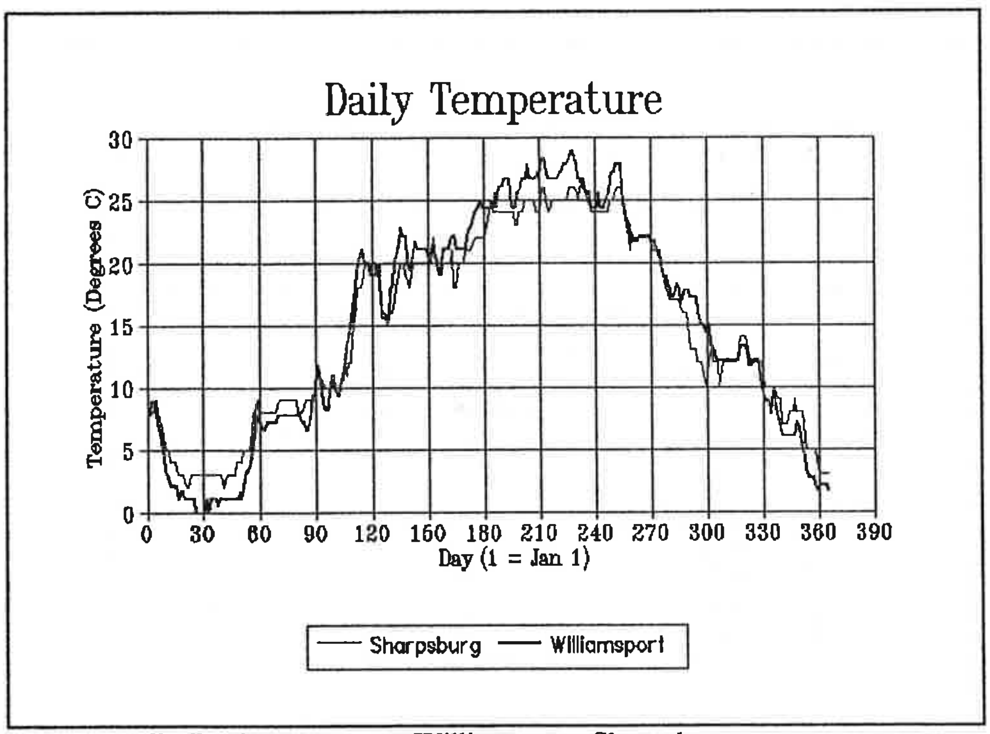

Figure 76. Daily Temperature: Williamsport, Sharpsburg

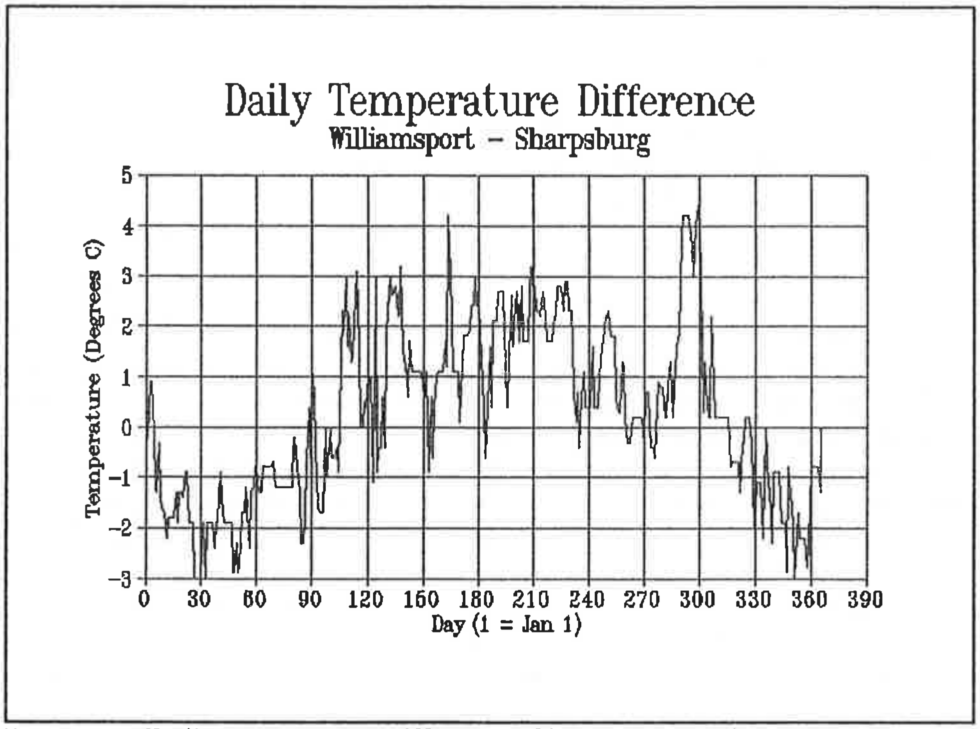

Figure 77. Daily temperature difference: Sharpsburg - Williamsport

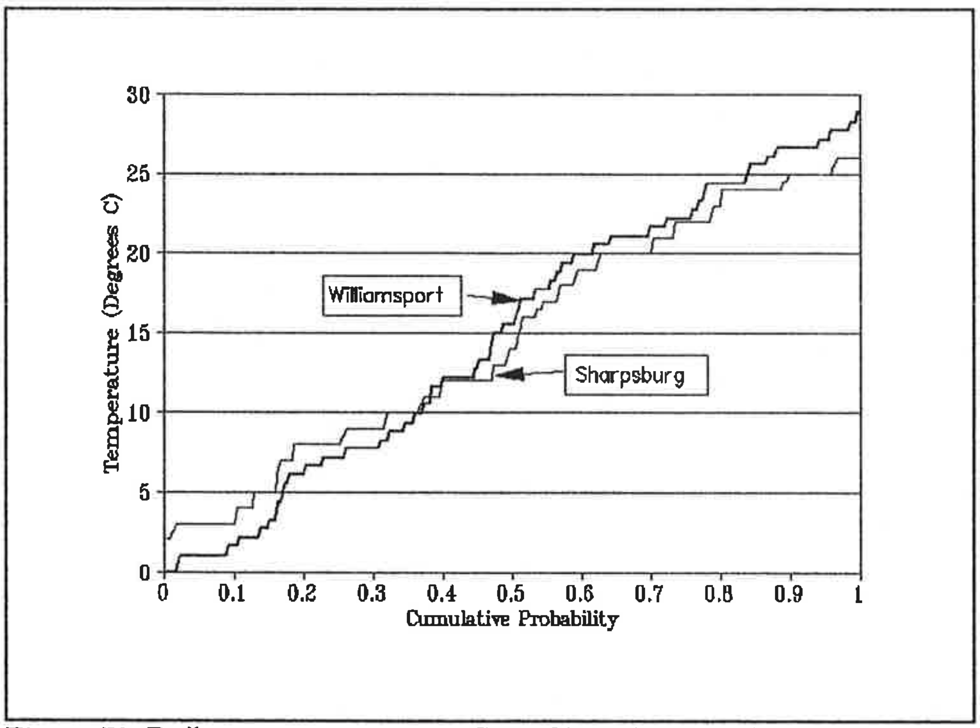

Figure 78. Daily water temperature CDF: Sharpsburg, Williamsport

Sharpsburg vs Rockville

As shown in Figure 78 summer temperatures at Sharpsburg are consistently lower than those at Williamsport. Since Williamsport temperature are consistently lower than those at Rockville we expect the differences in summer temperature between Sharpsburg and Rockville to be even more significant. Figure 79 shows both the seasonality in temperature differences between the two locations as well as the significant difference during summer months. Ambient water temperatures at Rockville are 2-4 degrees higher than those at Williamsport. Despite the seasonal change in the pattern of temperature differences, the sign test shows a difference at the 0.0000008 significance level, with similar, highly significant differences detected using the KS test.

Figure 80 summarizes the temperature patterns. Throughout most of the year, ambient water temperature at Rockville is consistently warmer than that at Williamsport, which in turn is consistently warmer than ambient temperature at Sharpsburg. The temperatures differences average approximately 2 degrees during the summer months and all temperature differences are highly significant. The annual temperature pattern is made more complex by the observation of consistently warmer water temperatures at Williamsport during winter months.

Pinto

The monitoring station at Pinto is the furtherest upstream source of daily water temperature. In comparison with all other stations, Pinto temperatures are cooler, with the maximum differences in summer months. The signs test comparison of Pinto temperatures with each other station shows significant differences in each case: 293 positive differences of 364 possible at Rockville; 200 of 227 at WSSC; 225 of 319 at Sharpsburg; and 248 of 365 at Williamsport

Conclusion

Analysis of 1985 water temperature data from the Pinto monitoring station, and from the Williamsport, Sharpsburg, Rockville, and WSSC treatment plant intakes shows significant differences in temperature between all stations. The pattern of differences is complex. The magnitude of differences changes seasonally, and sometimes the direction of differences changes seasonally.

During the summer when temperatures are high and flows low (the periods that will be modeled by PRM), there is a general trend toward cooler water upstream. This may be explained by a regional air temperature gradient to the north and west from Washington and possibly increased shading by bankside vegetation as the river narrows upstream. The substantially cooler temperatures at Pinto probably also reflect the impact of cold water releases from the Jennings Randolph and Savage reservoirs. However this general trend is not consistent. The Rockville intake (RM 130) tends to be about 1°C warmer than the WSSC intake (RM 128), and at Williamsport (RM 211) temperatures are about 1.4°C warmer than at Sharpsburg (RM 179). Differences in mean summer temperatures are indicated in Table 30. Other, unknown, factors may be affecting the temperatures recorded at these stations. These may include such things as location of the measuring point and depth of withdrawal, but add to the uncertainty in estimating temperature.

Assessment of the sensitivity of PRM model results to temperature differences will be evaluated with separate temperature functions for segments at the top, middle, and bottom sections of the river.

Wind

Wind speed may affect mixing and reaeration rates in water bodies. In the WASP4 model framework, mean wind speed is an optional miscellaneous time function intended primarily for non flowing water bodies such as lakes. In the Potomac River Model this variable has no effect and is turned off. Wind velocity does affect mixing and reaeration in the DYNHYD hydrodynamic component of WASP. However, DYNHYD is not being used in the PRM to generate channel geometry and velocity. Aside from model requirements, there are very few weather stations near the River that might provide wind data, and application of those data to the entire length of the river would be problematic.

Table 30. Summer (July-September) Mean Difference Between Daily Temperature (°C) at WSSC, Rockville, Sharpsburg, Williamsport, and Pinto

	Rockville	Sharpsburg	Williamsport	Pinto
WSSC	-0.99	2.01	0.59	4.35
Rockville		2.97	1.56	5.30
Sharpsburg			-1.37	2.27
Williamsport				3.73

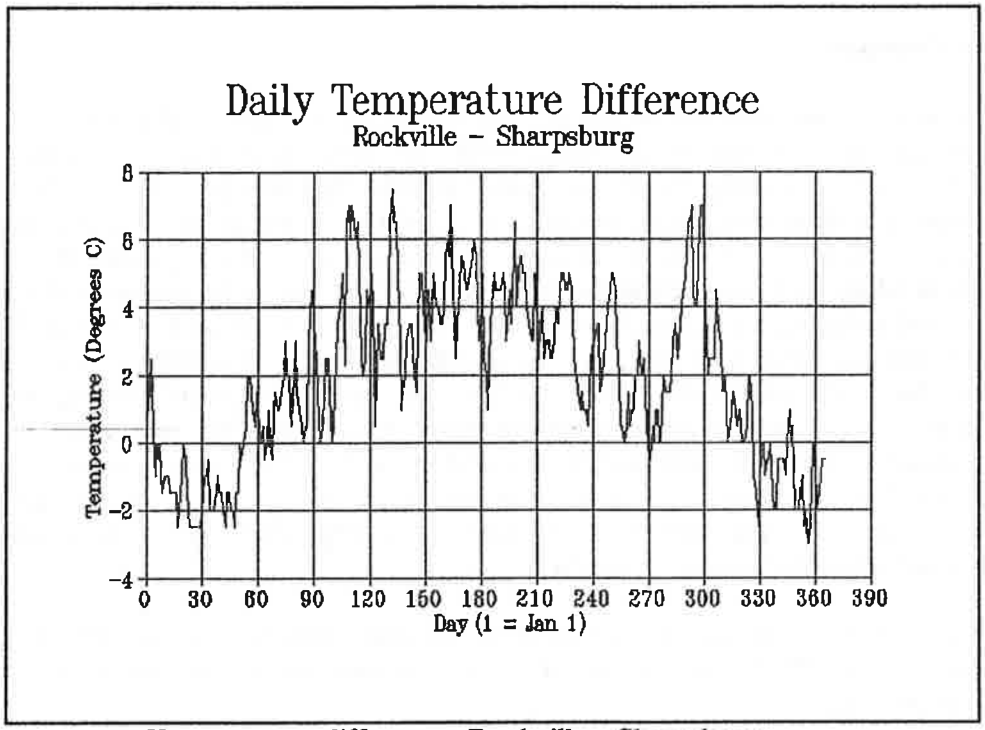

Figure 79. Temperature difference: Rockville - Sharpsburg

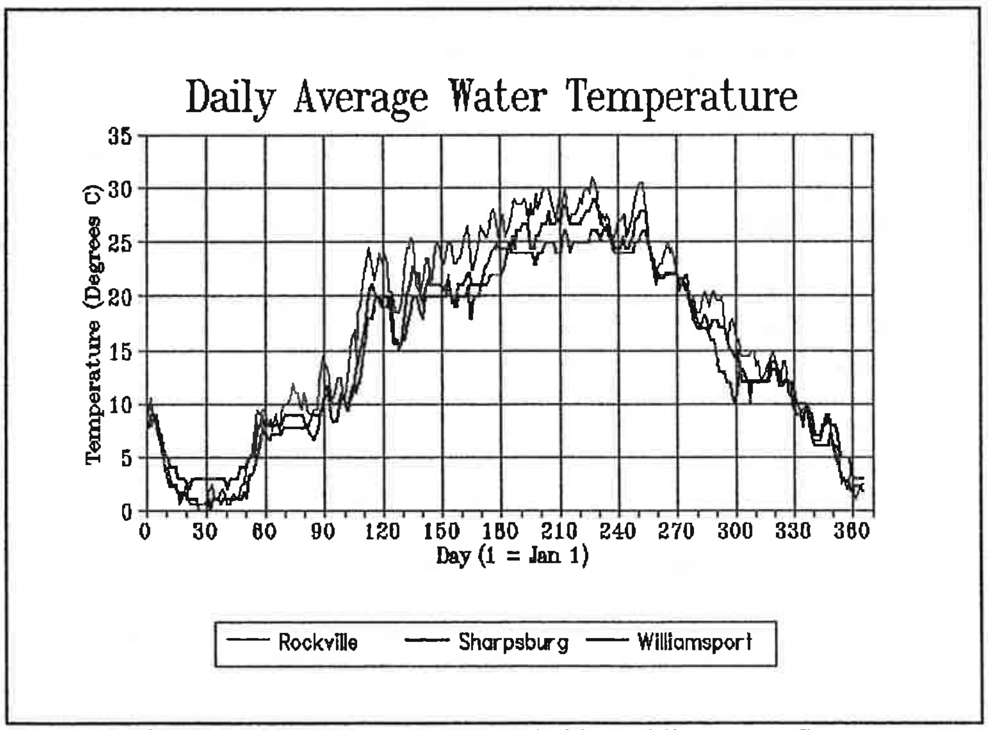

Figure 80. Daily water temperature: Rockville, Williamsport, Sharpsburg

Kinetic Rate Constants

Major kinetic interactions among state variables in the PRM are illustrated in Figure 81. These interactions include nutrient uptake by algae, remineralization, and nutrient transformations. Each of the equations describing these interactions includes kinetic rate constants that determine the rate at which reactions take place, generally as a function of temperature and concentration. For example, ammonium and nitrate are both used by phytoplankton for growth; the uptake rate at which each is taken up is proportional to its concentration relative to the ratio of ammonium or nitrate to total inorganic nitrogen. Ammonium is the preferred nitrogen source and generally nitrate uptake will not occur until ammonium concentrations are below 0.03mg N/L. Nitrogen is returned from the algal biomass either through direct excretion or bacterial decomposition. Organic nitrogen is converted to ammonium at a temperature dependent rate, and ammonium can then be converted to nitrate via nitrification at a temperature and dissolved oxygen dependent rate. Nitrate can be converted to nitrogen gas via denitrification in anoxic environments (i.e., zero dissolved oxygen) at a concentration and temperature dependent rate. The kinetics of phosphate are similar to the nitrogen system.

This section describes the procedure used to select the initial constants for the PRM. For the Potomac River Model, PRM, the following reaction rate constants are needed to describe the eutrophication process:

K12C	: nitrification rate @20°C (/day)
K12T	: temperature coefficient for K12C (unitless)
K1C	: phytoplankton saturated growth rate @20°C (/day)
K1T	: temperature coefficient for K1C (unitless)
CCHL	: carbon-to-chlorophyll ratio (mg C/mg chla)
IS1	: saturation light intensity for phytoplankton (Ly/day)
KMNG1	: nitrogen half-saturation constant for phytoplankton growth (mg N/L)
KMPG1	: phosphorus half-saturation constant for phytoplankton growth (mg P/L)
NCRB	: nitrogen-to-carbon ratio in phytoplankton (mg N/mg C)
PCRB	: phosphorus-to-carbon ratio in phytoplankton (mg P/mg C)
K1RC	: endogenous respiration rate of phytoplankton @20° (/day)
K1RT	: temperature coefficient for K1RC (unitless)
K1D	: non-predatory phytoplankton death rate (/day)
KDC	: BOD deoxygenation rate @20°C (/day)
KDT	: temperature coefficient for KDC (unitless)
OCRB	: oxygen-to-carbon ratio in phytoplankton (mg O_2/mg C)
K71C	: mineralization rate of dissolved organic nitrogen (/day)
K71T	: temperature coefficient for K71C (unitless)
K83C	: mineralization rate of dissolved organic phosphorus (/day)
K83T	: temperature coefficient for K83C (unitless)

Table 31 lists the range of values for these kinetic rates compiled from reports on estuary studies, stream water quality studies, lake water quality studies, and default values from some existing models. Table 31 also shows the initial values selected for the PRM. The table shows that for some of the rate constants there is a wide range of values reported. Bowie et al. (1985) compiled a listing of rate constants from different studies and showed that the rates may change significantly due to geographical, geological, hydrological and climatical differences, as well as the characteristics of the water body. These constants may also change from one water body type to another, such as lake, river, and estuary. In addition, they may vary from one algal population to another. A limitation of the WASP4 framework for the PRM is that these rate constants are specified only once and are used in all segments and times. Thus the model does not allow for changing conditions within a single model run over the entire geographic area. The problem is to select values that are reasonable approximations for the conditions being simulated.

To select the kinetic rate constants for the PRM, the values presented in Table 31 were reviewed carefully. These rates are compiled from different rivers and waterbodies from around the country. The rates to be used were selected using specific criteria. First, information from rivers and streams in the same geographic region as the Potomac River were selected. Studies from Mattawoman Creek (Domotor et al., 1987), 4 Mile Run (Domotor et al., 1987), and the upper Potomac River from Point of Rocks to Chain Bridge (MWCOG, 1985) were given highest priority. Since Mattawoman Creek and 4 Mile Run are small tributaries, their rate constants may not be representative for a larger river such as the Potomac. The rate constants used for the upper Potomac River study, which covers a portion of the PRM study area, were compared with the rate constants from rivers within the region (Patuxent River, O'Connor et al., 1981) and other regions around the country. The EPA (Bowie et al., 1985) kinetic data shown in Table 31 are compiled from different rivers around the country. Comparing the kinetic rate constants from the Mattawoman Creek, 4 Mile Run, Upper Potomac, and the Patuxent River studies with the EPA values, most are in good agreement except K12C and K83C. The EPA rate constants did not consider K1RC, K1RT, and OCRB. QUAL2E models of Brown & Barnwell (1987) have been widely used for stream water quality studies. Hence, the QUAL2E default kinetic rate constants were also considered along with the EPA rate constants. If no kinetic constants were available from any of these studies, then kinetic constants from other studies, such as from estuaries and lakes, were considered. These study areas include Lake Ontario, Chesapeake Bay, Potomac Estuarine Model (PEM), Gunston Cove and WASP4 default values. The studies of the PEM and Chesapeake Bay were considered first.

In general, the initial rate constants used for PRM were selected from upper Potomac River study and Mattawoman Creek study. Rate constants from other studies were also take into consideration. For example, the K83C value in Mattawoman Creek study were 0.05-0.06, 1.0 for 4 Mile Run, whereas it is 0.2 in the EPA study and 0.01-0.7 in QUAL2E. Taking into consideration the size of the Potomac River, the value of 0.2 was selected. It should be kept in mind that there is no theoretical based in choosing these initial rate constants. Thus, there may be major differences between these rate constants and the PRM calibrated constants.

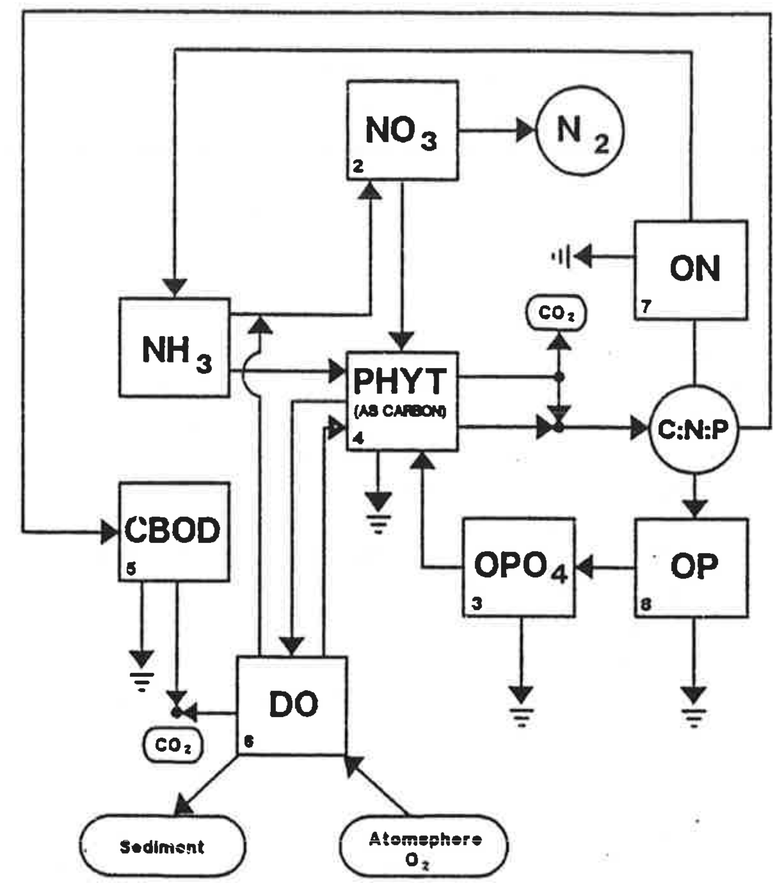

Figure 81. WASP4 State Variable Interactions

Table 31. Kinetic Rate Constants

Kinetic Rate Constant	WASP4	QUAL2E	EPA	PEM	Mattawoman Creek	4 mile Run	Gunston Gove	Chesapeake Bay	Upper Potomac	Patuxent River	Lake Ontario	PRM
K12C	0.15	0.1-2.0	0.2-1.25	0.03-15.8	0.1	0.1	0.1	0.05	0.14			0.14
K12T	1.08	1.083	1.02-1.08	1.08	T/20.0	1.04	1.04	1.08	1.08			1.08
K1C	2.0		1.0-2.53	2.0	1.8	2.0	2.0	2.0	1.992	2.4	2.0	2.0
K1T	1.08		1.01-1.2	1.068	1.08	1.087	1.087	1.068		1.066	1.08	1.07
CCHL	30.0		20.0-100.0	12.0-68.0	60.0	50.0	50.0	30.0		50.0	30.0	50.0
IS1	350.0		200.0-350.0		250.0	250.0	250.0			350.0	300.0	300.0
KMNG1	0.025	0.01-0.3	0.01-0.4	0.025	0.015	0.025	0.025	0.015				0.015
KMPG1	0.001	0.001-0.05	0.0005-0.08	0.001	0.001	0.001	0.001	0.0015			0.002	0.001
NCRB	0.25		0.17-0.25	0.1-0.48	0.117	0.14	0.14	0.25		0.14		0.14
PCRB	0.025		0.024-0.025	0.01-0.047	0.017	0.016	0.016	0.025		0.01	0.02	0.016
K1RC	0.125			0.125	0.11	0.09	0.09	0.125	0.151	0.125	0.025	0.125
K1RT	1.045			1.045	T/20.0	1.15	1.15	1.047		1.08	1.08	1.08
K1D	0.02	0.05-4.0	0.003-0.17	0.02	0.02-0.03	0.02	0.02	0.02	0.12	0.125		0.12
KDC	0.23	0.02-3.4	0.12-0.23	0.16-0.21	0.1	0.15	0.15	0.08	0.12	0.2		0.12
KDT	1.05	1.047	1.02-1.15	1.047	1.047	1.04	1.04	1.047	1.04			1.047
OCRB	2.67			2.67	2.67	2.67	2.67	2.67		2.67		2.67
K71C	0.08	0.02-0.4	0.035-0.14	0.075	0.02-0.03	0.075	0.075	0.03		0.02		0.02
K71T	1.08	1.047	1.02-1.08	1.08	T/20.0	1.04	1.04	1.08		1.045		1.045
K83C	0.22	0.01-0.7	0.2	0.22	0.05-0.06	1.0	0.22	0.3		0.02	0.075	0.2
K83T	1.08	1.047	1.08	1.08	T/20.0	1.04	1.04	1.08		1.045	1.08	1.045
Reference	Ambrose et al. (1988)	Brown & Barnwell (1987)	Bowie et al. (1985)	Thomann & Fitzpatrick (1982)	Domotor et al. (1987)	Domotor et al. (1987)	Domotor et al. (1987)	O'Connor et al. (1987)	MWCOG (1985)	HydroQual (1981)	Chapra & Reckhow (1983)	This Study

Note: T is temperature in °C

Sediment Oxygen Demand

Benthic deposits of organic matter in streams have long been known to have effects on the quality of the overlying water. Sediment oxygen demand, SOD, is a general parameter used to define the rate of dissolved oxygen consumption in the overlying water by respiration of benthic organisms and by the decomposition of organic matter (Uchrin and Ahlert, 1985). SOD is composed of both a biological and geochemical component. The biological component of the SOD reflects the consumption of oxygen by all living organisms at the sediment/water interface or within the sediments. This component encompasses both macroscopic (i.e., worms) and microscopic (i.e., bacteria) organisms and accounts for the respiration by all organisms in the sediment. The chemical component of the SOD includes the oxidation of all reactive, reduced substances such as hydrogen sulfide and ferrous iron (Wang, 1980). Hydrogen sulfide and ferrous iron, which are produced during the bacterial decomposition of organic matter, can be oxidized by oxygen and can account for a major fraction of oxygen demand of the sediments. Ammonium oxidation (i.e., nitrification) also consumes oxygen but is mediated by nitrifying bacteria in both the sediments and water column.

Sediment oxygen demand is a function of water temperature, dissolved oxygen concentration at the sediment water interface, water velocity, organic matter concentration and type, and the makeup and density of the biological community (Bowie et al., 1985). Thomann and Mueller (1987) stated that water temperature and dissolved oxygen concentrations in the overlying water are the most important variables. A review of the literature shows a wide range of SOD rates determined from numerous studies (Table 32). This range of values indicates that SOD is a site specific parameter where rates determined at one location may not be applicable at other sites.

To estimate the SOD it is necessary to evaluate the sediment distribution in the Potomac River system. In their study of the Upper Potomac River (from Point of Rocks to Chain Bridge), MWCOG (1984) showed that at low flow, there is net sediment deposition; especially between Seneca Pool and Little Falls Dam. At moderate flows, between 5000 to 15000 cfs, current velocities are sufficiently high to carry all suspended sediment but not strong enough to cause scouring of fine-grained sediment from the bottom, i.e. there is no net deposition of sediment to the river bed. At high flows, greater than 30000 cfs, the current velocities reach the critical threshold velocity necessary to scour both sand and silt. During extreme floods, hydraulic conditions are sufficient to scour and transport sediment stored in long-term floodplain and island sediment deposits. Based on the long-term sedimentation trends observed in the Potomac River system, Smith and Shoemaker (1984) suggested that the sediment stored in channels and floodplains in the river may be so great that it is effectively inexhaustible as a sediment supply. However, in a survey of bed deposits, MWCOG (1984) did not find significant deposits of fine-grained sediment stored in the free-flowing portions of the river. MWCOG (1984) suggested that the backwater areas behind low head dams are the most likely sites for fine-grained sediment deposition and storage. However, sediment deposition in these sites appears to be restricted to low discharge events. This information implies that there may be some sediment oxygen demand, especially behind the low head dams, during periods of low flow (summer to early fall). However, it is still necessary to determine the organic matter concentration and type (i.e., refractory or labile organic matter) and biological density in the study area. As this data does not exist, a review of the literature should provide a SOD rate that can be used as a first approximation for the PRM.

In WASP4, SOD is a miscellaneous function which can be specified for each segment. Upon a careful review of the values reported in the literature (Table 32), a value of 0.35 g O_2/m^2-day (MWCOG, 1985) was selected as an initial estimate of the SOD rate for all segments of the PRM.

Table 32. Measured and Calculated SOD in Lakes and Rivers

Description	SOD, g O_2/m^2-day	Reference
Lake Erie	0.3	Adams et al., 1982
Lake Erie	0.3-2.4	Lucas and Thomas, 1972
Upper Illinois Waterway	0.5-5.0	Butts, 1974
Rivers	0.5-5.3	Chiaro and Burke, 1980
Freshwater Passaic River (Summer-Fall)	0.0-2.43	O'Connor et al., 1981
Upper Patuxent River Estuary	0.5-1.0	O'Connor et al., 1981
Hunting Creek	1.3-7.2	Domotor et al., 1987
Four Mile Run	6.3-7.4	Domotor et al., 1987
Upper Potomac Estuary	2.3	Jaworski, 1971
Upper Potomac Estuary	2.5-2.7	Clark and Roesch, 1978
Rivers and Streams (Measured)	0.022-12.8	Bowie et al., 1985
Mattawoman Creek	0.5	Domotor et al., 1987
Upper Potomac River	0.35	MWCOG, 1985
Potomac (Calculated)	1.06-1.88	HydroQual, 1987

Chapter 7. Selection of Calibration and Validation Periods

Introduction

The previous chapters primary address the data that will be used for the Potomac River Model (PRM). Once the quantity and quality of the data is verified, it is then necessary to determine, using the data, the calibration and verification periods for steady state simulation. The selection of the calibration and verification periods depend on hydrological conditions (i.e., low flow vs. high flow) and data availability. The first task is to identify suitable periods with relatively stable flow that approximate steady state. Also, it is desirable to calibrate and validate the model under various flow conditions. For periods with suitable flow characteristics, water quality monitoring records and point sources are then compared to select periods with better data records. Other criteria for selection of calibration periods include antecedent flow patterns (high vs low spring flows) and changes in point source loadings (e.g. phosphorus ban in Maryland effective in 1986). This chapter discusses flow characteristics, data availability and other criteria, for each year 1983-1988, and concludes with the selection of calibration and validation periods.

Streamflow Characteristics - Potomac River Basin

The general pattern of streamflow on the Potomac reflects regional meteorological patterns expressed over the varying geologic and physiographic provinces of the Appalachians. The well developed dendritic drainage of the Alleghany plateau dominates the North Branch Potomac River. This region's hydrologic contribution to Potomac River streamflow is captured at the USGS gauge at Cumberland, Md. (Figure 82). The South Branch Potomac river is the largest tributary of the upper basin with a drainage area of over 1,500 square miles in the valley and ridge (Figure 83). The combined drainage of the Alleghany plateau and the South Branch Potomac river is gauged at Hancock, Md. (Figure 84). The Shenandoah river draining the limestones of the Great valley is the Potomac's largest tributary and is representative of both the meteorologic and geologic conditions of the Hagerstown valley as well (Figure 85). At the Blue Ridge separating the Piedmont from the Great valley, the USGS streamflow gauge at Point of Rocks, Md. provides a long continuous record representing the combination of non-Piedmont drainage of the upper basin (Figure 86).

The consistent pattern in monthly streamflow shows high spring runoff with low evapotranspiration and snowmelt in March, followed by low summer flows in August and September with normal low flow typically occurring in September. Discharge and water yield (cfs/mi^2) is summarized in Table 33. The variation in the pattern of streamflow for specific calibration verification years is discussed in the following sections.

Yearly Hydrological Conditions in the Potomac River Basin

There are seven USGS stream gauging stations along the mainstem Potomac between Luke and Little Falls associated with a nearby water quality monitoring station. These stations are listed in Table 34 with their respective river mile. These seven stations provide calibration and verification stations for the PRM. For steady state model calibration, it is desirable to select a period during the summer with low, relatively stable streamflow. Summer low flow periods are likely to be the periods of worst water quality due to high temperature, lower dilution, and longer residence times and will be of greatest interest for permitting decisions.

The hydrographs and average monthly discharges for the mainstem gauging stations at Luke, Cumberland, Paw Paw, Shepherdstown, Point of Rocks and Little Falls (Figures 87 to 158) were used to review streamflow patterns along the mainstem in order to identify periods of near steady flow for calibration and validation. These stations were selected based on specific geographical factors. The gauging station at Luke is located near the upstream boundary of the PRM. The Little Falls gauge is located about one mile upstream from the downstream boundary of the PRM, providing a good estimate of the cumulative discharge to the water quality monitoring station at Chain Bridge. The gauging station at Cumberland is located 21 miles upstream from the confluence of South Branch Potomac River and reflects the runoff from the North Branch excluding Patterson Creek. The remaining stations were selected such that they would capture the contribution from major tributaries or physiographic regions such as the South Branch Potomac River, the Valley and Ridge (Shepherdstown), the Shenandoah River in the great valley (Point of Rocks), and Piedmont watersheds such as the Monocacy River, to the PRM boundary (Little Falls).

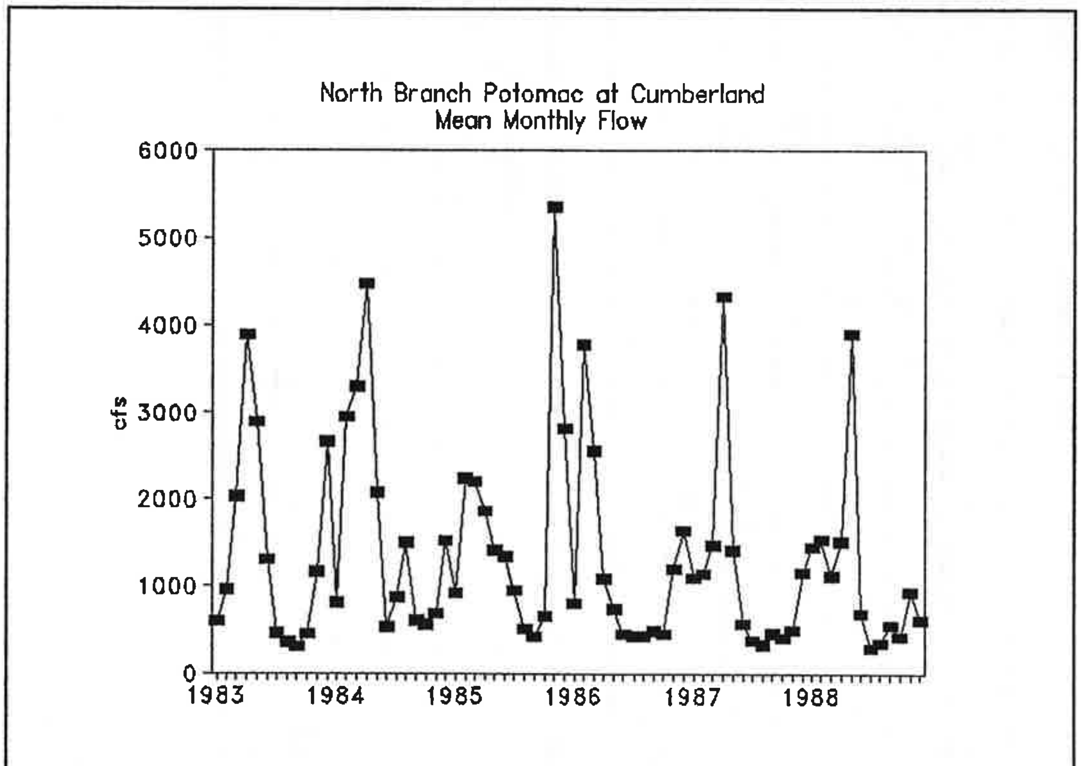

Figure 82. Mean monthly Discharge, North Branch Potomac River at Cumberland, MD.

Table 33. Seasonal Average Discharge

	March	July	Aug.	Sept.	July-Sept.	Annual	Drainage Area
	Average Daily Discharges (cfs)						
Cumberland	2880	465	431	382	426	1270	875
Hancock	8974	1428	1440	1222	1363	4153	4073
South Branch	2423	1217	484	720	807	1305	1471
Shenandoah	4789	1293	1503	1303	1366	2604	3040
Point of Rocks	19269	4461	4083	3595	4045	9406	9651
	Normalized Discharge (cfs/mi^2)						
Cumberland	3.29	0.59	0.49	0.44	0.49	1.45	875
Hancock	2.2	0.35	0.35	0.3	0.33	1.02	4073
South Branch	1.65	0.83	0.33	0.49	0.55	0.89	1471
Shenandoah	1.58	0.43	0.49	0.43	0.45	0.86	3040
Point of Rocks	2.0	0.46	0.42	0.37	0.42	0.97	9651

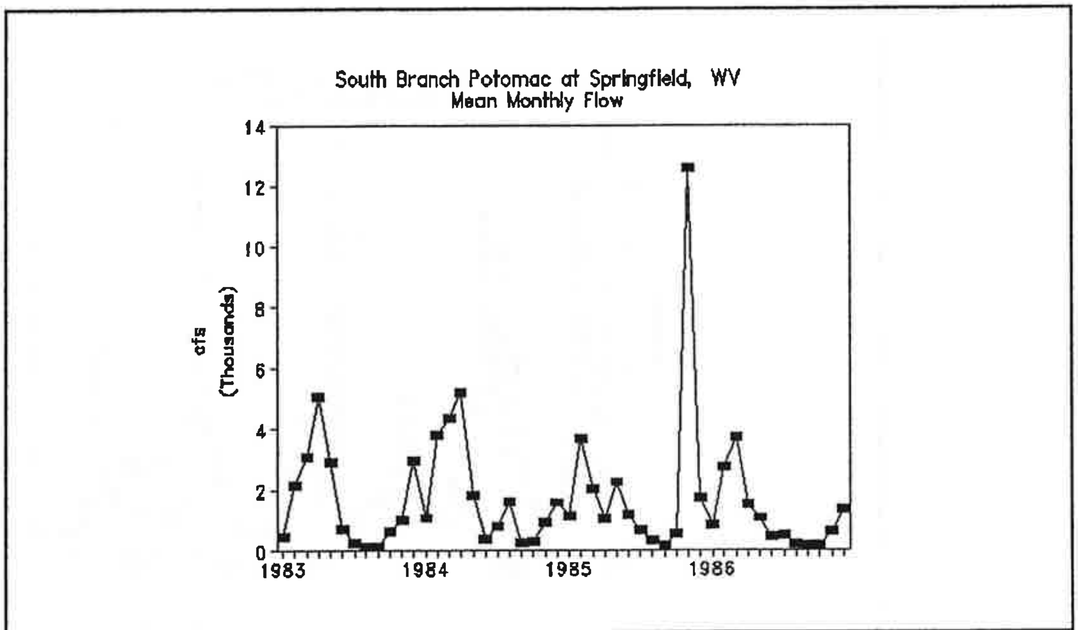

Figure 83. Mean monthly Discharge at South Branch Potomac River at Springfield, WV.

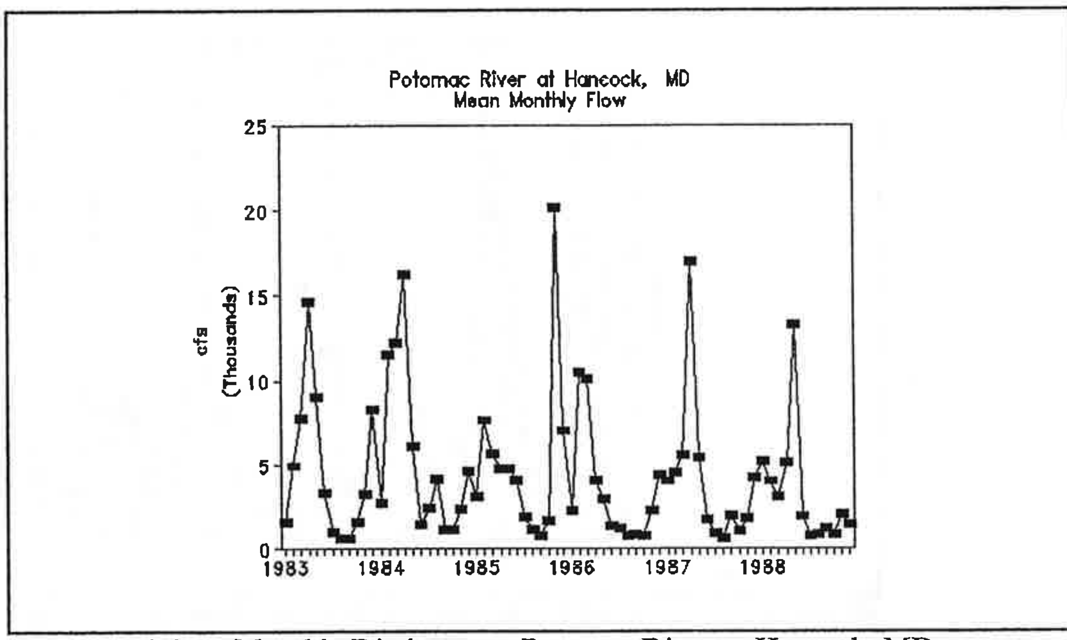

Figure 84. Mean Monthly Discharge at Potomac River at Hancock, MD.

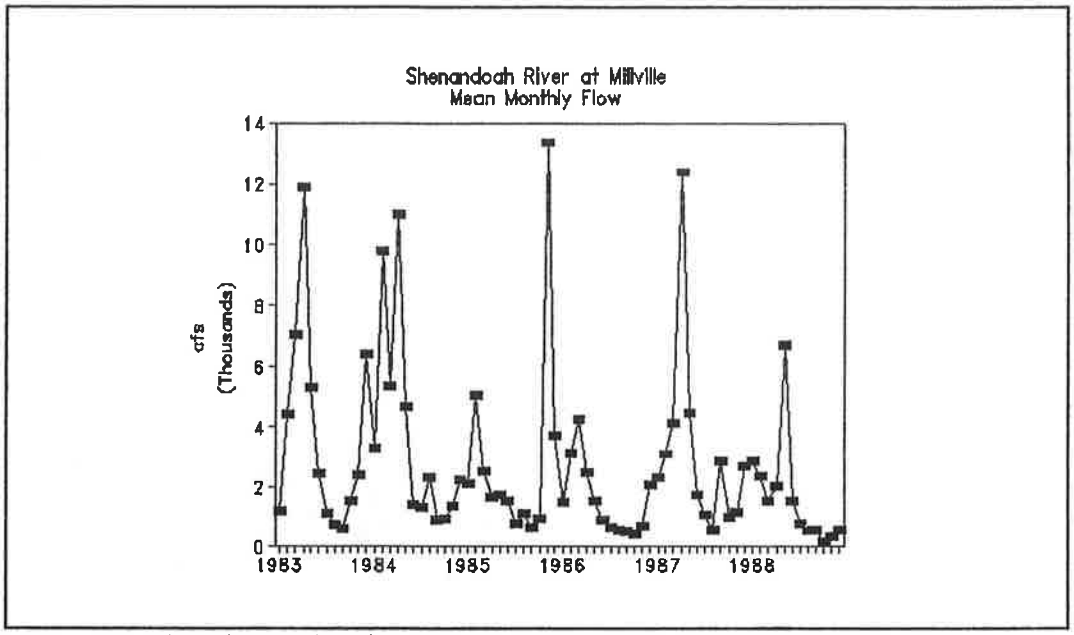

Figure 85. Mean Monthly Discharge at Shenandoah River at Millville, WV.

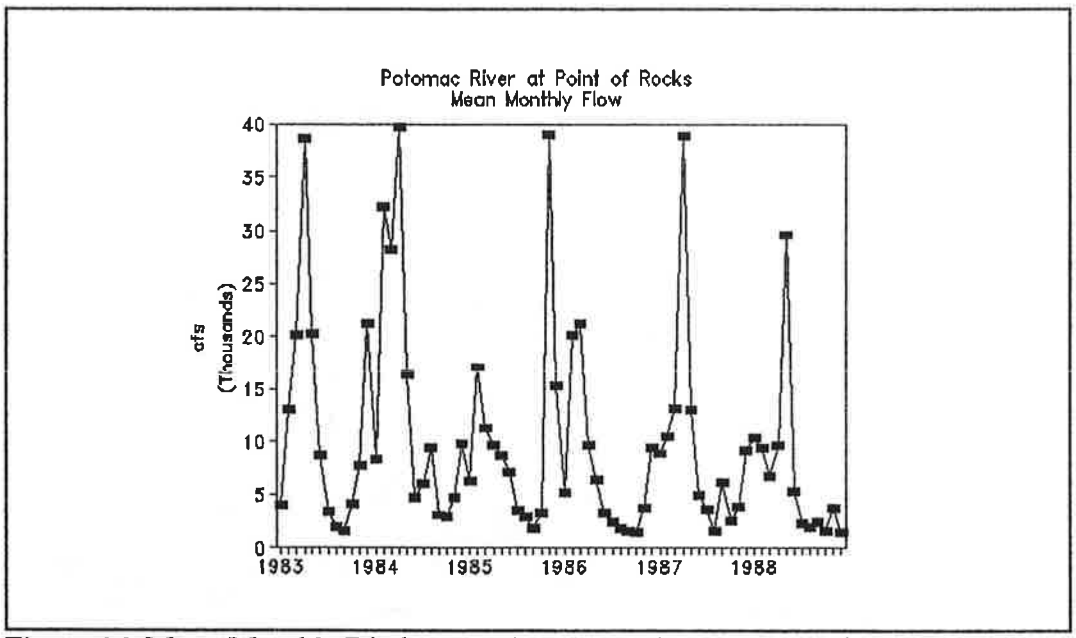

Figure 86. Mean Monthly Discharge at Potomac River at Point of Rocks, MD.

Hydrologic Data Assessment 1983-1988

Figures 87 to 98 show the 1983 hydrographs and average monthly flows at the six mainstem gauging stations considered. The hydrographs show the annual cycle of streamflow with high spring runoff from large frontal passages and some snowmelt in the North Branch. Streamflow gradually decreases through the late spring and summer with lowest flows in late summer or early fall. Summer low flows are punctuated with intense but localized convective thunderstorms. Periods of relatively low steady flow are found during the summer and early fall, with low flows at Point of Rocks of about 1,500 cfs. This is a promising period for model calibration.

Figures 99 to 110 show the hydrographs and average monthly flows for 1984. These figures show that, in general, there were numerous rainstorms during the spring which resulted in high stream flow. The summer streamflow was above average, with unusually high flows in August. The fall, in particular, September to November, was generally free from significant runoff events with low flows at Point of Rocks of 2,400 cfs. Based on the hydrological conditions shown in Figures 99 to 110, streamflow was generally steady between September and October (day 250 to day 310), offering a good candidate calibration period.

Table 34. Location of Mainstem Stations and River Mile

USGS Gauging Station	Station No.	River Mile (RM)
North Branch at Luke	01598500	340.
North Branch near Cumberland	01603000	305.2
Potomac River at Paw Paw	01610000	276.5
Potomac River at Hancock	01613000	238.6
Potomac River at Shepherdstown	01618000	183.6
Potomac River at Point of Rocks	01638500	159.5
Potomac River near Washington (Little Falls)	01646500	117.4

Figures 111 to 122 show the 1985 hydrographs and average monthly discharges for six of the seven stations in Table 34. These figures show the extreme runoff in November throughout the basin associated with Tropical Storm Juan. The sediment load delivered to the fall line during this one event is estimated to have accounted for 90% of the annual load that year. In addition, high runoff occurred in December in the upper portion of the North Branch. The spring runoff was unusually low, and was followed by an extremely dry summer with September low flows at Point of Rocks under 1,400 cfs. Little rainfall occurred during the summer, especially in the late summer and early fall (July to October). Figures 112, 114, and 116 show that the average monthly discharges above Paw Paw were relatively stable from February to March. The extended period of stable low flow during August and September is a good candidate for calibration.

The 1986 hydrology is characterized by a few isolated high flow events in the winter and early spring followed by an extended period of relatively low steady flows from late July to October. The lowest flows throughout the basin occurred in September, with low flows at Point of Rocks under 1,200 cfs.

The 1987 hydrological conditions were dominated by heavy runoff in the month of April (Figures 135 to 146). Periods of low summer flows were punctuated by significant runoff events in June and September. The daily hydrographs show periods of low steady flow from day 210 to day 240 (late July and August), and between day 280 and 320 (October), suggesting two candidate calibration periods. Low flows of 1,350 cfs occurred in August, while the steady flows of June ranged between 3,500 to 4,000 cfs.

The 1988 hydrological conditions are similar to conditions in 1987. Peak spring runoff occurred during the month of May (Figures 147 to 158). The seasonal low flows of summer and early fall were punctuated with a number of small, intense storms over the upper basin. Figures 147 to 158 show an extended period of relatively low discharge between July and October, in particular between days 200 and 230, and days 280 to 310. These periods from July to August appear to be the best calibration candidates with low flow at Point of Rocks under 1,500 cfs in mid-August.

After a review of the hydrographs and average monthly discharges (Figures 87 to 158) for the basin, several possible candidates for model calibration are selected for further investigation (Table 35). In general, these calibration periods are selected on a monthly basis except for 1987 in which there was no extended period of steady flow over several months. To select the actual calibration period, it is necessary to scrutinize both the hydrologic data and water quality data in its entirety, while considering that the resolution of the water quality and point source data may not support a calibration over a period of less than a month. As discussed in Chapter 3, a large portion of the available point source data are monthly average concentrations, while others are annual average concentrations. Hence, it is necessary to assume that the nutrient concentrations are constant over a month or a year. Any period longer than one month requires adjustment of the "observed" data. Also, the water quality monitoring data, in general, are monthly grab samples. Depending on the flow period selected, some load reconstruction may be required if no observed data are available for that period. To avoid using reconstructed data, the calibration and verification periods are selected to ensure that adequate point source and water quality monitoring data are available. The following section examines the available water quality data in conjunction with the flow regime of the candidate calibration periods listed in Table 35.

Table 35. Selected "Possible" Calibration Period

Year	Days	Flow Period
1983	190 to 270	late July to September
1984	260 to 300	September to October
1985	220 to 270	August to September
1986	210 to 300	August to October
1987	180 to 240, 290 to 310	late July to August, late September to October
1988	180 to 240	July to August

Water Quality Assessment 1983-1988

As discussed in Chapter 3, the majority of the point source data collected in PSI (Table 8, Chapter 3) do not contain monthly nutrient observations. Default effluent concentrations and effluent discharge rates must therefore be used to estimate many point source loads. However, as shown in Table 8, no 1983 discharge information is available in PSI for most of the point source dischargers. To overcome this constraint, a long term average discharge estimated from several years with observations could be used to estimate the 1983 discharge. This process could introduce added uncertainty to the point source load estimates due to changes at a facility such as a major upgrade or growth in the service area.

For the periods listed in Table 35, most tributary monitoring stations have at least one water quality observation for the necessary parameters (Chapters 2 and 3) which can be used directly or indirectly to calculate the needed inputs for the PRM. However, as reported in Chapter 2, there are only a few mainstem and tributary stations that reported BOD. Consequently, it is necessary to estimate the BOD and chlorophyll-a load for some tributaries. For the mainstem stations (calibration points) listed in Table 33, observed data are available for all water quality parameters except BOD5. Limited BOD5 data is available for stations below Point of Rocks. For the monitoring station at Cumberland, there are very few observations of any water quality parameters after 1983. However, there are observations at Oldtown and at Route 220 bridge which are about 18 miles downstream and 14 miles upstream, respectively from Cumberland. These two water quality stations may be used for calibration in addition to the flow data at Cumberland.

As in 1983, 1984 nutrient data is largely incomplete in the PSI. However, for most point sources, either average monthly flow or average annual flow are available. This flow information can be used to compute nutrient loads using default effluent concentrations. For tributary water quality monitoring data, at least one observation per month, or sufficient data for load reconstruction are available for all systems, except BOD and chlorophyll-a. For mainstem stations, no BOD and chlorophyll-a observations are available for upstream monitoring stations (above Point of Rocks), and no data are available at Cumberland. Again, there are observations at Oldtown and at Route 220 bridge that can be used in addition to the flow data at Cumberland.

The status of the point sources and water quality data in 1985-1988 are the same as in 1984. In 1985 at least one observation is available at each mainstem station during the proposed calibration period except Cumberland. In 1986, there are no observations in some of the mainstem stations in August, and there are no observations at any stations in October, except at Chain Bridge. In 1987, there are observations for August and October at most stations except at Cumberland. The status of the point sources and water quality data in 1988 is the same as in 1987, and there are no observations at Cumberland. As in 1984, there are no observation of BOD or chlorophyll-a at stations above Point of Rocks, Md. for these four years.

Selection of Calibration and Verification Period

The point source data, in general, consists of monthly average data. The water quality monitoring data generally contains monthly grab samples. Based on the water quality data assessment, the number of possible candidates for calibration and validation was reduced from ten to four (Table 36). For steady state calibration and verification, monthly observations are assumed to be steady state concentrations at that location. Since most of the point source data are monthly average observations, both the calibration and verification period were selected to include a period that included a monthly observation. The purpose of model verification is to test the validity of the model under different flow and loading conditions, thus it is desirable to select a different flow regime from the calibration. As shown in Table 37, calibration and validation periods are selected for periods preceding and following Maryland's ban on phosphate detergents.

Table 36. List of "Possible" Calibration Candidates

Year	Flow Period
1984	September, October
1985	August, September
1986	September
1987	July, September, October
1988	July, August

Table 37. Calibration and Verification Period

Steady State Simulation	Period 1	Period 2
Calibration	1984 October	1986 September
Verification	1985 September	1987 July

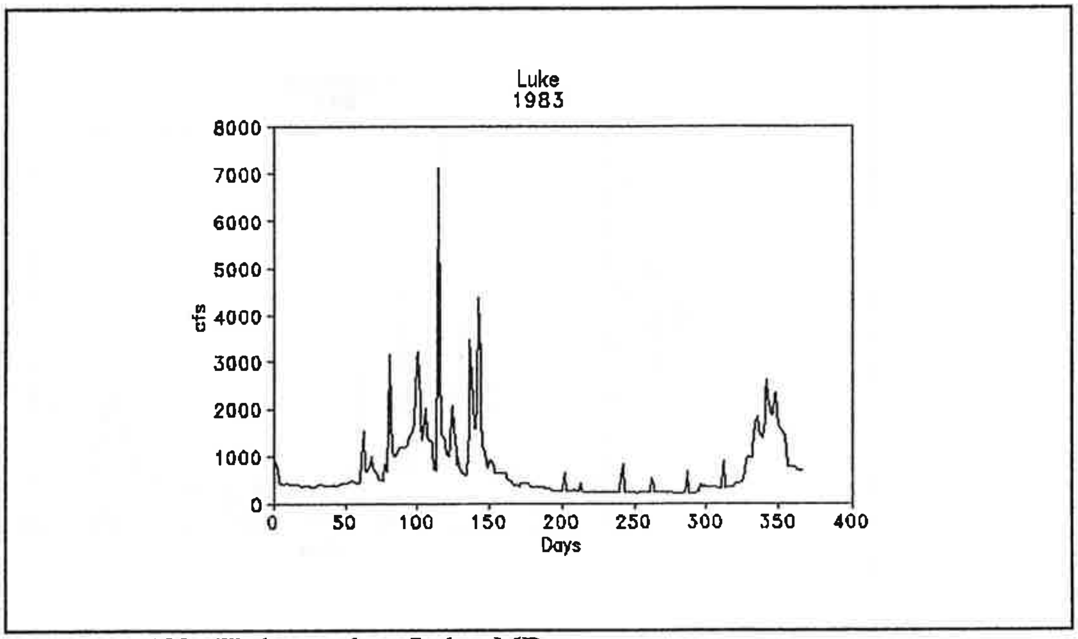

Figure 87. 1983 Hydrograph at Luke, MD.

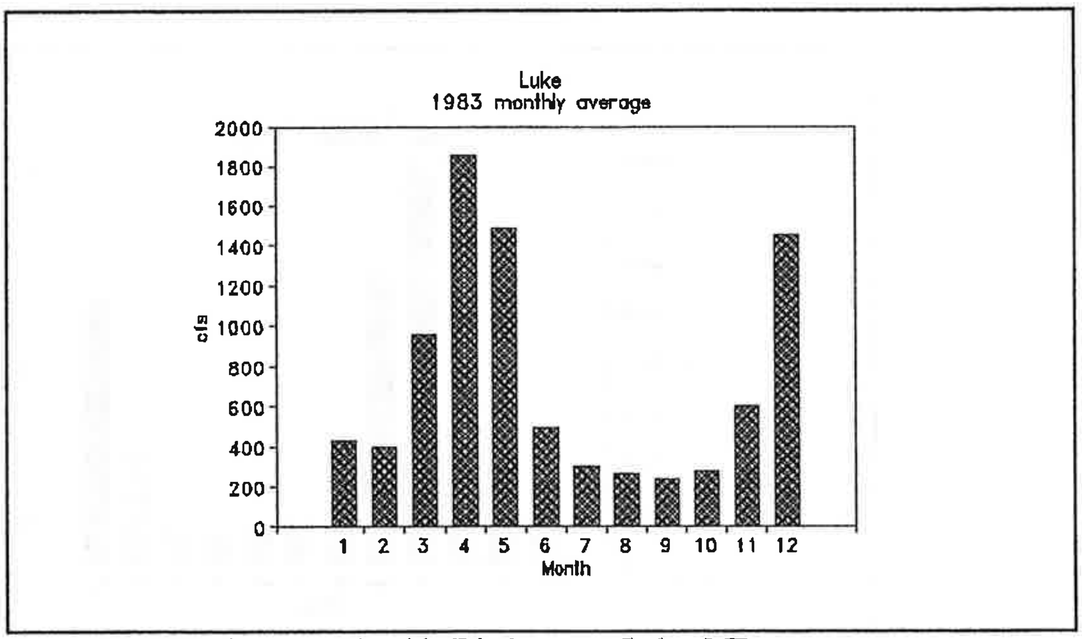

Figure 88. 1983 Average Monthly Discharge at Luke, MD.

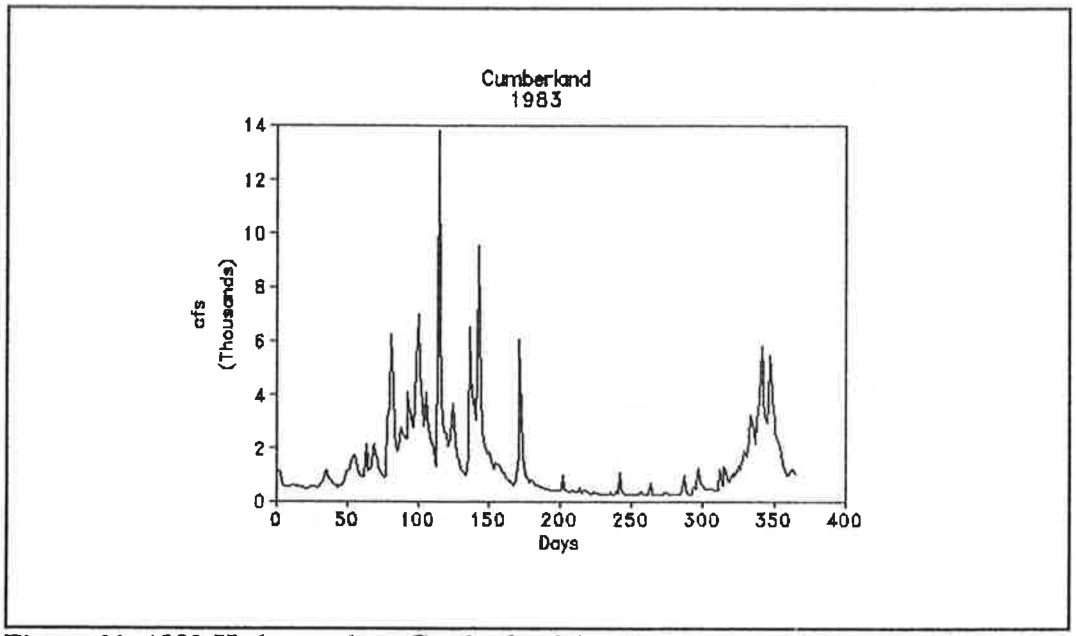

Figure 89. 1983 Hydrograph at Cumberland, MD.

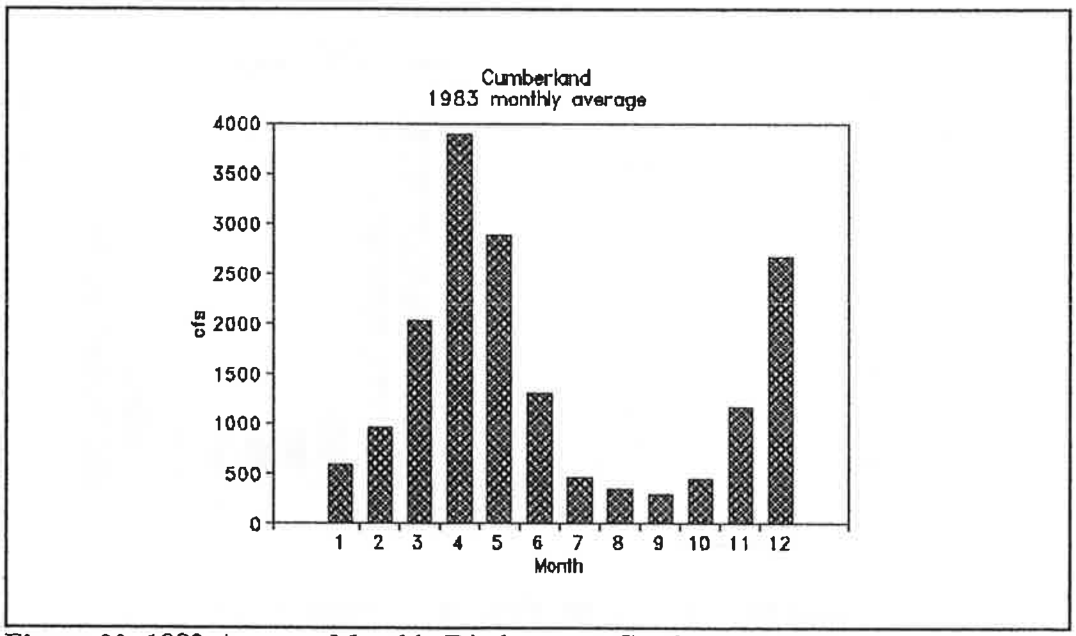

Figure 90. 1983 Average Monthly Discharge at Cumberland, MD.

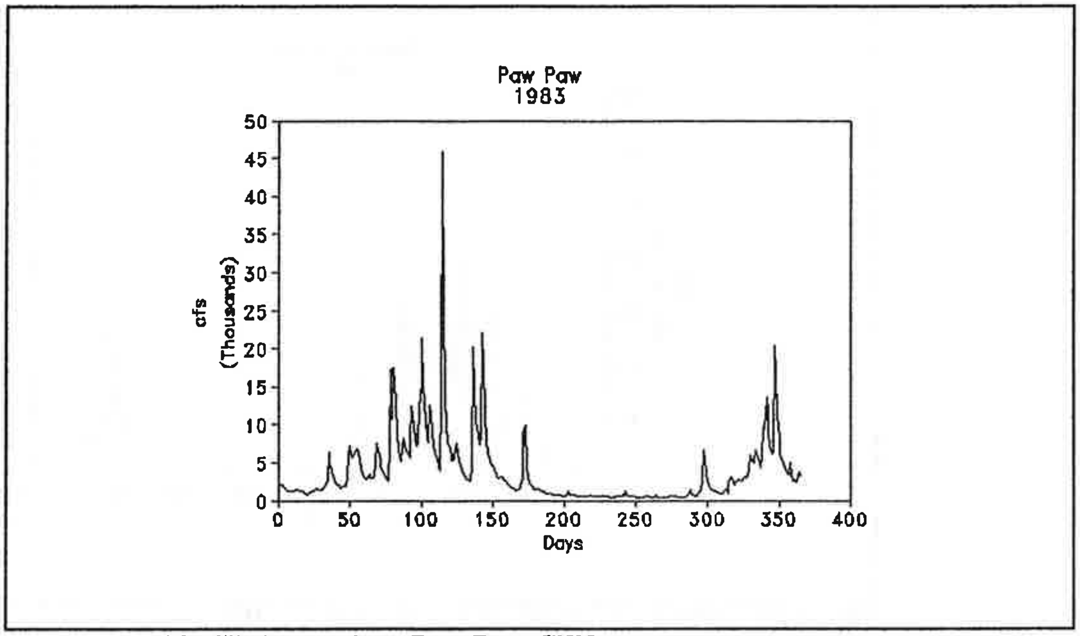

Figure 91. 1983 Hydrograph at Paw Paw, WV.

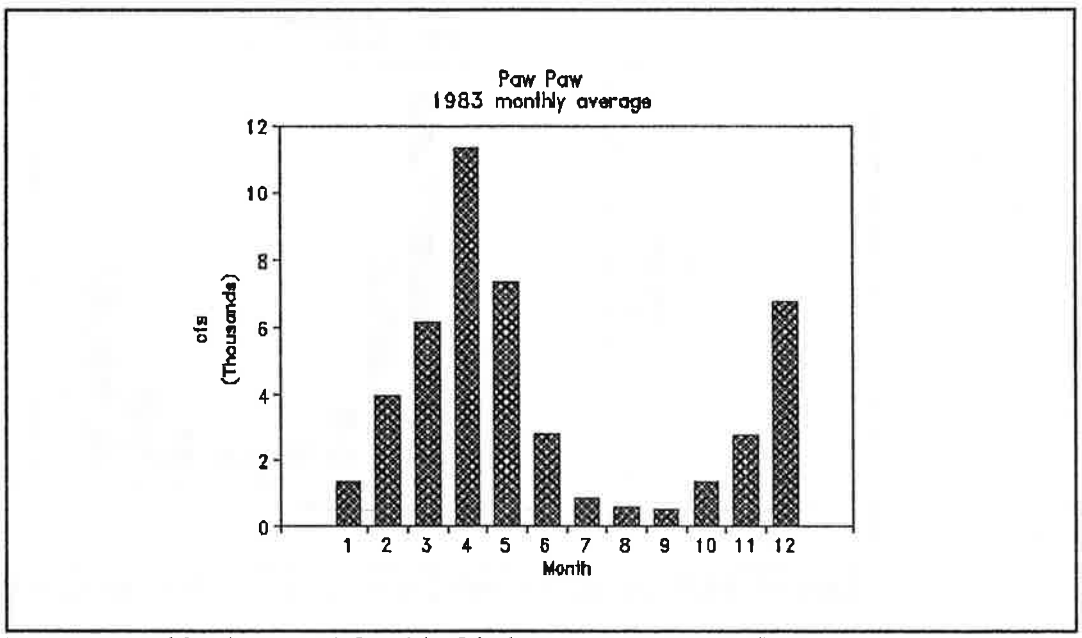

Figure 92. 1983 Average Monthly Discharge at Paw Paw, WV.

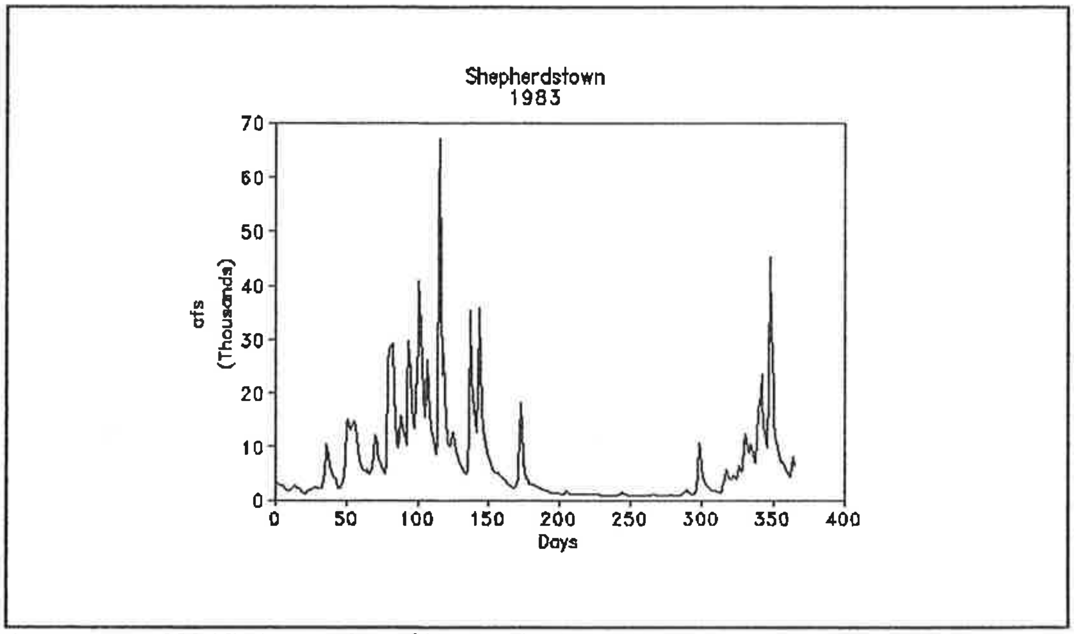

Figure 93. 1983 Hydrograph at Shepherdstown, WV.

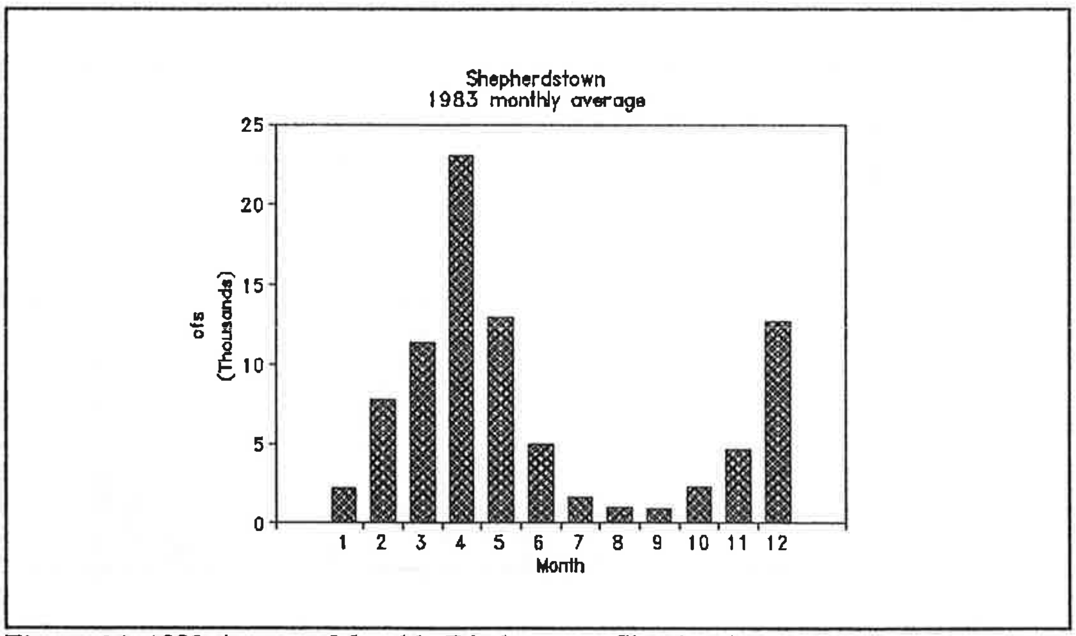

Figure 94. 1983 Average Monthly Discharge at Shepherdstown, WV.

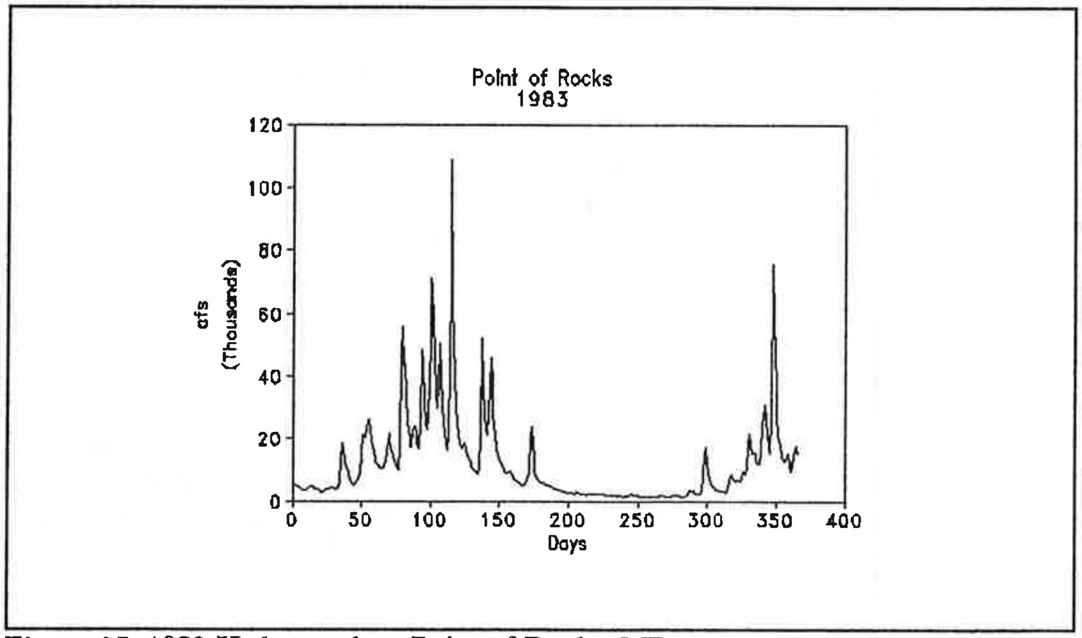

Figure 95. 1983 Hydrograph at Point of Rocks, MD.

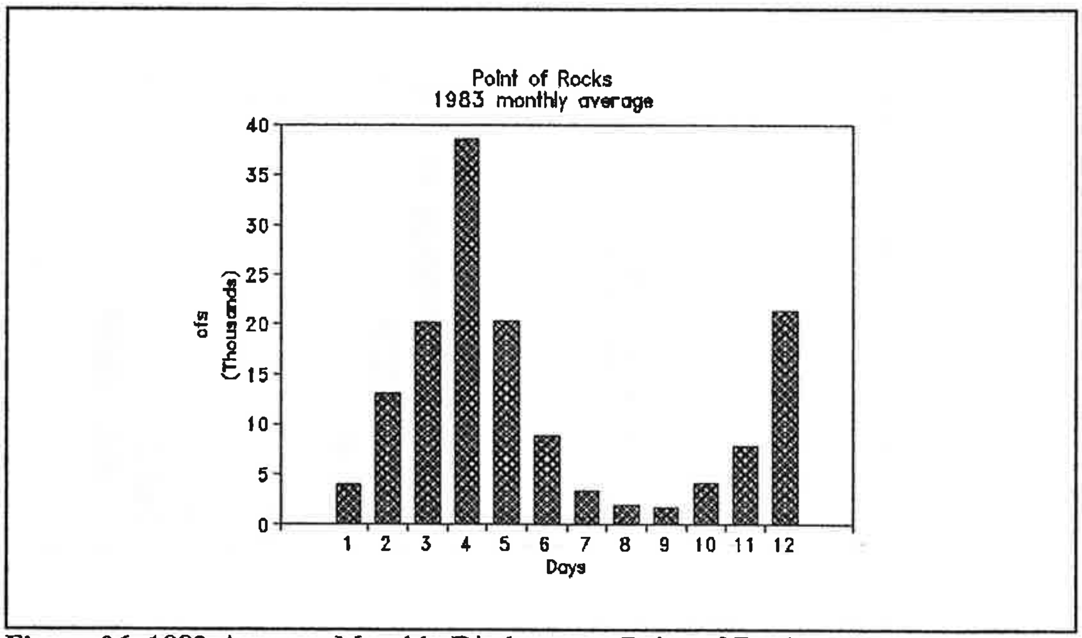

Figure 96. 1983 Average Monthly Discharge at Point of Rocks, MD.

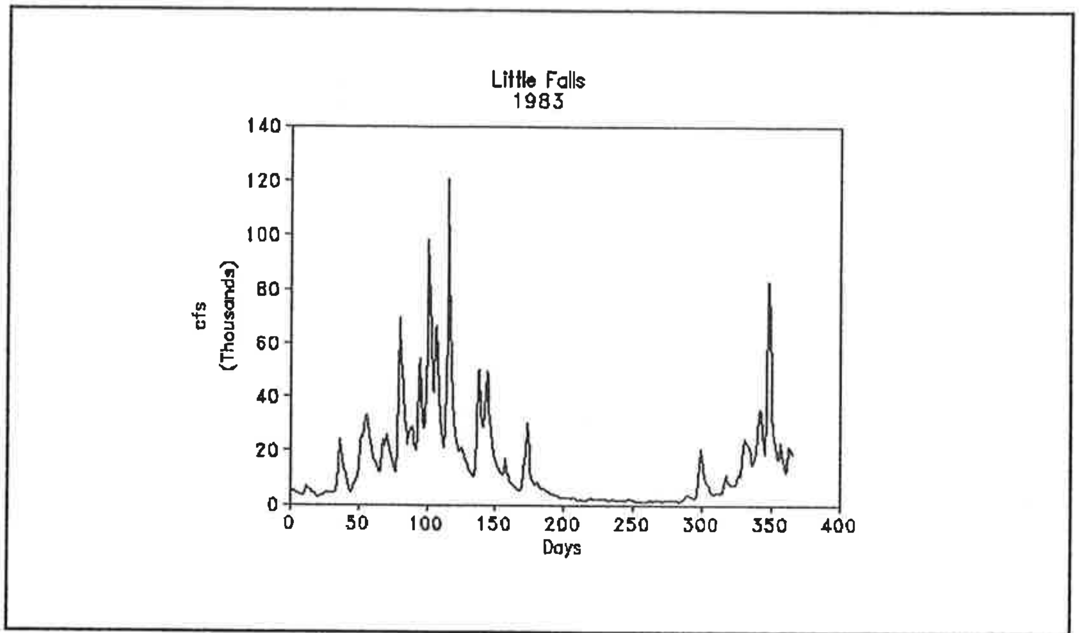

Figure 97. 1983 Hydrograph at Little Falls Dam, MD.

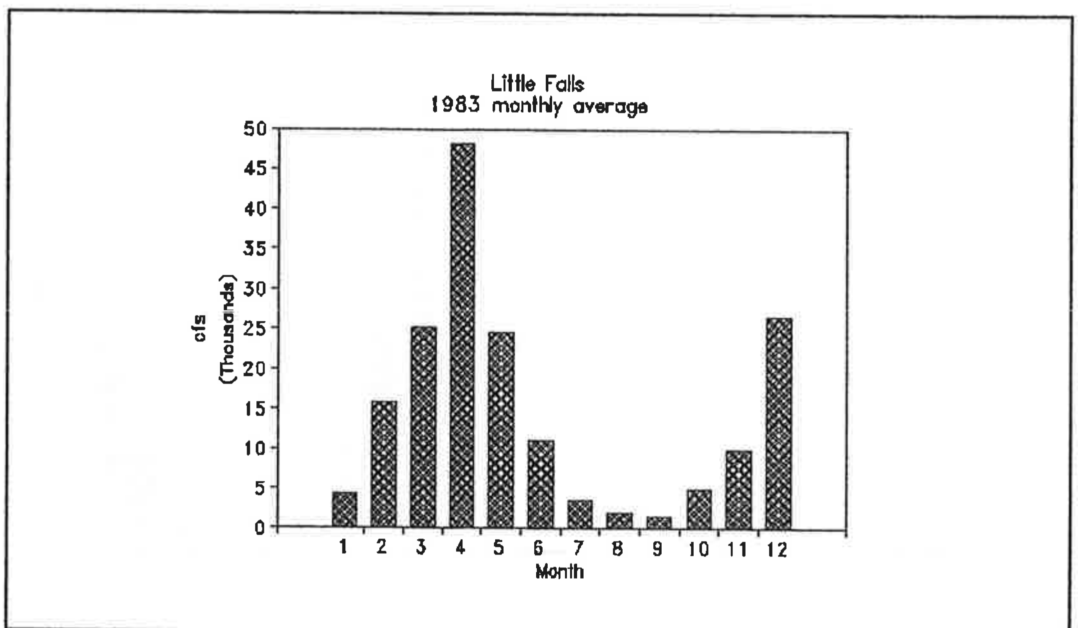

Figure 98. 1983 Average Monthly Discharge at Little Falls Dam, MD.

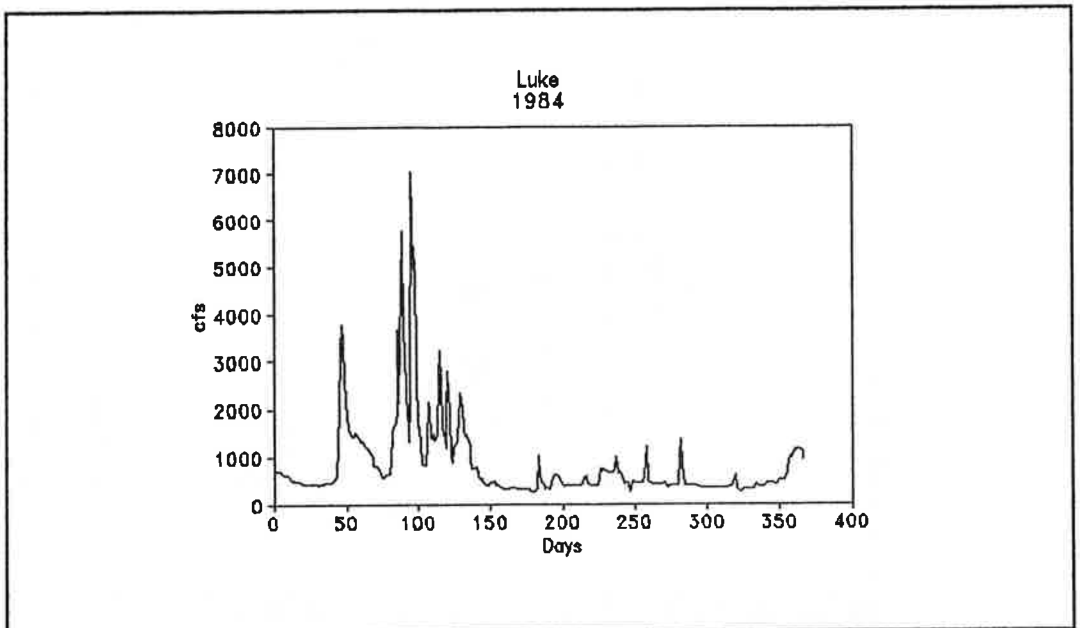

Figure 99. 1984 Hydrograph at Luke, MD.

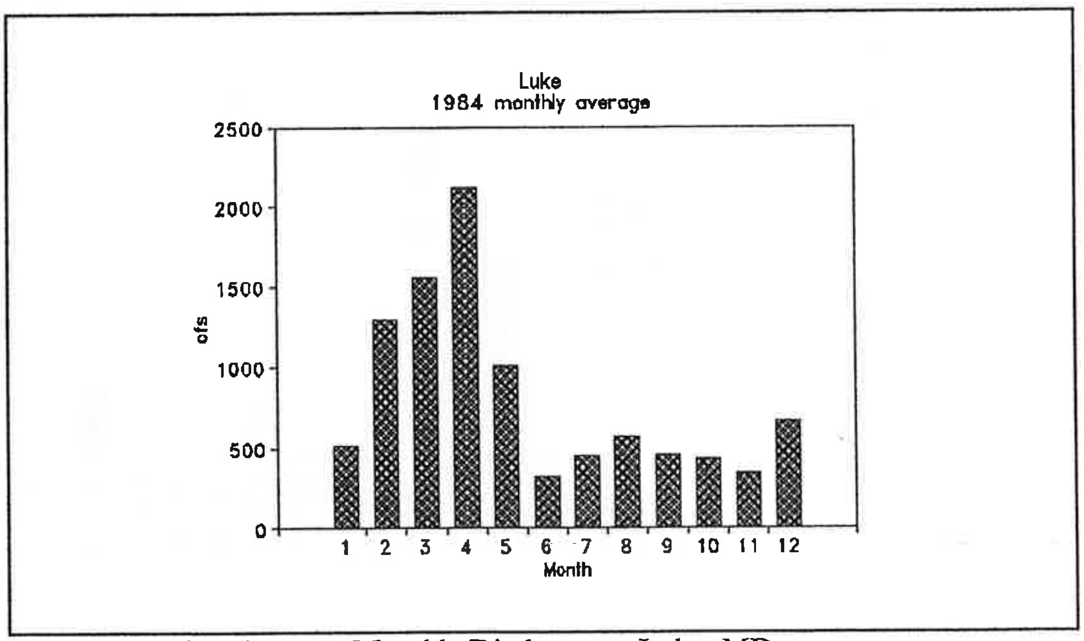

Figure 100. 1984 Average Monthly Discharge at Luke, MD.

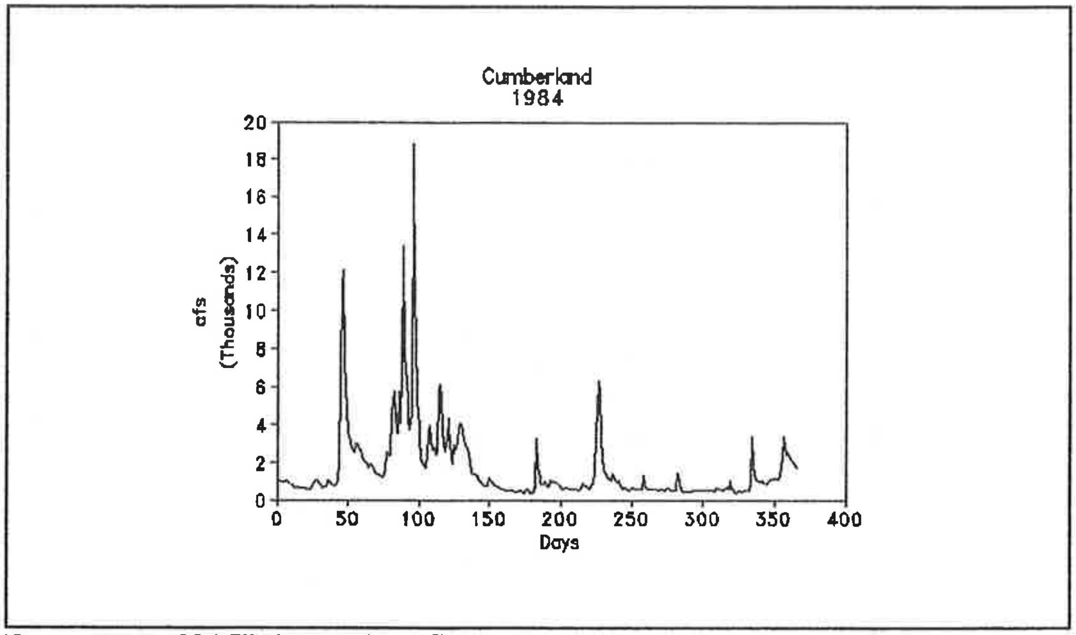

Figure 101. 1984 Hydrograph at Cumberland, MD.

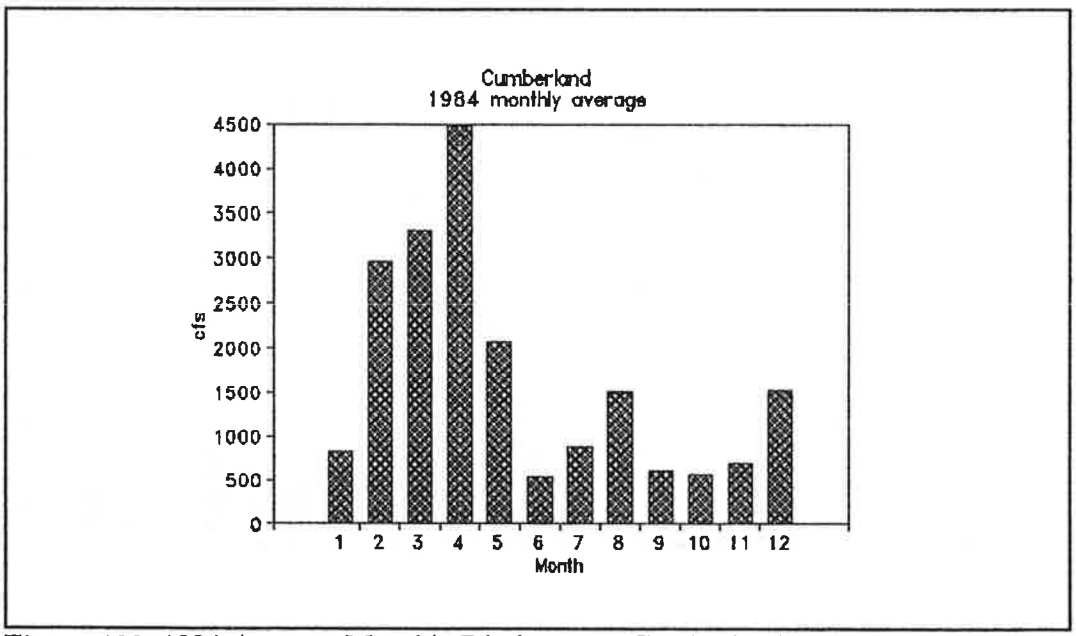

Figure 102. 1984 Average Monthly Discharge at Cumberland, MD.

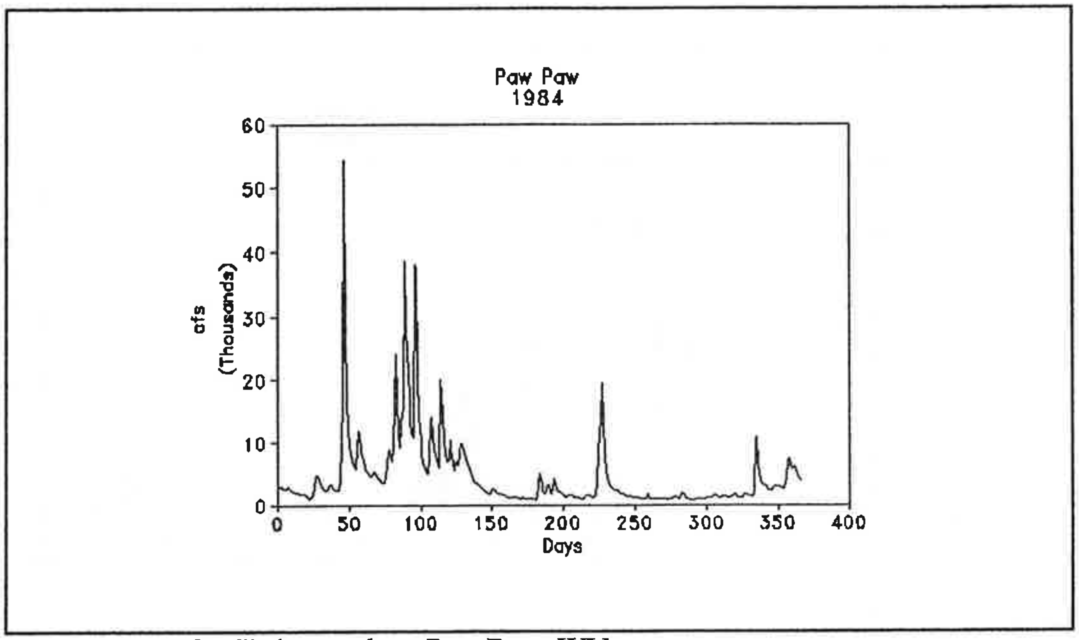

Figure 103. 1984 Hydrograph at Paw Paw, WV.

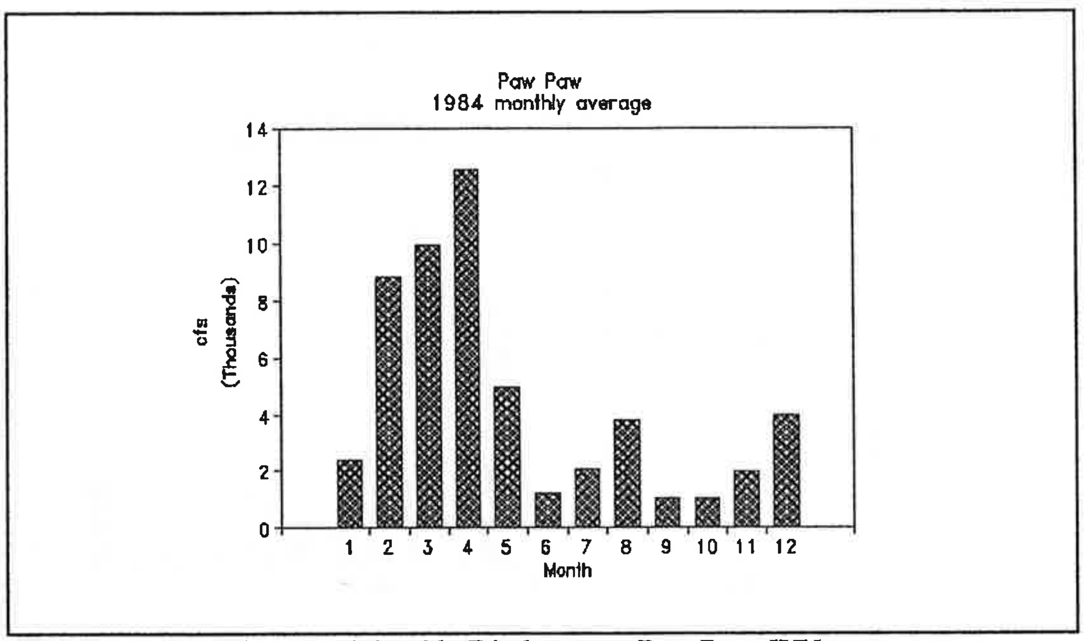

Figure 104. 1984 Average Monthly Discharge at Paw Paw, WV.

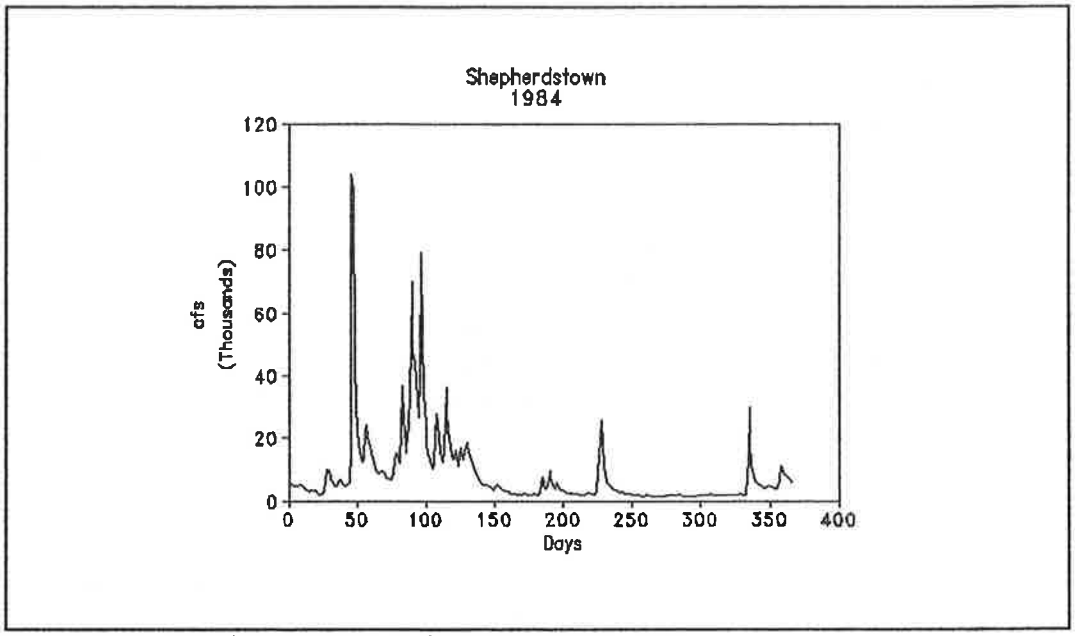

Figure 105. 1984 Hydrograph at Shepherdstown, WV.

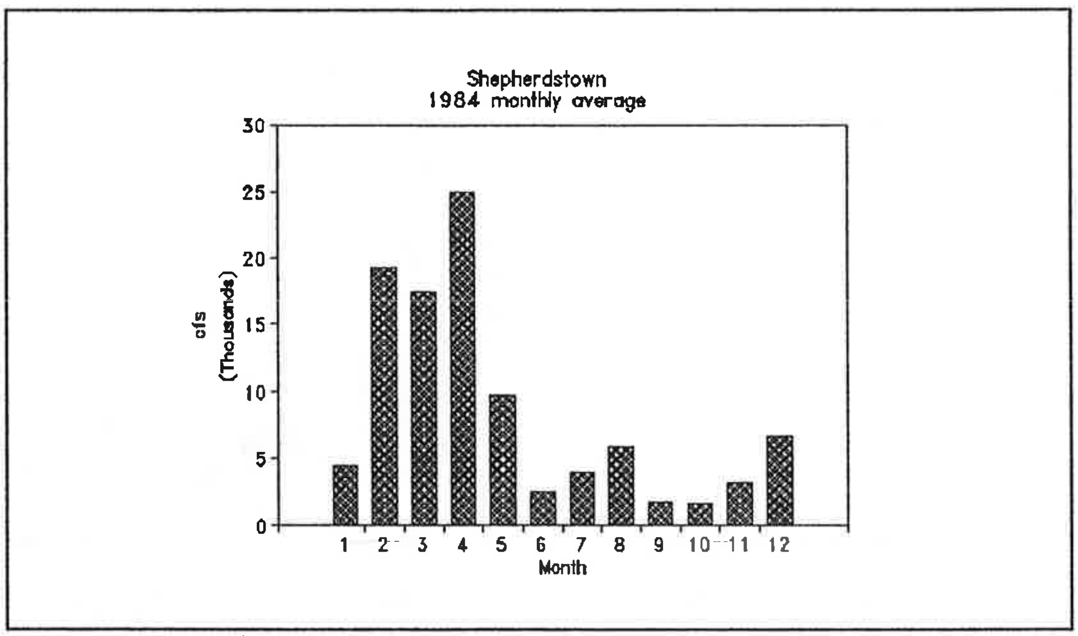

Figure 106. 1984 Average Monthly Discharge at Shepherdstown, WV.

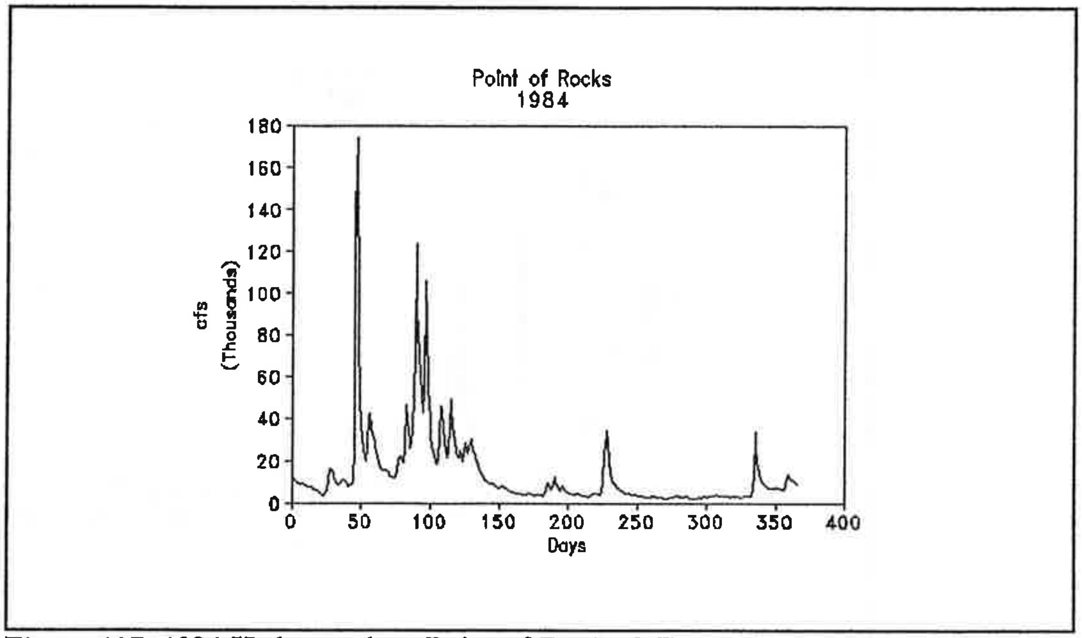

Figure 107. 1984 Hydrograph at Point of Rocks, MD.

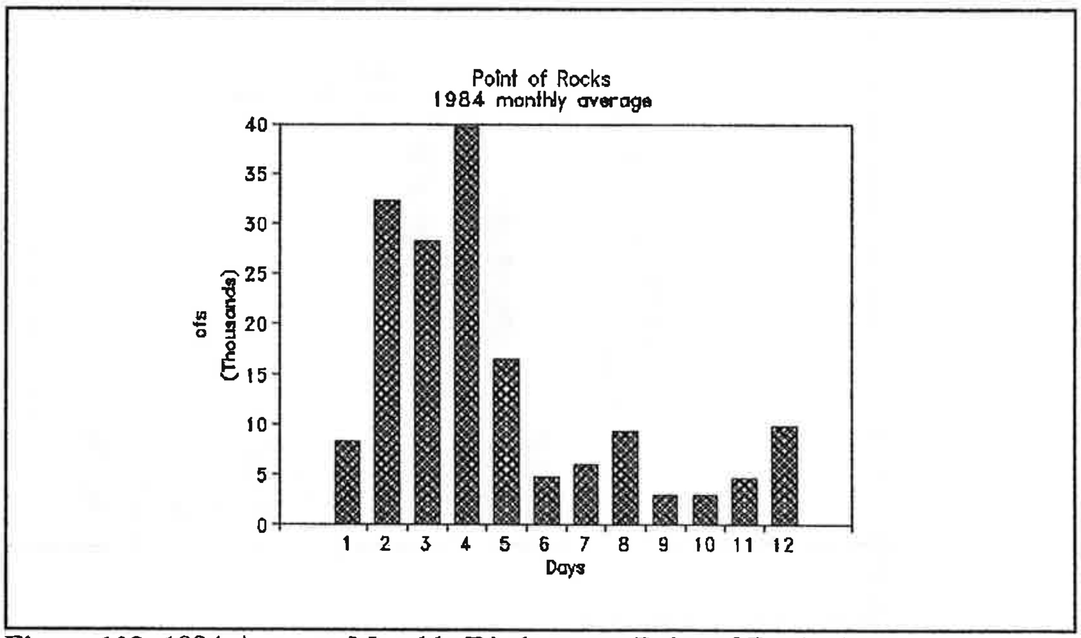

Figure 108. 1984 Average Monthly Discharge at Point of Rocks, MD.

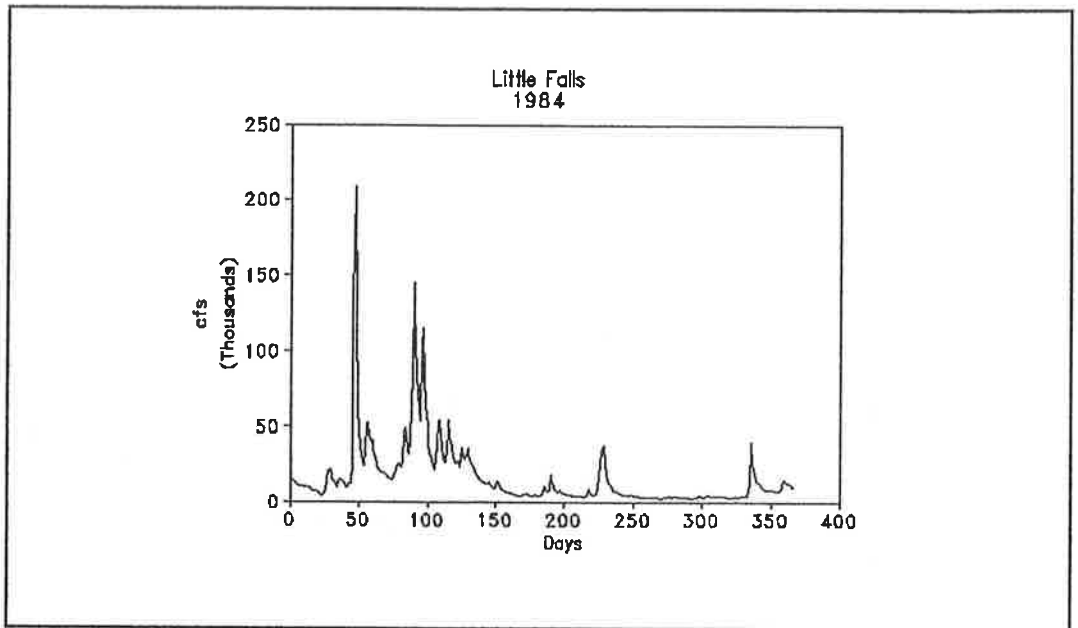

Figure 109. 1984 Hydrograph at Little Falls Dam, MD.

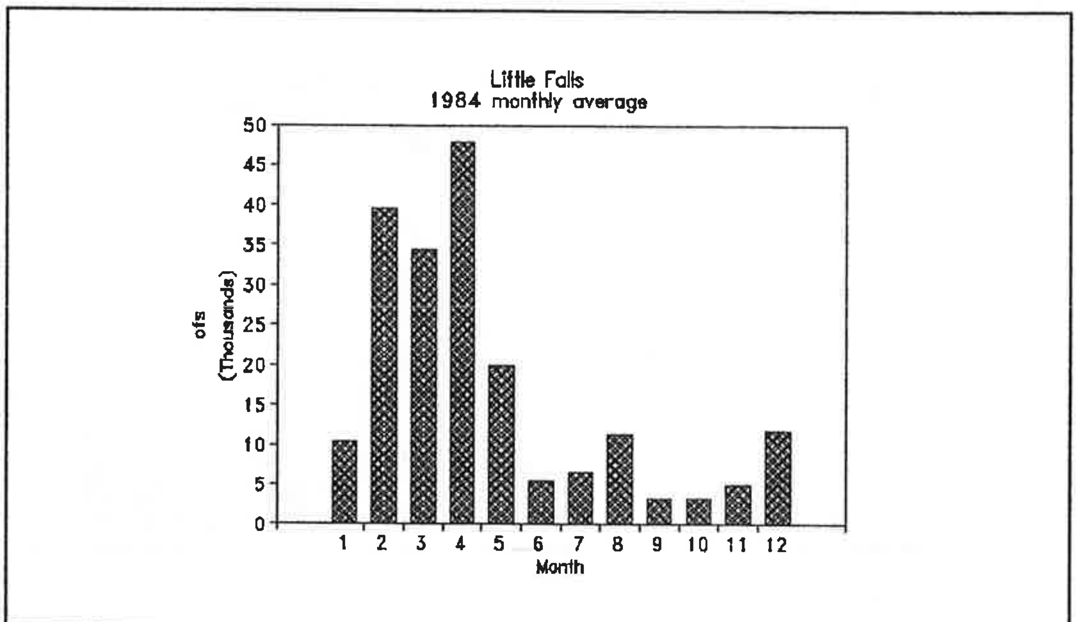

Figure 110. 1984 Average Monthly Discharge at Little Falls Dam, MD.

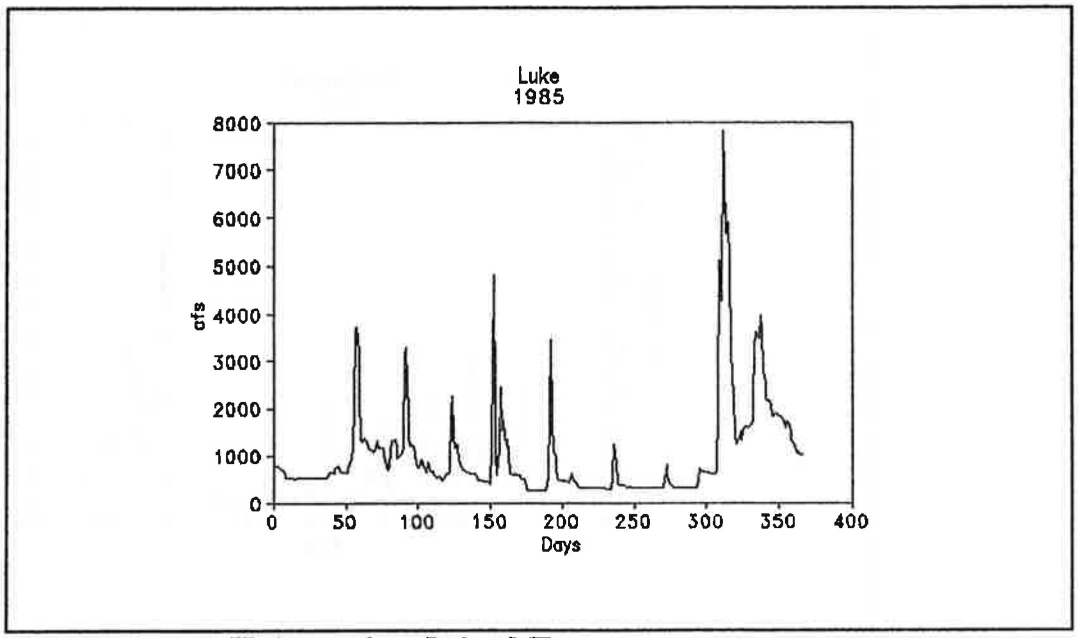

Figure 111. 1985 Hydrograph at Luke, MD.

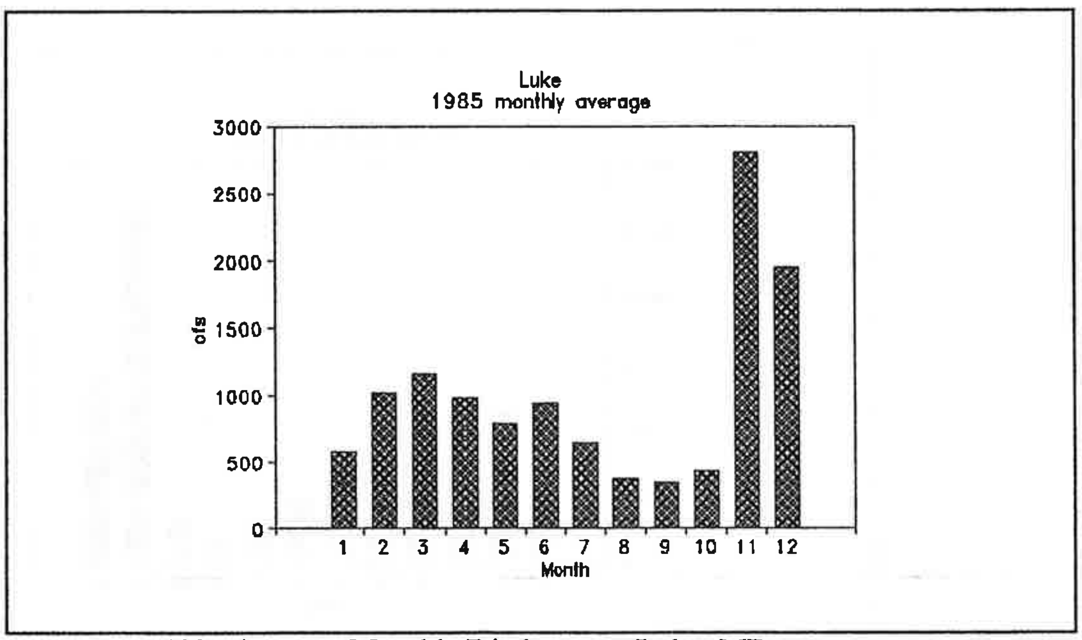

Figure 112. 1985 Average Monthly Discharge at Luke, MD.

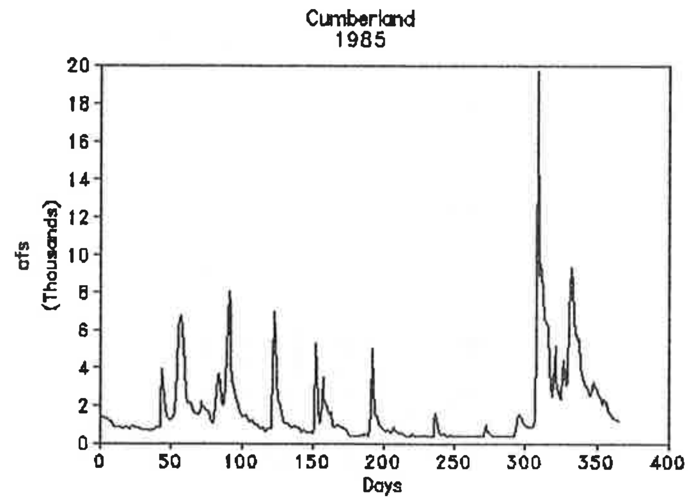

Figure 113. 1985 Hydrograph at Cumberland, MD.

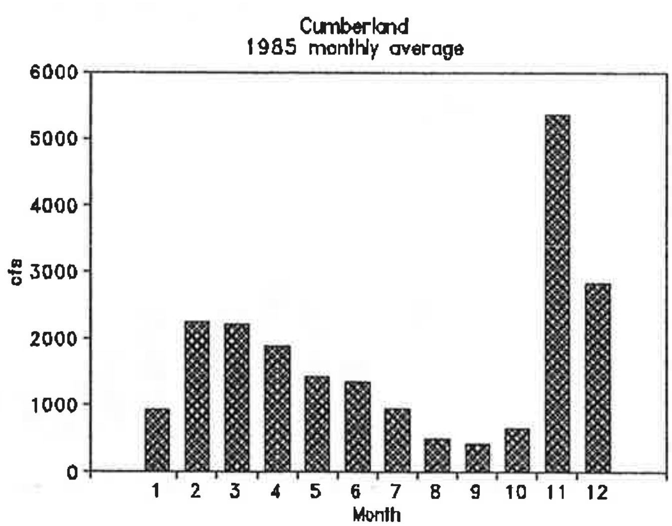

Figure 114. 1985 Average Monthly Discharge at Cumberland, MD.

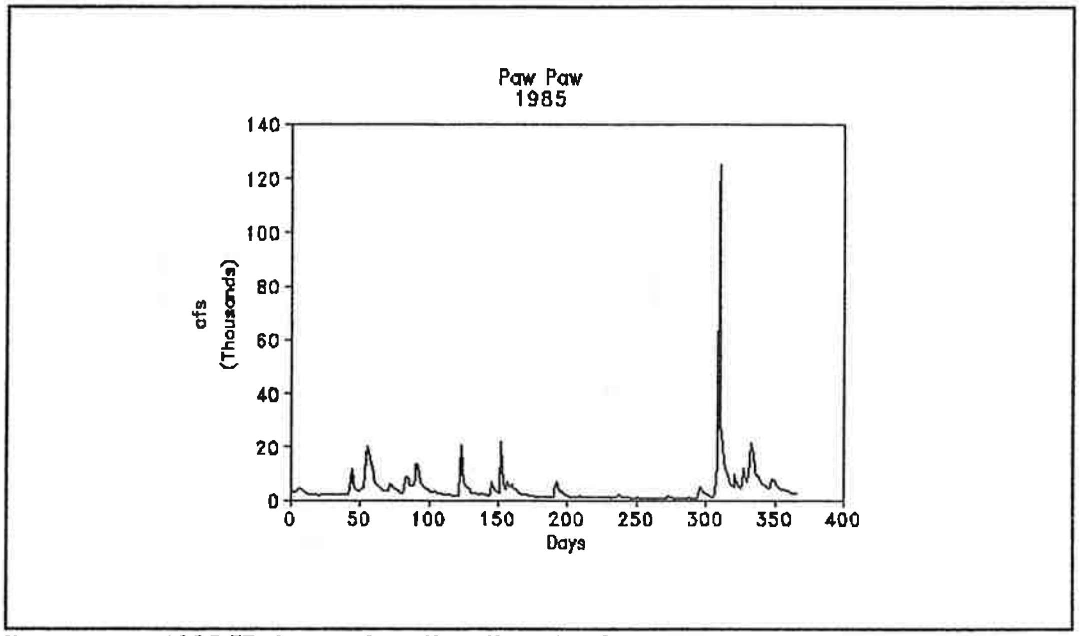

Figure 115. 1985 Hydrograph at Paw Paw, WV.

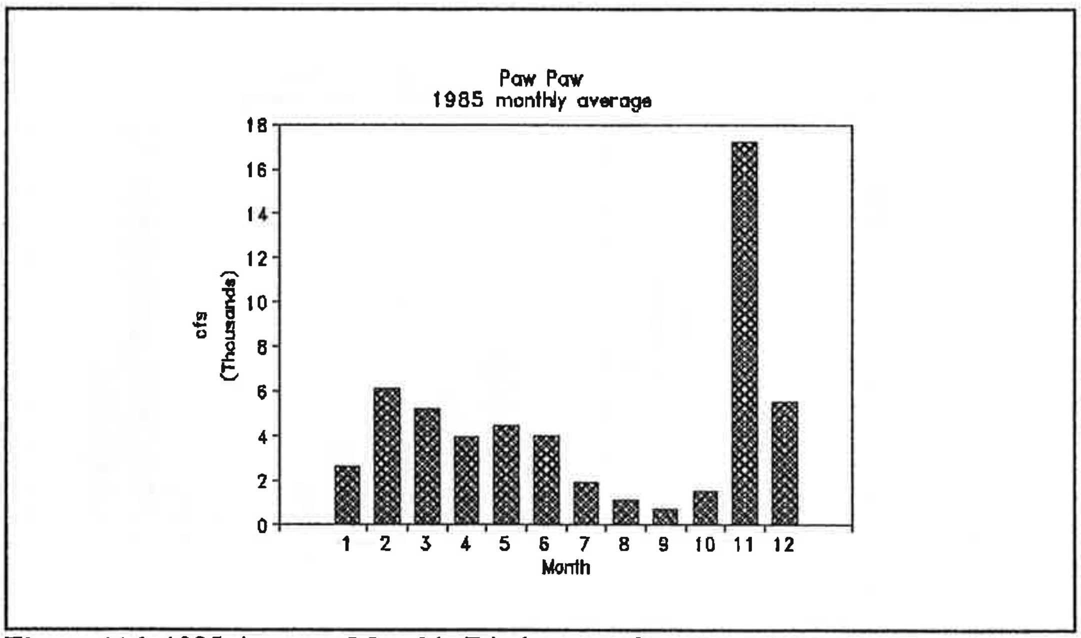

Figure 116. 1985 Average Monthly Discharge at Paw Paw, WV.

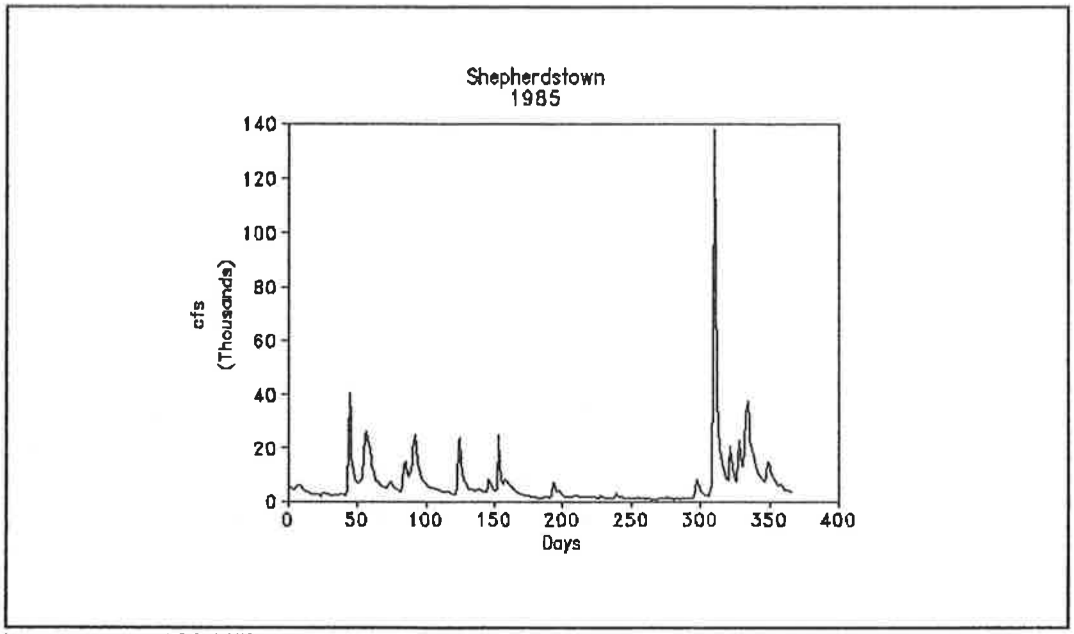

Figure 117. 1985 Hydrograph at Shepherdstown, WV.

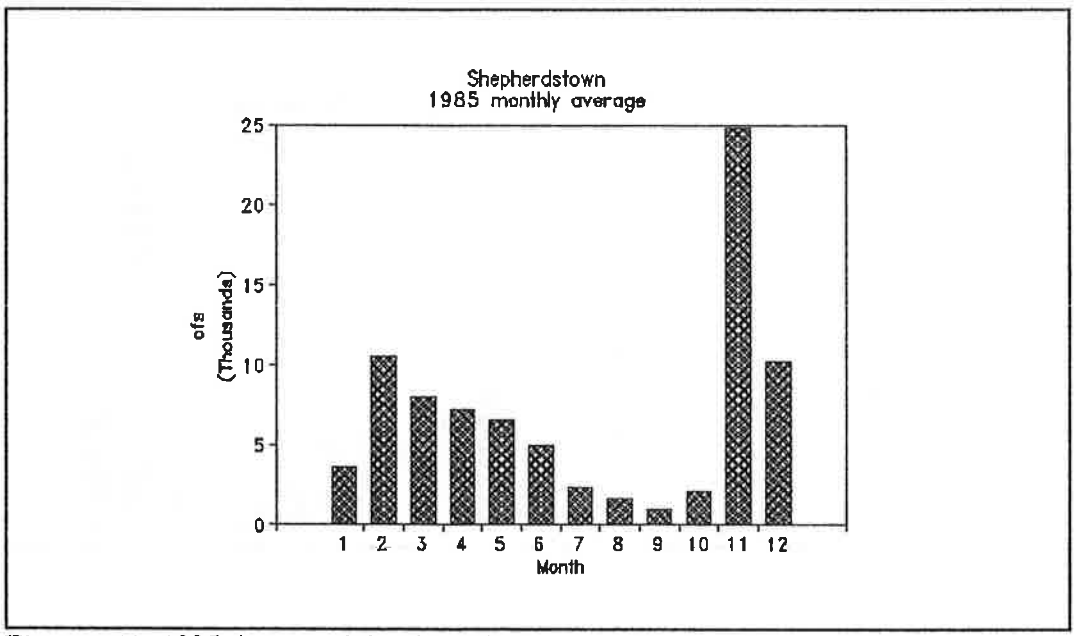

Figure 118. 1985 Average Monthly Discharge at Shepherdstown, WV.

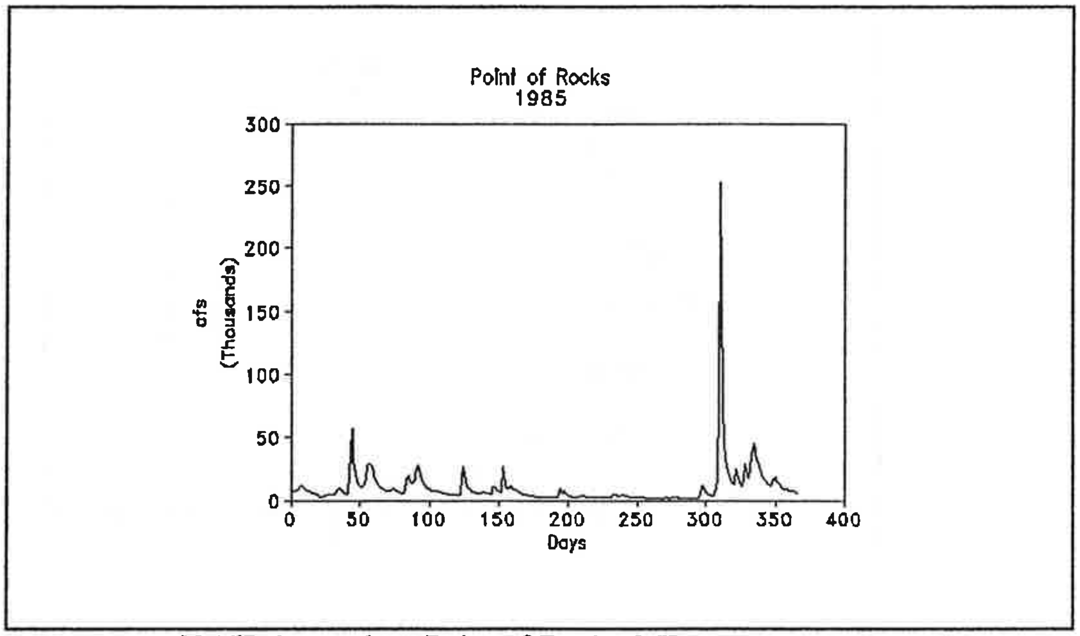

Figure 119. 1985 Hydrograph at Point of Rocks, MD.

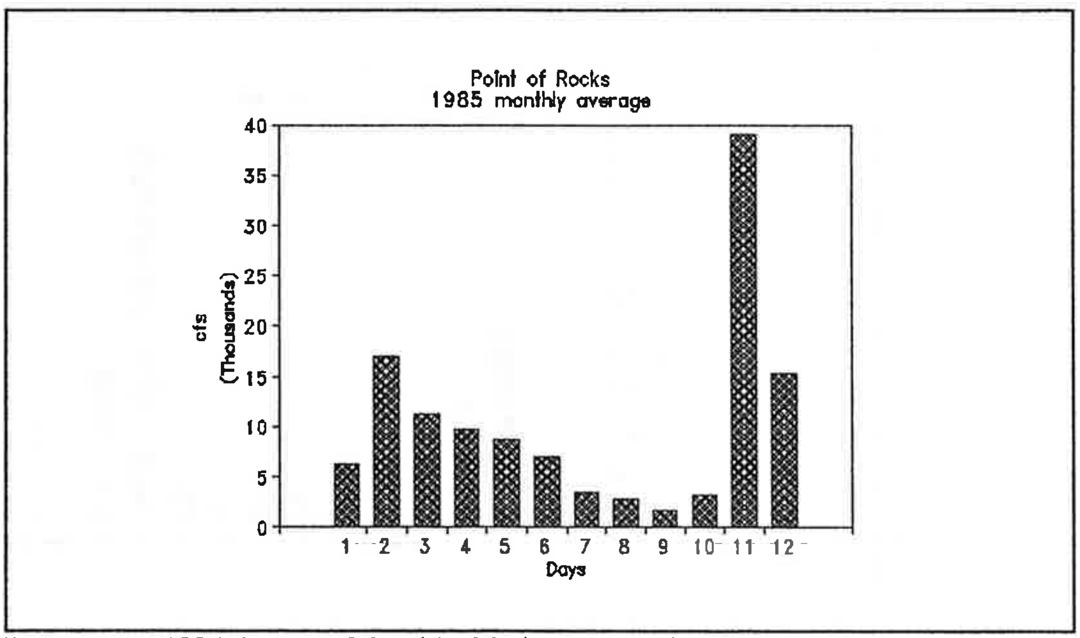

Figure 120. 1985 Average Monthly Discharge at Point of Rocks, MD.

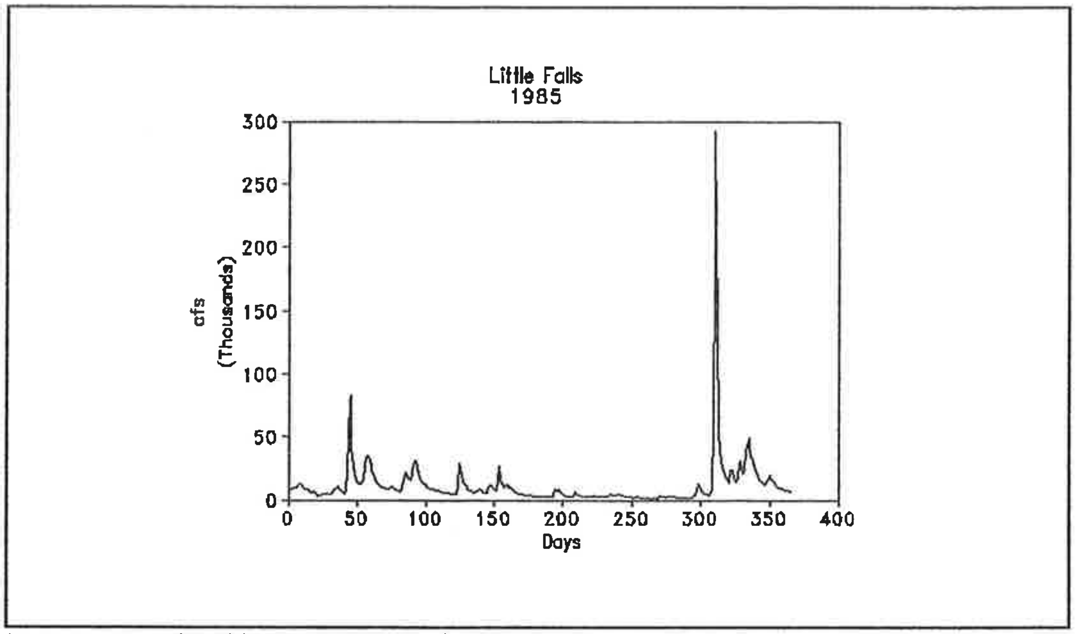

Figure 121. 1985 Hydrograph at Little Falls Dam, MD.

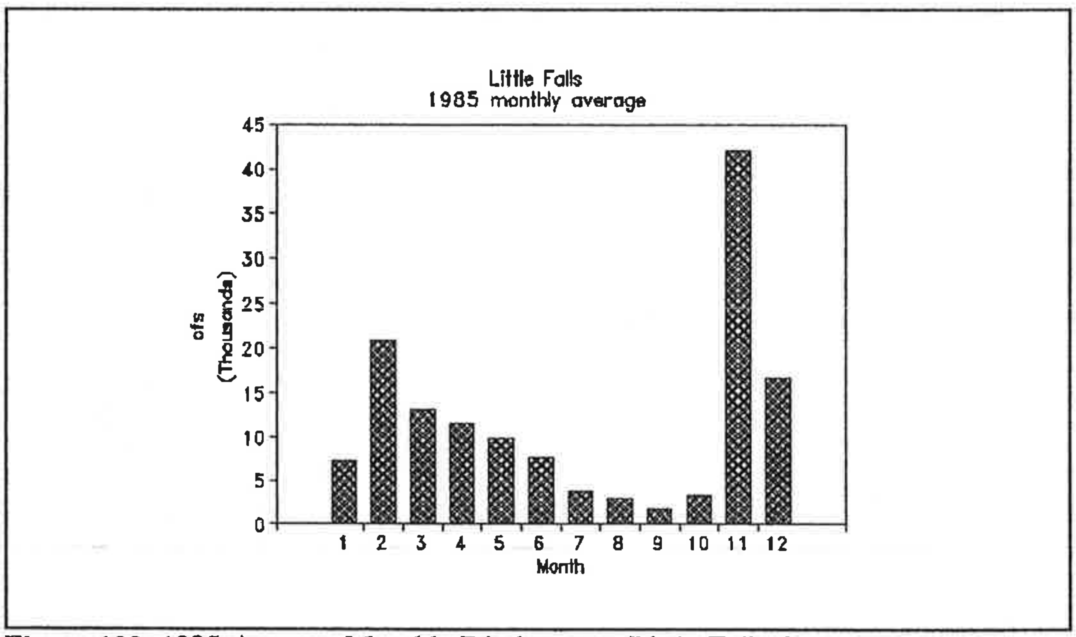

Figure 122. 1985 Average Monthly Discharge at Little Falls Dam, MD.

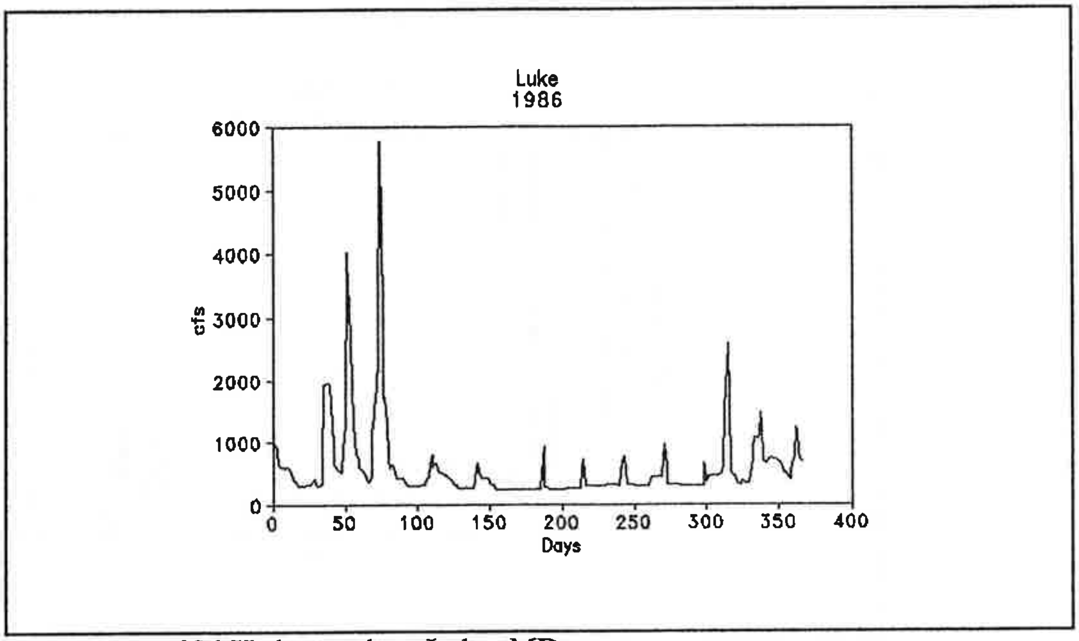

Figure 123. 1986 Hydrograph at Luke, MD.

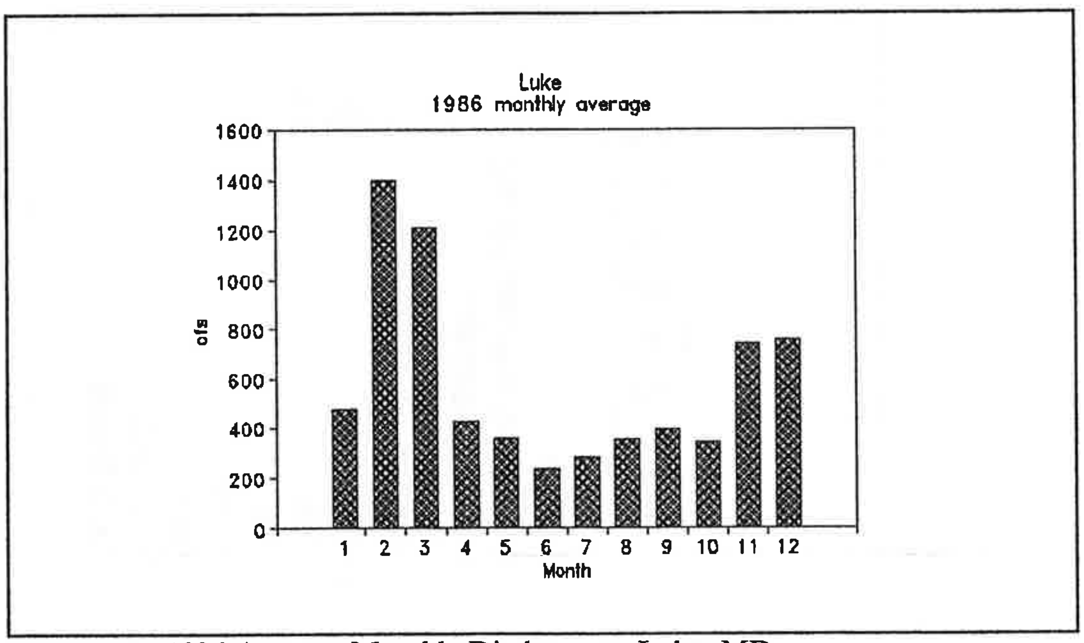

Figure 124. 1986 Average Monthly Discharge at Luke, MD.

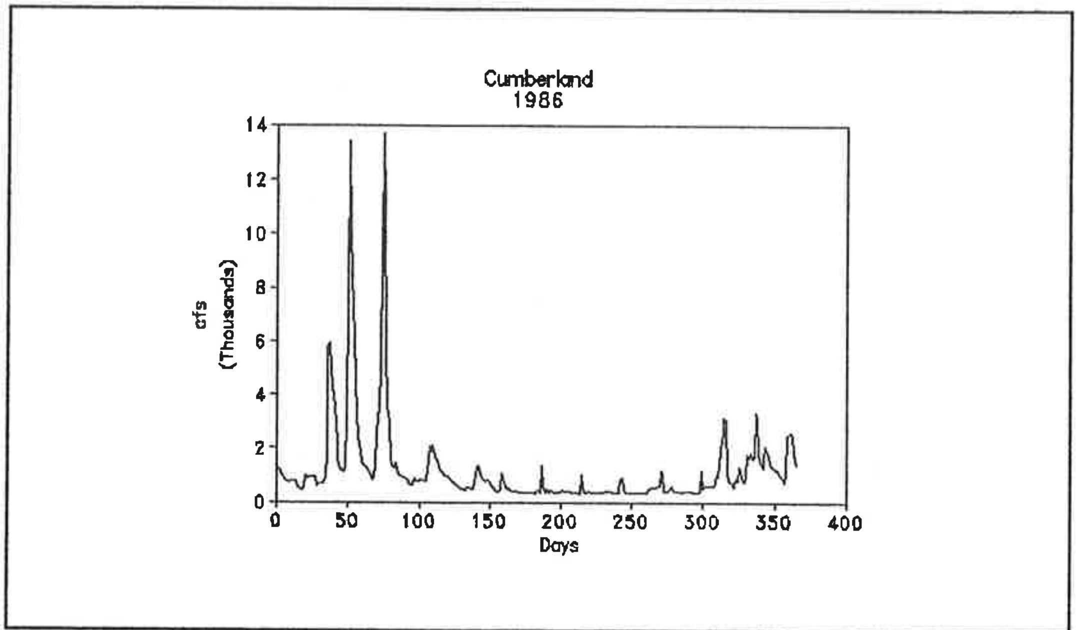

Figure 125. 1986 Hydrograph at Cumberland, MD.

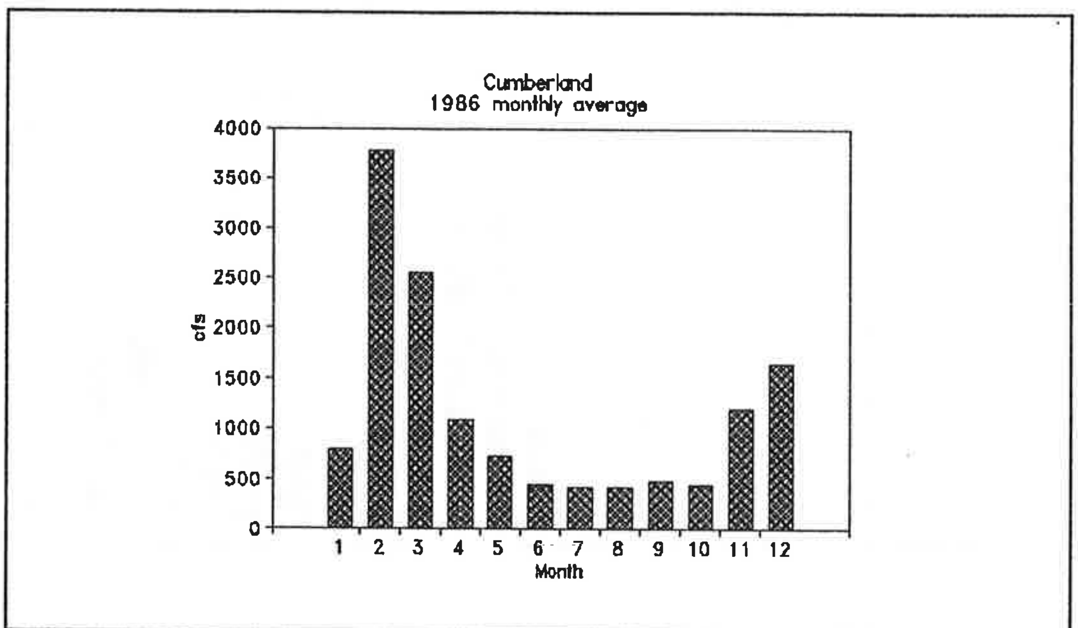

Figure 126. 1986 Average Monthly Discharge at Cumberland, MD.

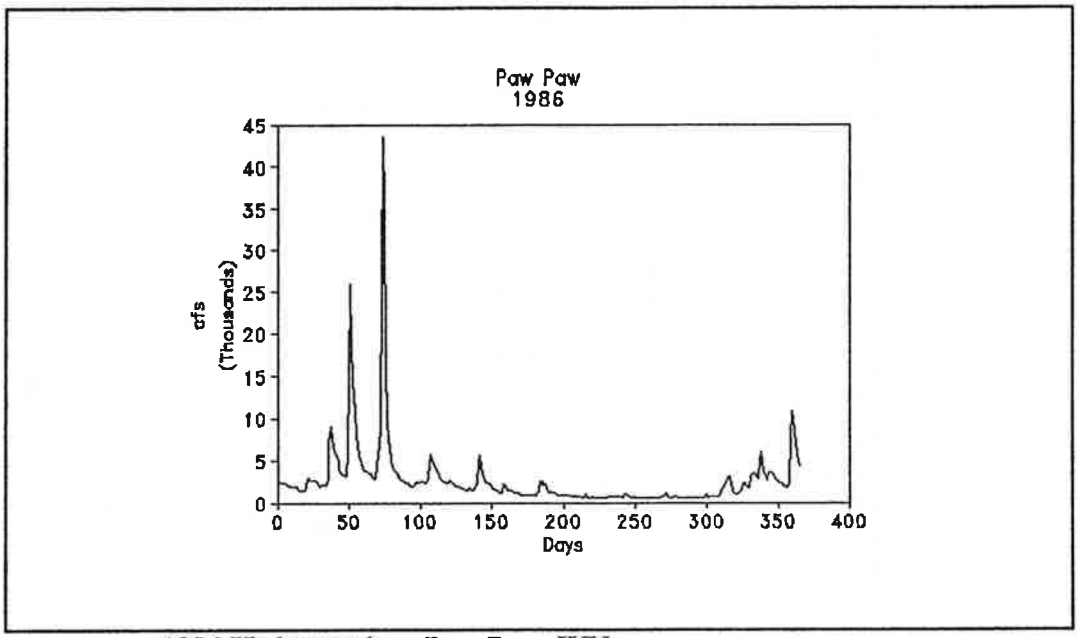

Figure 127. 1986 Hydrograph at Paw Paw, WV.

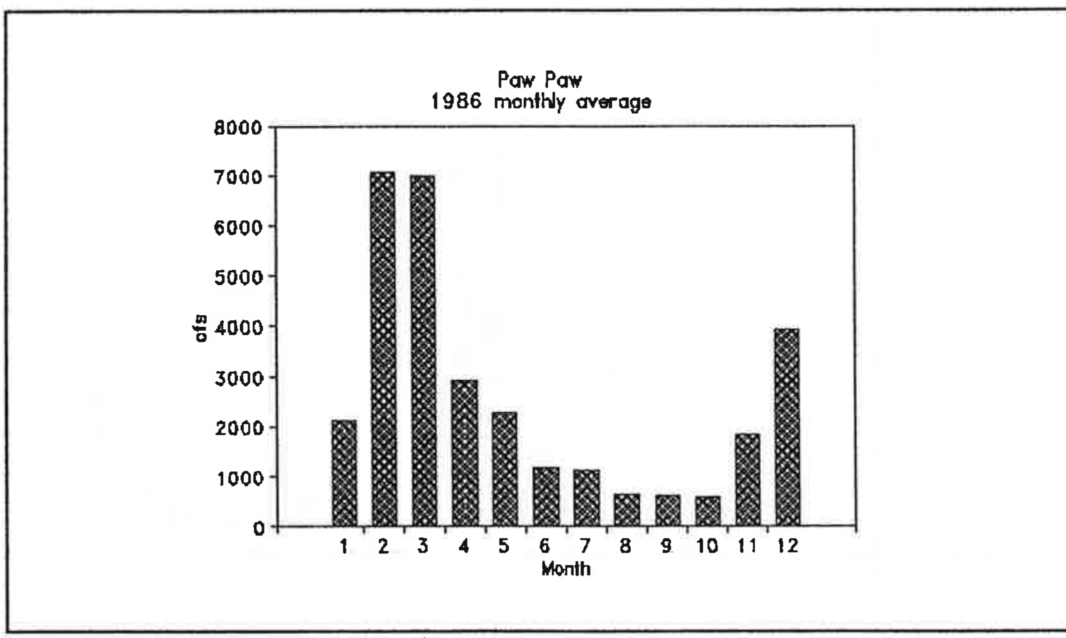

Figure 128. 1986 Average Monthly Discharge at Paw Paw, WV.

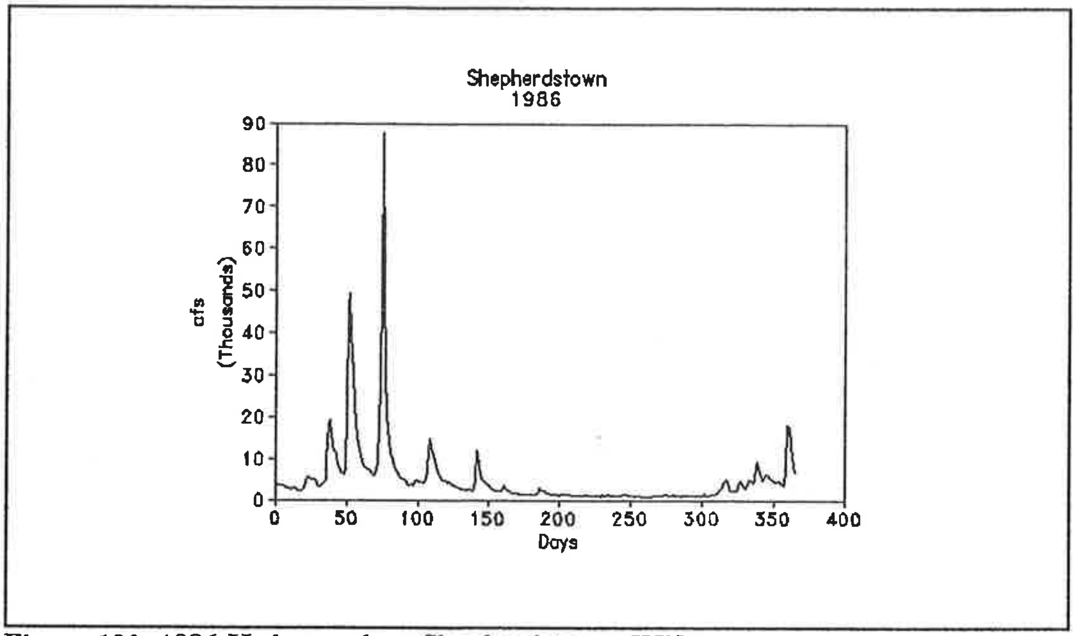

Figure 129. 1986 Hydrograph at Shepherdstown, WV.

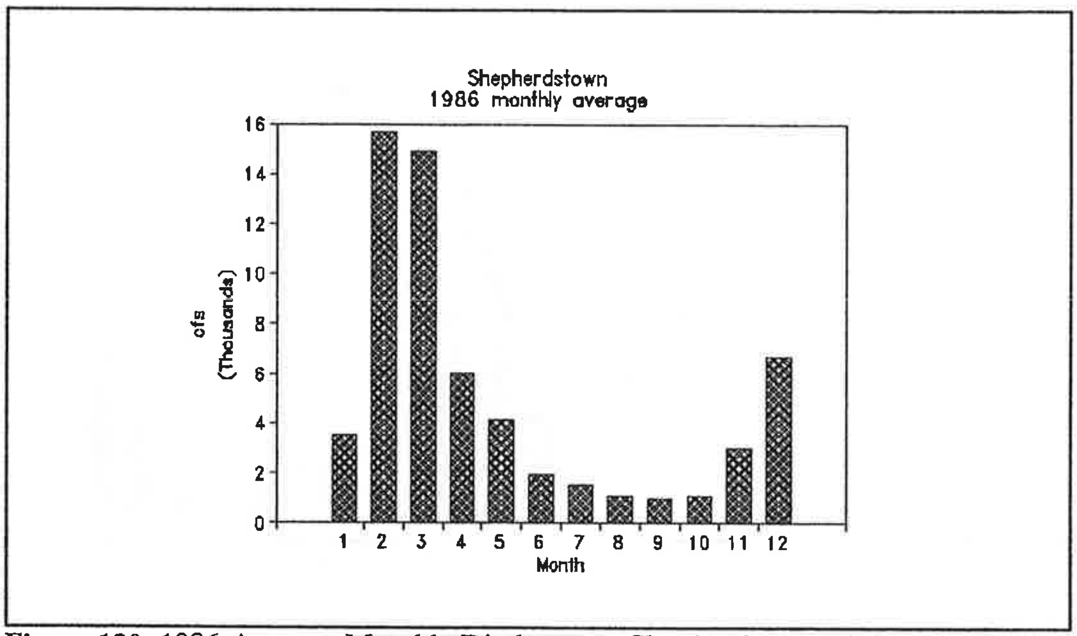

Figure 130. 1986 Average Monthly Discharge at Shepherdstown, WV.

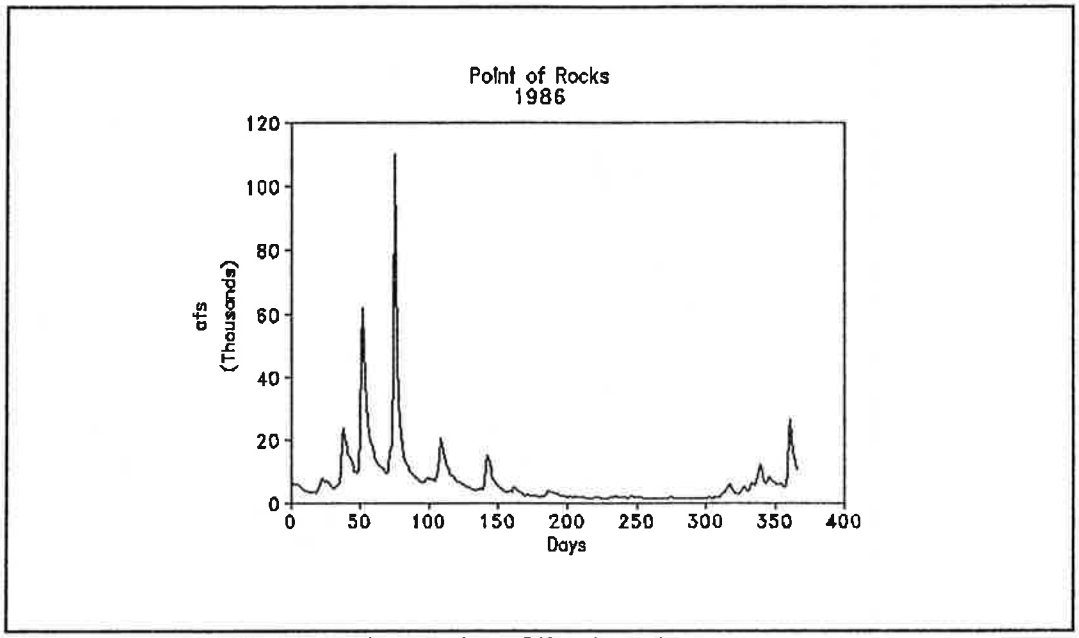

Figure 131. 1986 Hydrograph at Point of Rocks, MD.

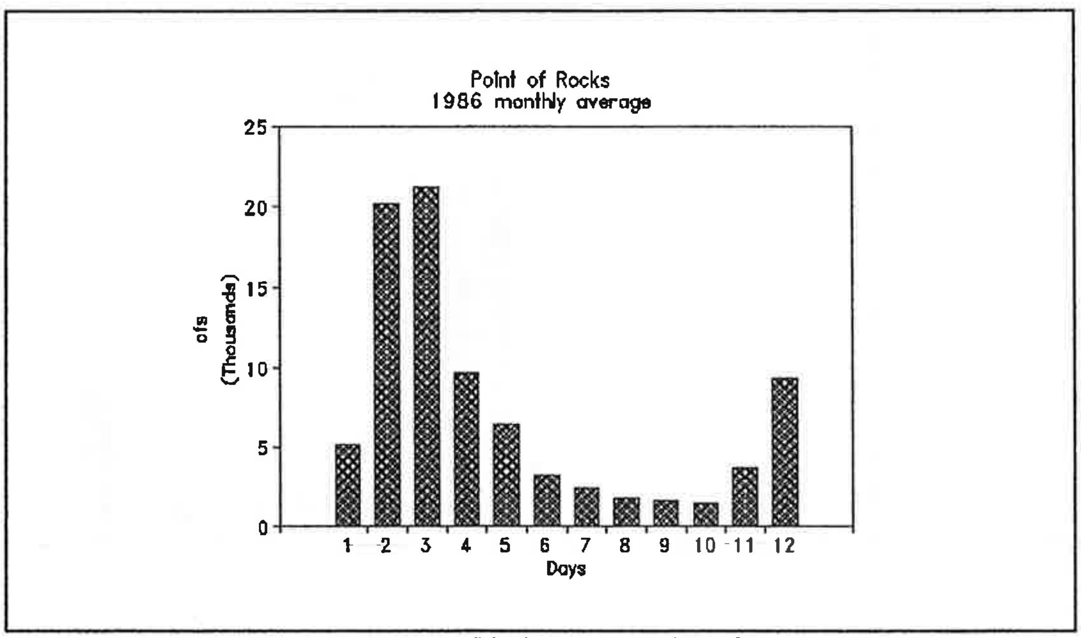

Figure 132. 1986 Average Monthly Discharge at Point of Rocks, MD.

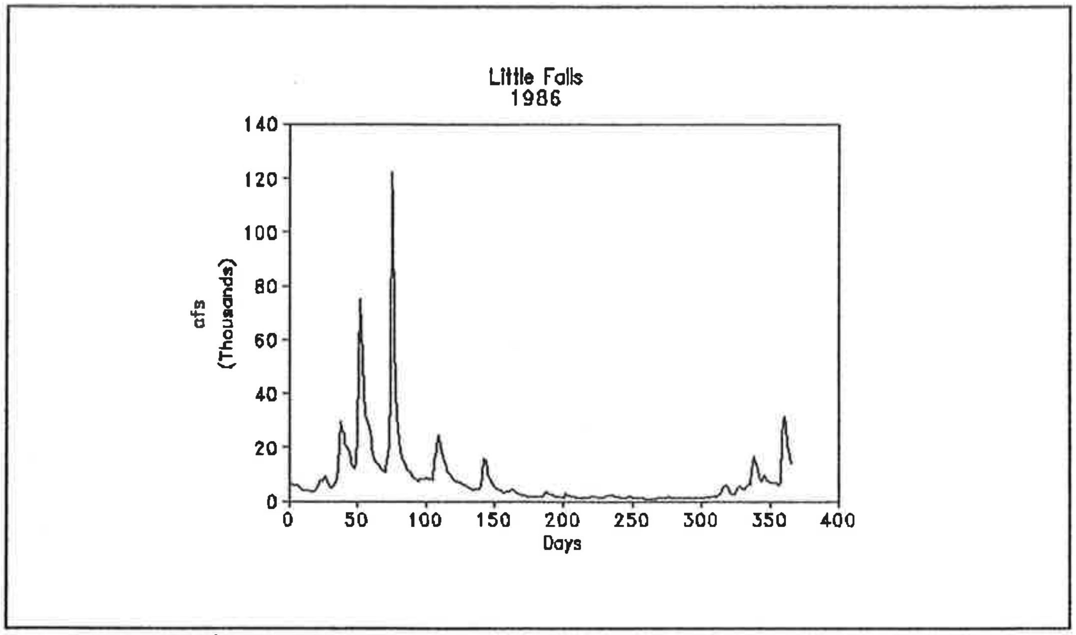

Figure 133. 1986 Hydrograph at Little Falls Dam, MD.

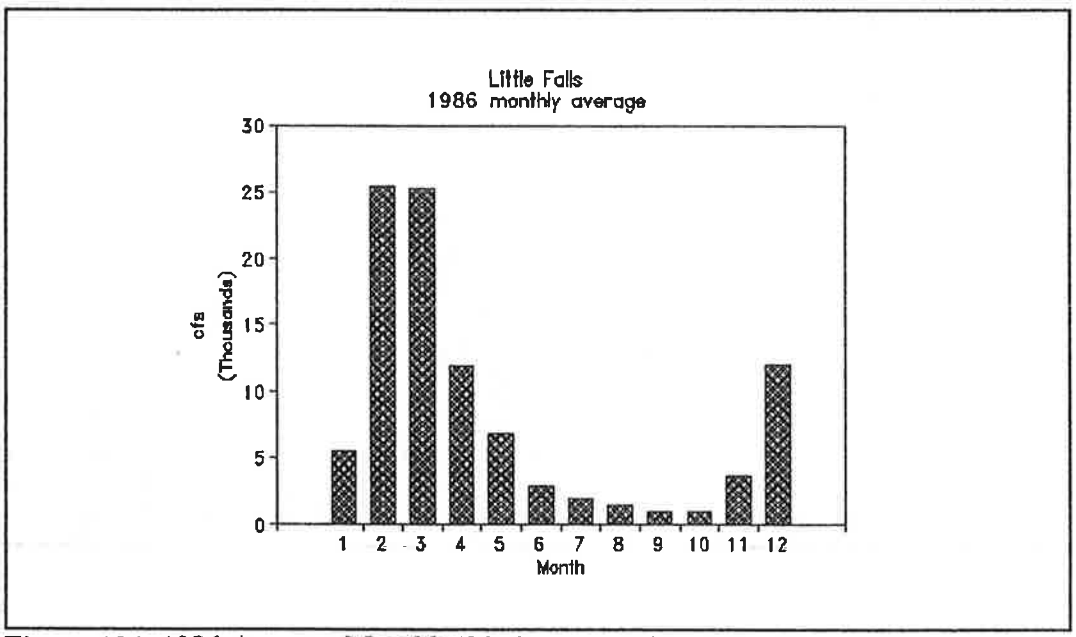

Figure 134. 1986 Average Monthly Discharge at Little Falls Dam, MD.

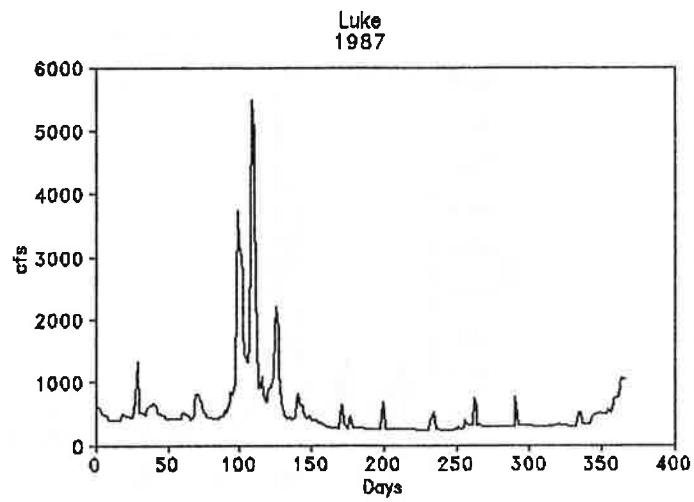

Figure 135. 1987 Hydrograph at Luke, MD.

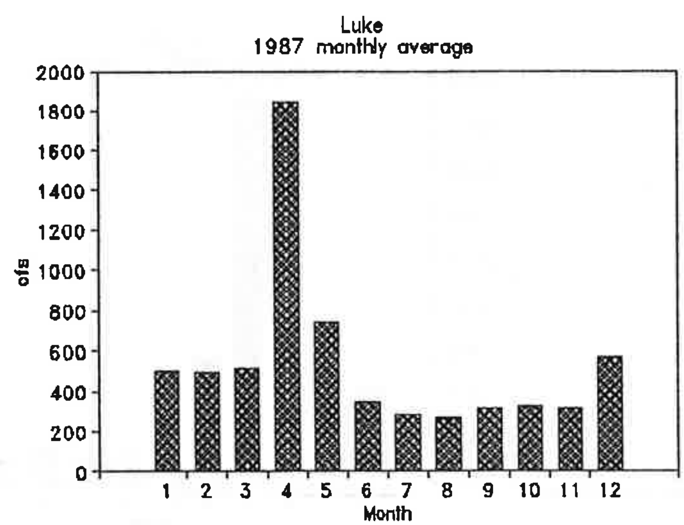

Figure 136. 1987 Average Monthly Discharge at Luke, MD.

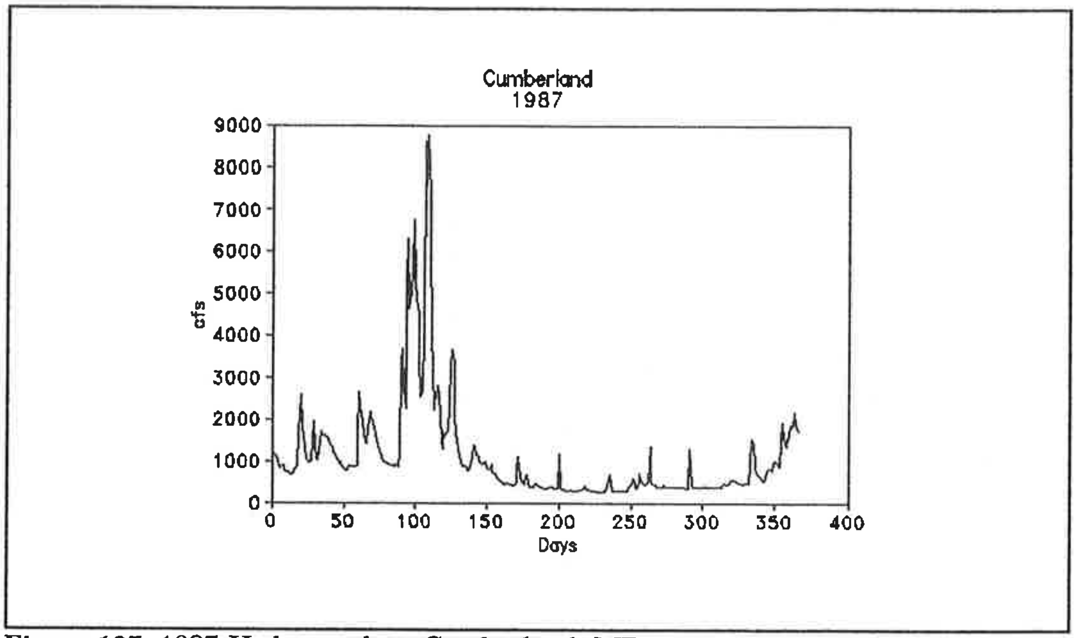

Figure 137. 1987 Hydrograph at Cumberland, MD.

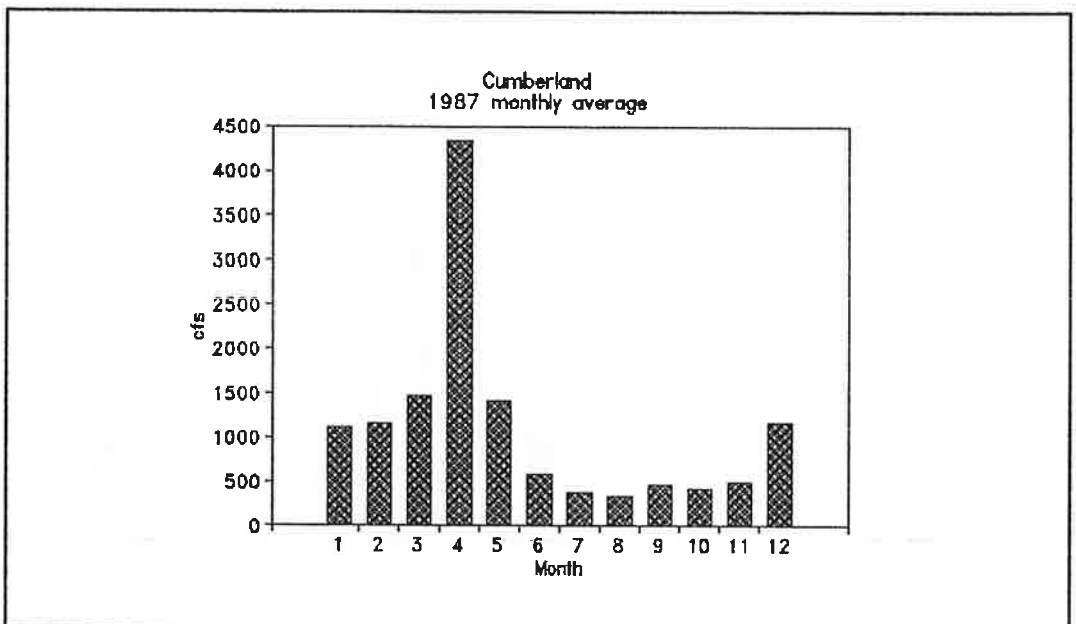

Figure 138. 1987 Average Monthly Discharge at Cumberland, MD.

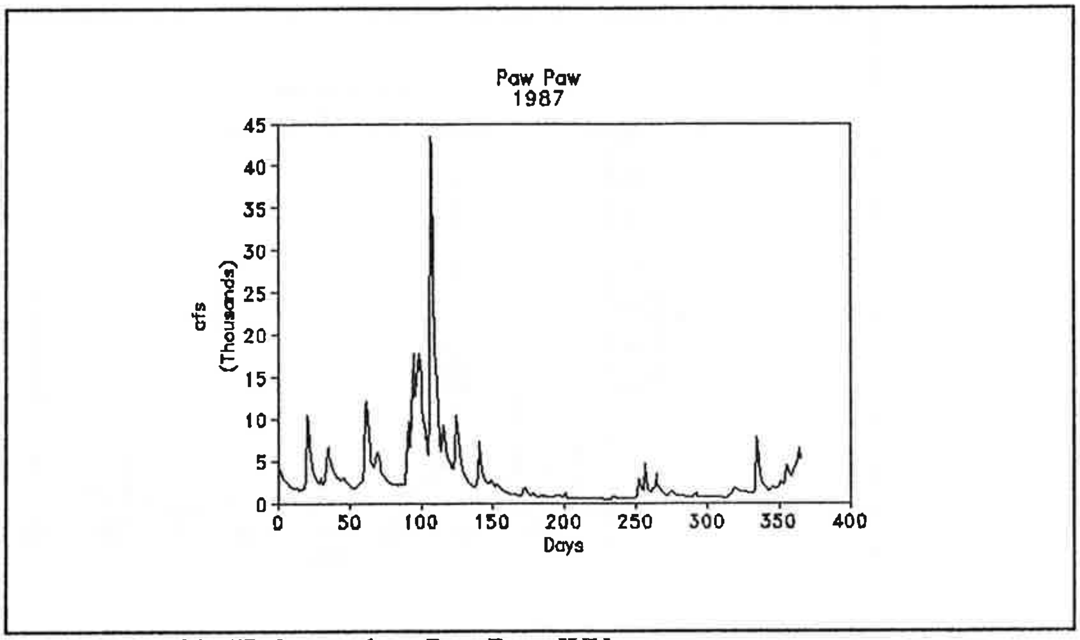

Figure 139. 1987 Hydrograph at Paw Paw, WV.

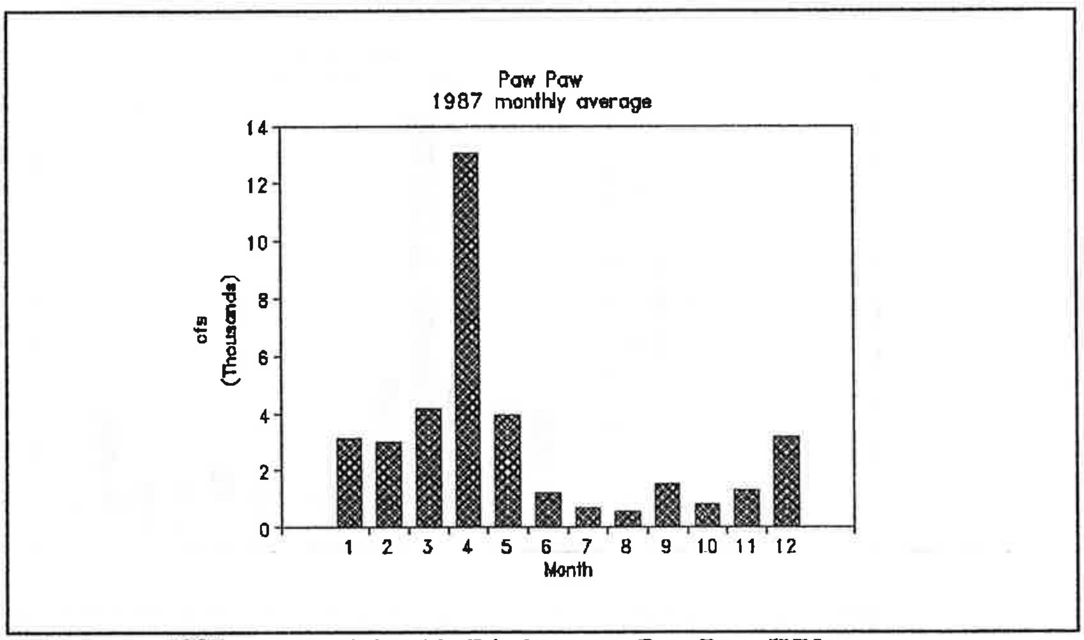

Figure 140. 1987 Average Monthly Discharge at Paw Paw, WV.

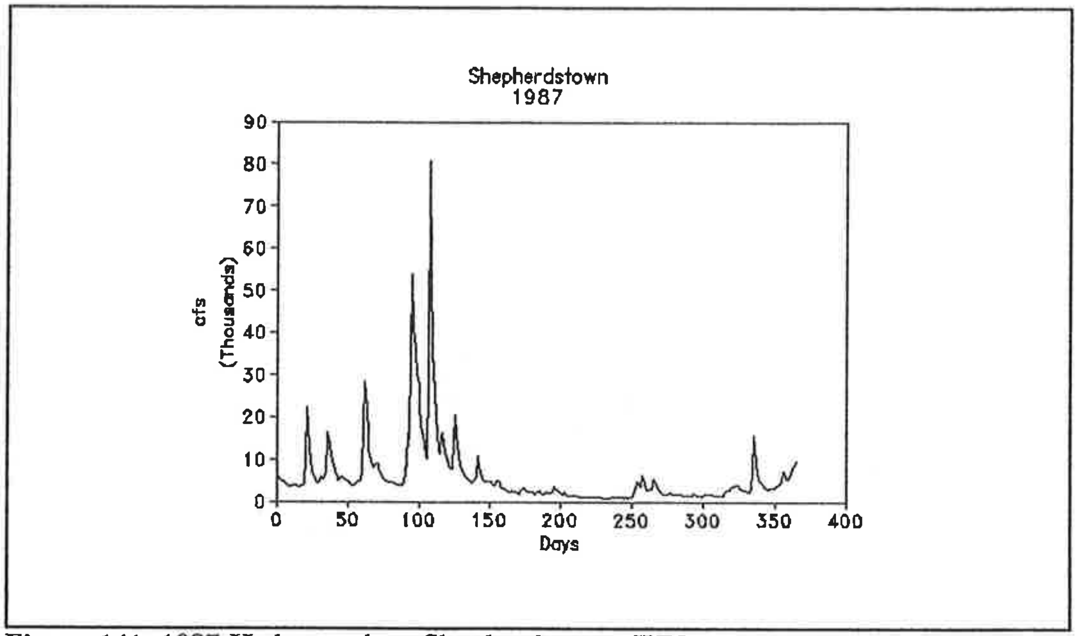

Figure 141. 1987 Hydrograph at Shepherdstown, WV.

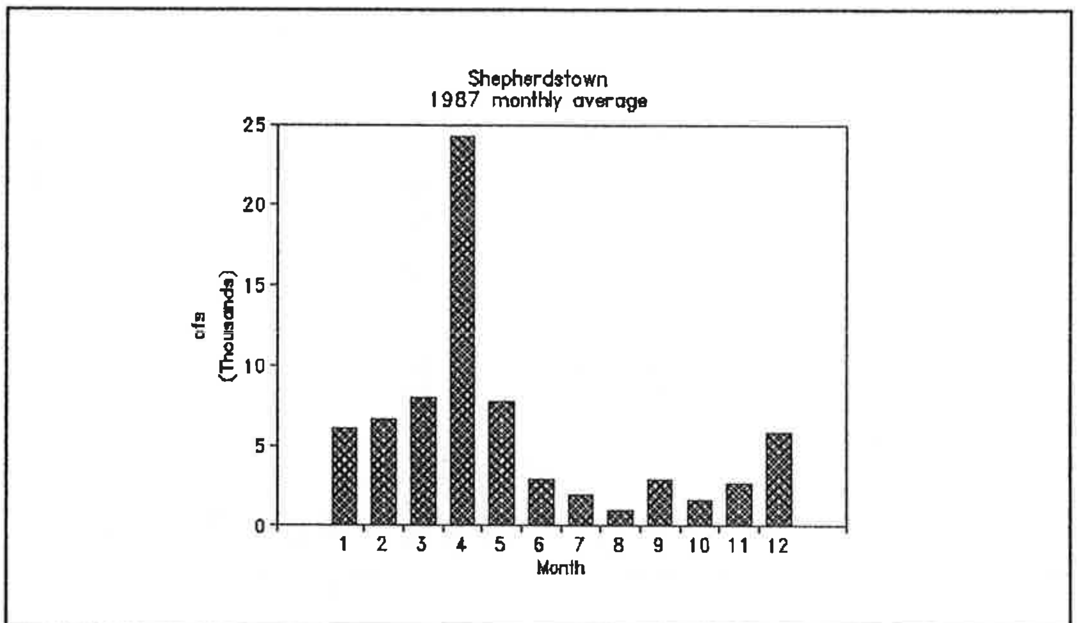

Figure 142. 1987 Average Monthly Discharge at Shepherdstown, WV.

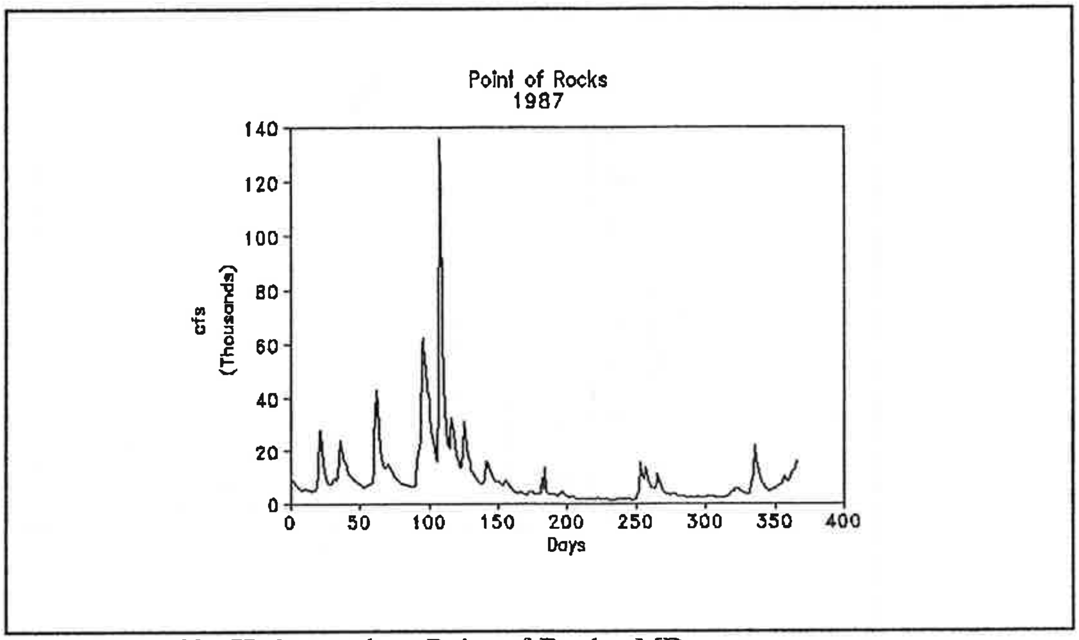

Figure 143. 1987 Hydrograph at Point of Rocks, MD.

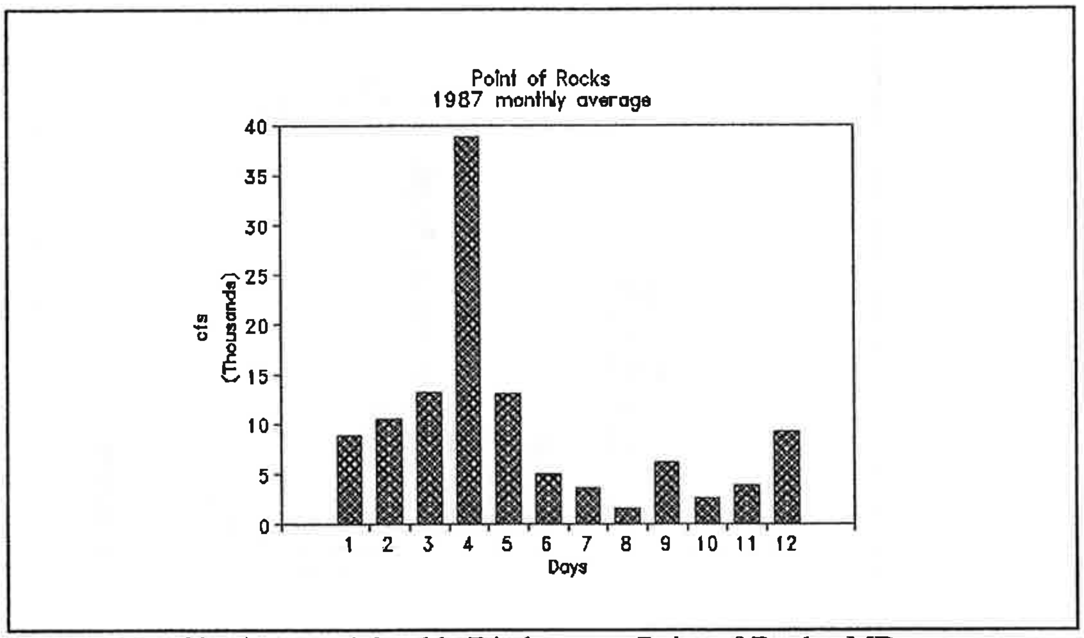

Figure 144. 1987 Average Monthly Discharge at Point of Rocks, MD.

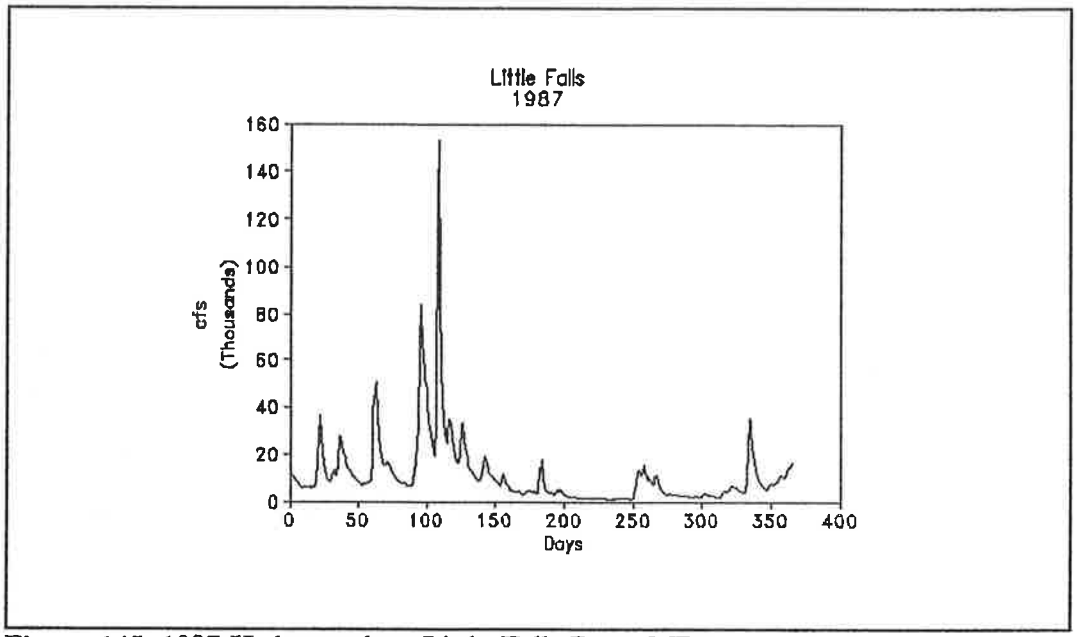

Figure 145. 1987 Hydrograph at Little Falls Dam, MD.

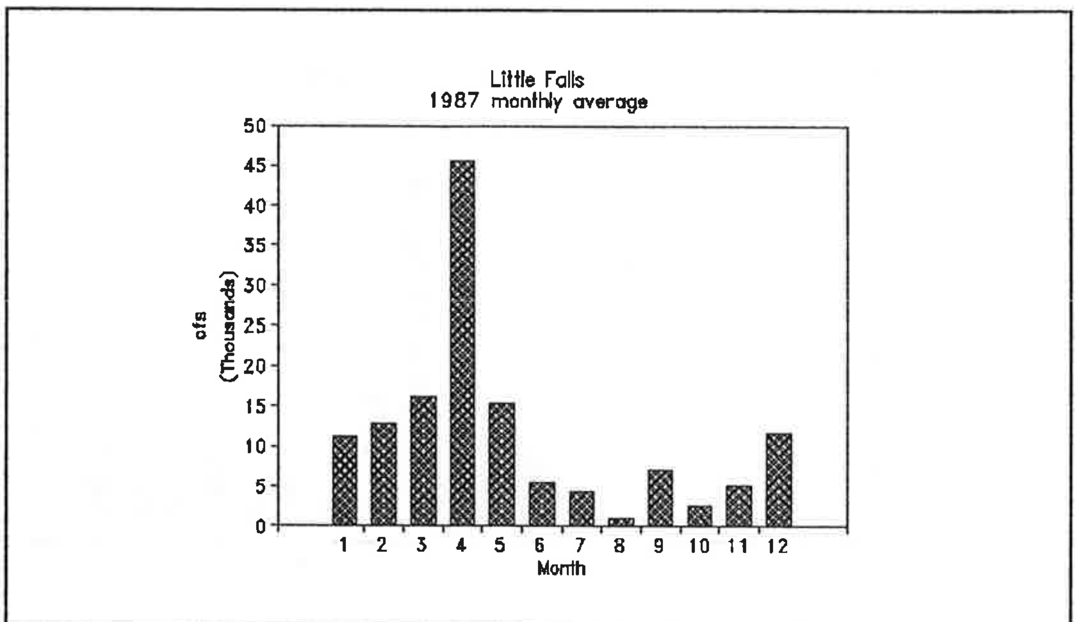

Figure 146. 1987 Average Monthly Discharge at Little Falls Dam, MD.

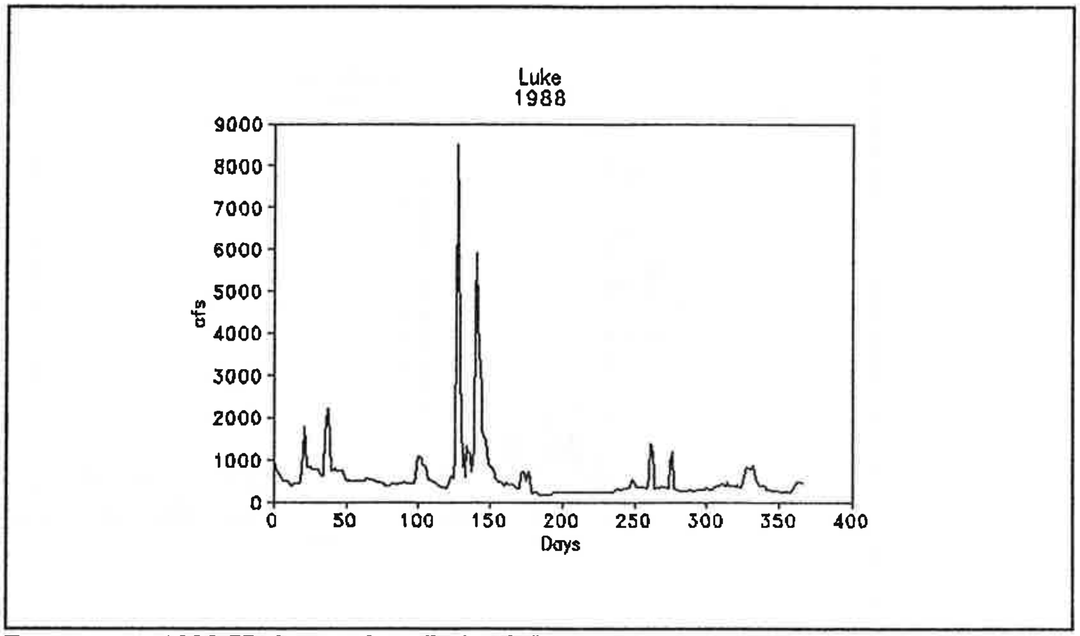

Figure 147. 1988 Hydrograph at Luke, MD.

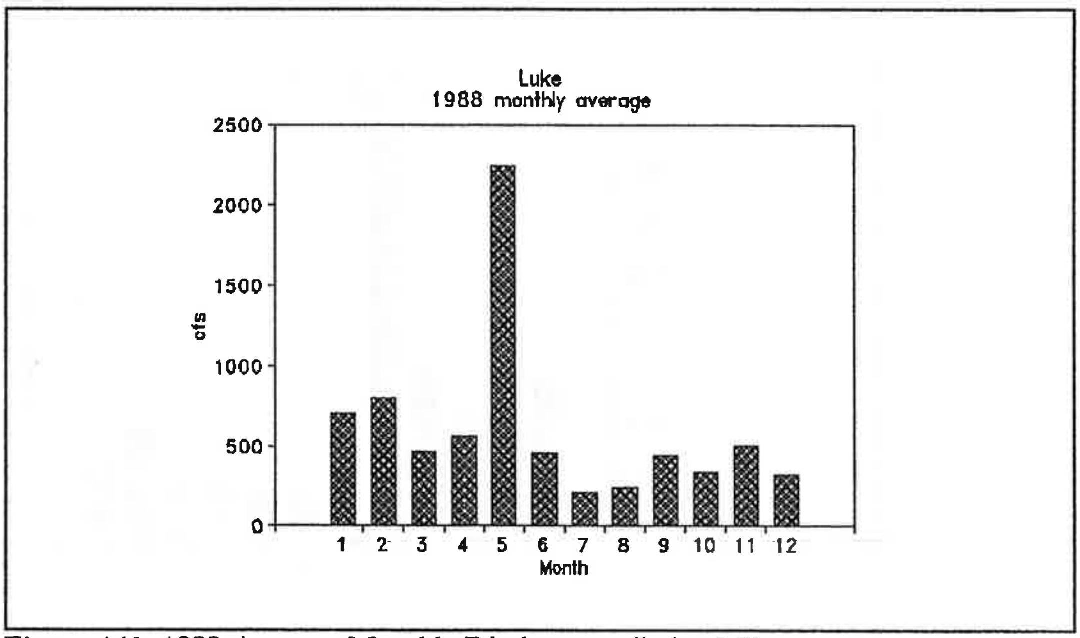

Figure 148. 1988 Average Monthly Discharge at Luke, MD.

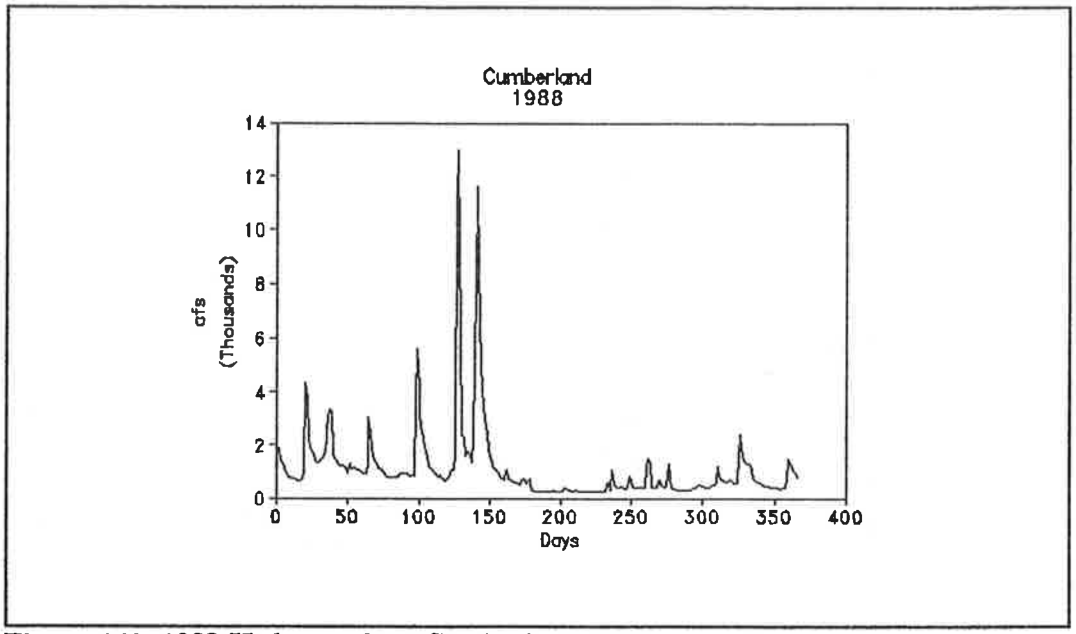

Figure 149. 1988 Hydrograph at Cumberland, MD.

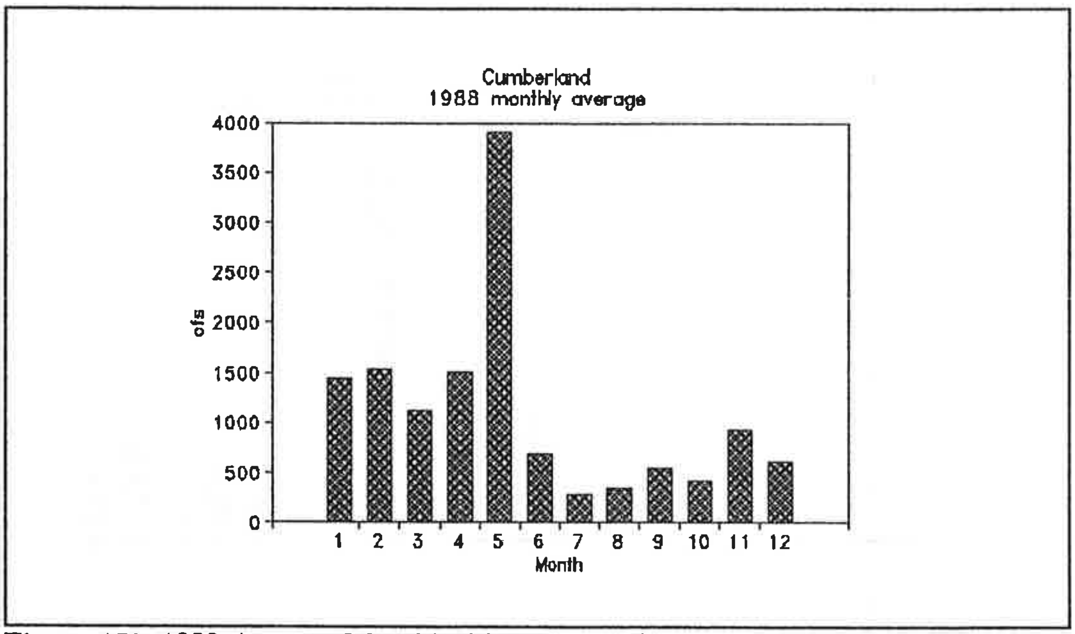

Figure 150. 1988 Average Monthly Discharge at Cumberland, MD.

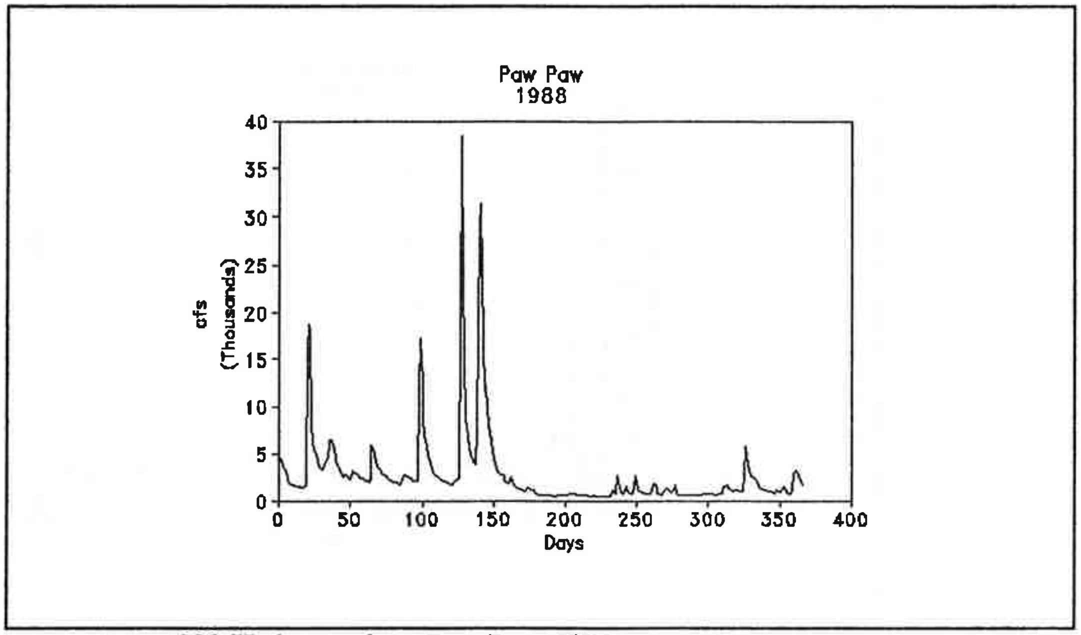

Figure 151. 1988 Hydrograph at Paw Paw, WV.

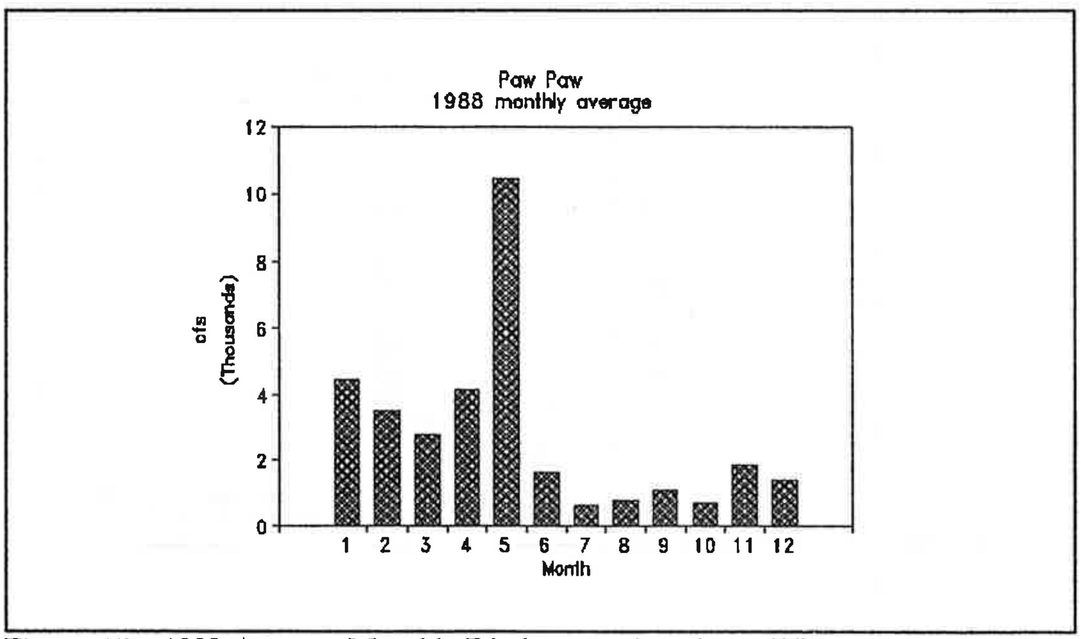

Figure 152. 1988 Average Monthly Discharge at Paw Paw, WV.

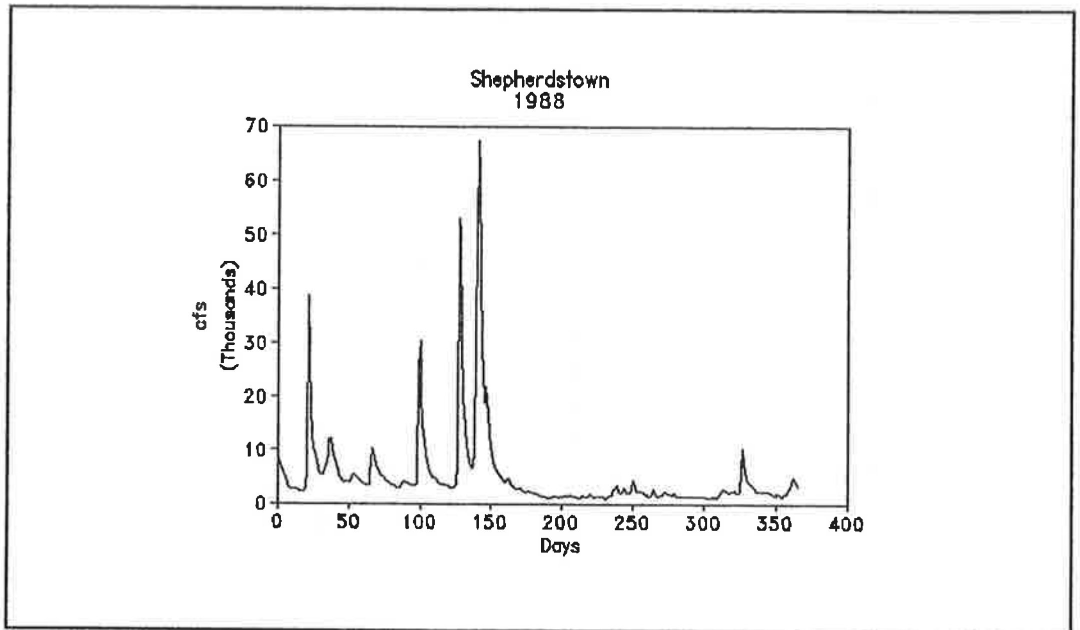

Figure 153. 1988 Hydrograph at Shepherdstown, WV.

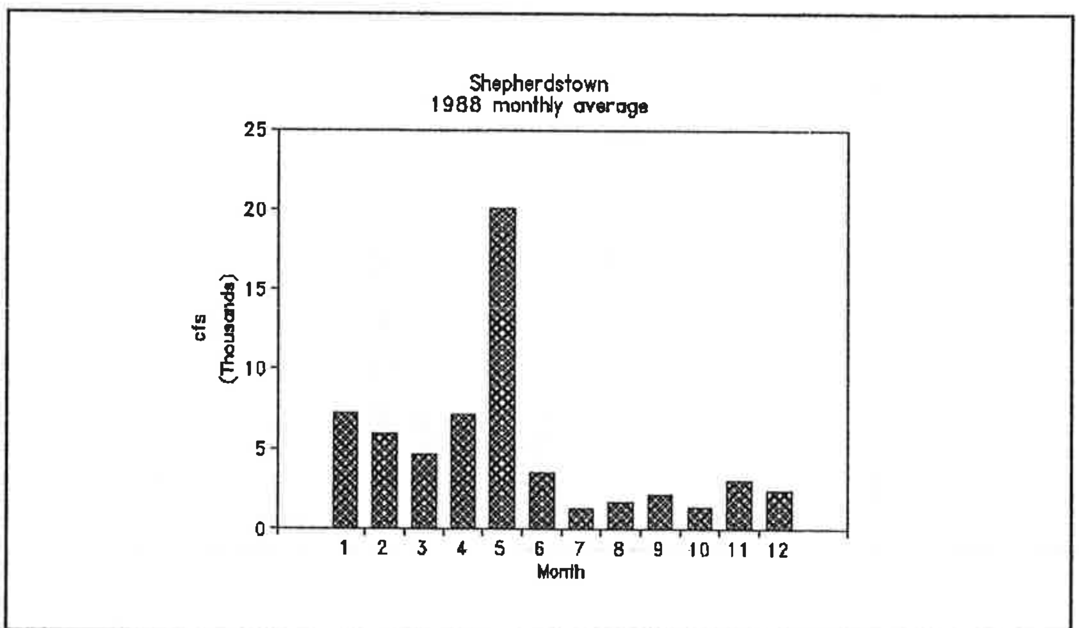

Figure 154. 1988 Average Monthly Discharge at Shepherdstown, WV.

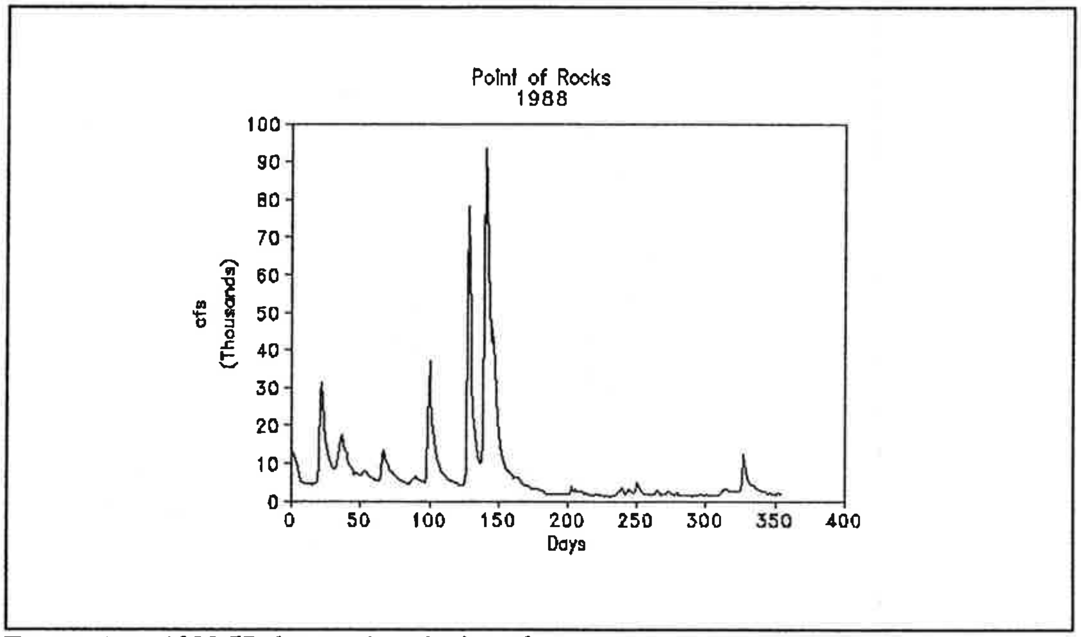

Figure 155. 1988 Hydrograph at Point of Rocks, MD>

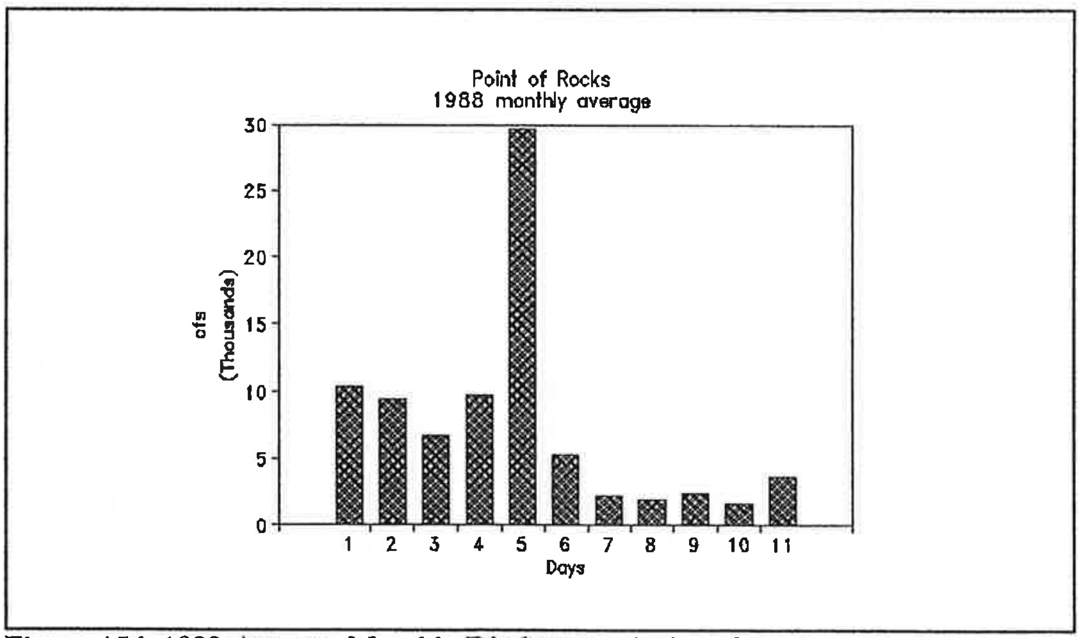

Figure 156. 1988 Average Monthly Discharge at Point of Rocks, MD.

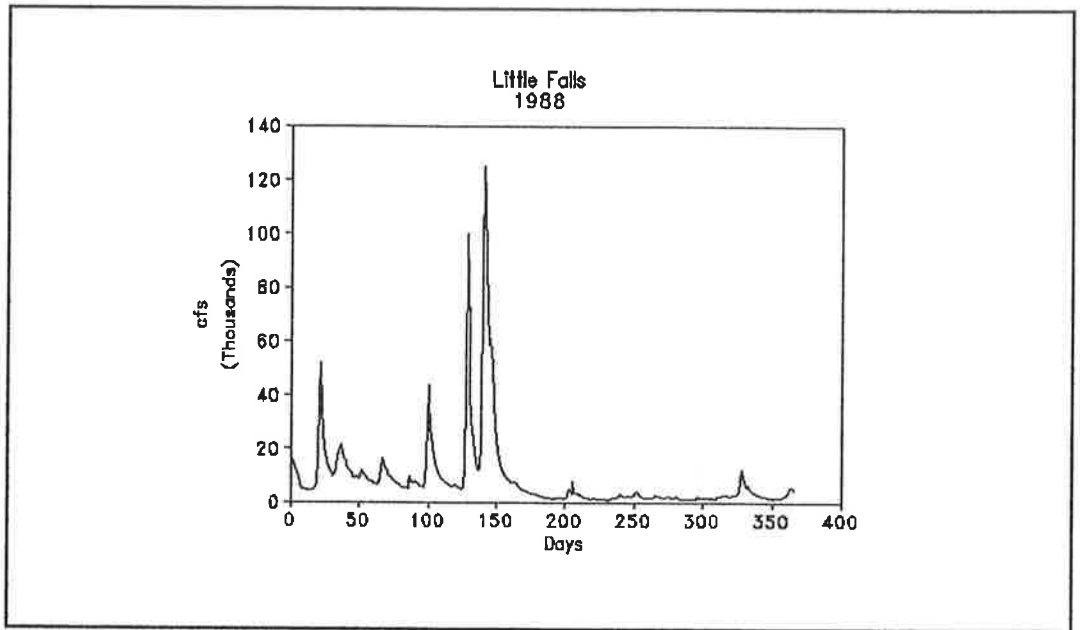

Figure 157. 1988 Hydrograph at Little Falls Dam, MD.

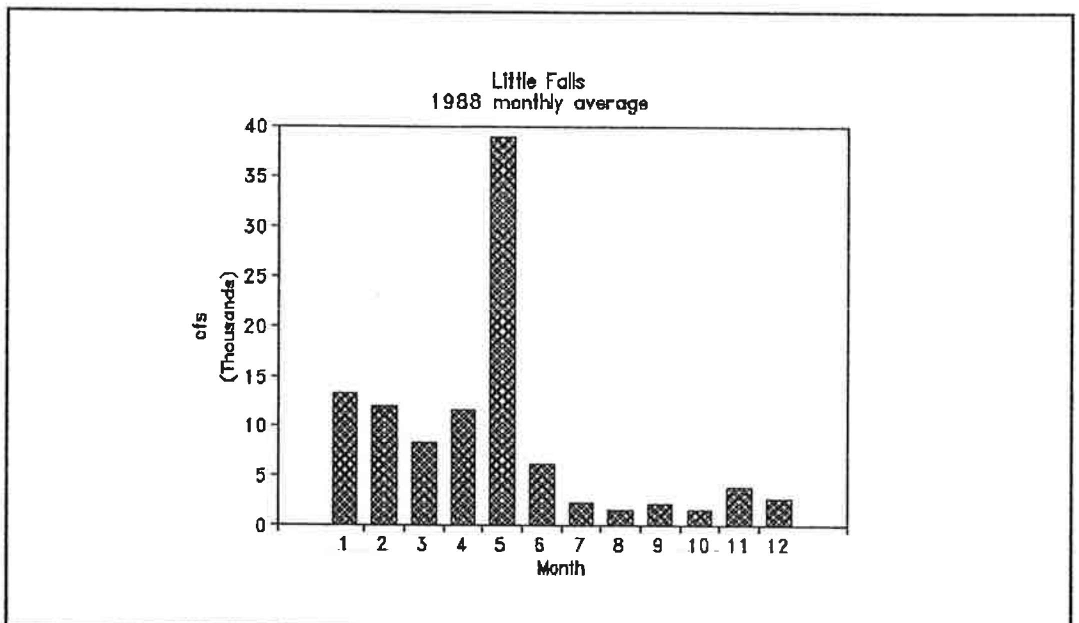

Figure 158. 1988 Average Monthly Discharge at Little Falls Dam, MD.

Chapter 8. Summary and Conclusions

Overall Assessment

The Potomac River Model covers a total distance of 224 river miles of the mainstem Potomac and North Branch river. The data required for the PRM includes: NO_3-N, NH_4-N, Organic-N, OPO_4, Organic-P, DO, and CBOD concentrations and loadings. In the previous seven chapters information was compiled and reviewed to assess the quality and quantity of the data needed for the Potomac River Model. Overall, there are sufficient data and information to complete a steady-state simulation of the river. However, certain assumptions must be made in order to "transform" the data into the proper format for the WASP4 framework. In this regard, missing input functions and data were obtained through an extensive literature search. This is most evident in the use of the kinetic rate constants for nutrient transformations.

To adapt the WASP4 model framework for the PRM, the study area was divided into 47 segments with lengths ranging from 0.5 mile to over 20 miles depending on the geographic, hydrologic and nutrient loading conditions. Since each segment is assumed to be completely mixed, additional segments may need to be added to analyze near field problems in some reaches. For example, lateral differences in nutrient concentrations can be significant in the vicinity of Whites Ferry.

In this version of the PRM, sediment-water interactions are not taken into account. In certain environments, the sediments can be a significant source or sink of dissolved and particulate nitrogen and phosphorus. Furthermore, the consumption of oxygen by bacterial processes in the sediments can exert a controlling influence on the oxygen balance in the overlying water. In the free-flowing Potomac River the effects of sediment-water interactions are largely unknown and are not included in this investigation.

The major sections of this report are summarized below along with the assumptions that must be made to develop consistent model inputs.

Monitoring Data

Water quality monitoring data were obtained for 18 mainstem locations and for 16 tributaries during 1983-1989. Data sources included agencies from the states of Maryland, Virginia, West Virginia, the U.S. Geological Survey and the Occoquan Watershed Monitoring Laboratory. At some of these locations, data were available from more than one agency. Different constituents were measured by each of these agencies, and those measured did not always include parameters required for the model. This necessitated developing conversion factors that transformed the nutrients into dissolved and particulate, organic and inorganic forms. These transformations ignore any spatial or temporal changes between these chemical forms. Particularly lacking are BOD and chlorophyll-a data; this is especially true for the river above Point of Rocks. BOD loads from some tributaries are therefore estimates based on other tributaries, rather than observed values. Consequently, it will not be possible to accurately calibrate BOD and Chl-a in the upstream segments above Point of Rocks.

MDE has indicated a lack of confidence in data collected by Maryland before 1986, particularly nitrogen parameters. Reported total nitrogen concentrations were found to be incorrect. These concentrations were replaced by the sum of TKN and nitrate. However, reported TKN concentrations in the pre-1986 data may also be low (see Chapter 2) and could be a source of error.

The frequency of sample observations were generally, at best, once per month. Consequently there is very little information on diurnal and day to day variation in constituent concentrations. While the current modeling effort is intended to simulate steady-state conditions, short term variation captured in the monitoring data will represent a source of potential error that will be encountered in calibration. Other sources of error include treating point observations as representative of entire stream segments, and the assumption that observed concentrations represent steady-state conditions. Despite the limitations in the monitoring data sufficient data are available to support the calibration and validation of a steady state model of the mainstem Potomac River.

Nutrient Trends

In general, Whites Ferry had the highest concentrations of nitrogen and phosphorus, followed by Point of Rocks, Chain Bridge and Hancock (see Chapter 2). Spatial trends in monitoring data seems to represent the changes in dilution and nutrient loadings from both point and non-point sources. Biogeochemical processes also modify the observed distributions. For example, algal uptake and/or nitrification appear to keep ammonium concentrations low throughout the river. Nutrient loads from the tributaries and to a lesser extent point sources from Paw-Paw to Whites Ferry, significantly affect the nutrient concentrations of the Potomac River. A dilution effect is observed as the South Branch enters the Potomac River. These trends can be accounted for in a simple mass balance (see Chapter 4).

Certain tributaries exhibit elevated concentrations of nitrogen and phosphorus during low flow periods. This is most evident in the concentration of dissolved inorganic phosphorus in the Monocacy River and Antietam Creek where higher concentrations were observed in the late summer and early fall. These trends are most likely due to the decrease in flow during the summer and the greater contribution of point sources to the total load.

Point Source Data

ICPRB developed a Point Source Inventory (PSI) which contains over 80 municipal and industrial point source dischargers. A review of the PSI shows that a major portion of the large dischargers are located upstream from monitoring stations in major tributaries, such as the Antietam Creek, the Monocacy River, Seneca Creek and Conococheague Creek. Consequently, the loadings from these dischargers should be captured by the tributary water quality monitoring stations.

Most permitted dischargers are not currently required to report effluent nutrient concentrations. Consequently, it was necessary to develop a set of default values to estimate these nutrient concentrations and loads. Various sources were consulted to develop default values which were based on treatment level and treatment process. Data from the small number of treatment plants for which monthly data are available was compared to default effluent concentrations based on treatment process to quantify the variability of estimated point source nutrient loads. This analysis shows that the error in estimated monthly loads can be significant. In general the contribution of nutrients from point sources is small under the summer low flow conditions of interest in this study. A notable exception occurs on the North Branch, Potomac River where point source nutrient inputs dominate tributary loadings. Despite the irregular quality of available point source nutrient data, a consistent methodology has been developed to estimate PRM nutrient inputs from all of the point sources identified in the Point Source Inventory.

Nutrient Mass Balance

To evaluate the quality and completeness of the nutrient data obtained from both water quality monitoring stations and point source dischargers, a simple four segment mass balance was calculated for the mainstem Potomac River. For each reach, the sum of point source, tributary and upstream inputs is compared to the downstream load observed at a mainstem monitoring station. Physical and biological processes are not considered in the mass balance calculations. Diffuse non-point inputs from unmonitored tributaries are similarly ignored.

Differences in the calculated mass balances are generally consistent with the range of variation observed in the monthly monitoring data. Estimated TP inputs consistently overestimate observed values suggesting the need to consider nutrient kinetics. On the North Branch, where TP inputs are dominated by point source loadings, the overestimation of TP is significant suggesting that default effluent concentrations used to develop these loads should be reexamined. For the reach between Shepherdstown and Chain Bridge, summer water supply diversions appear to represent a significant loss of both flow and nutrients. For the near steady-state conditions considered in this report, diffuse non-point inputs are not in general significant, although non-point loads from both monitored and unmonitored tributaries would need to be constructed for seasonal, time varying simulations.

The mass balance indicates that the PRM nutrient inputs appear to be reasonable and complete. Two areas that require further examination are point source TP inputs on the North Branch, and non-point source TN inputs between Hancock and Shepherdstown under higher flow conditions. Using these inputs, the Potomac River Model will provide the finer spatial resolution and the representation of physical and biological processes necessary for permitting and management decisions.

Calibration and Validation Periods

Based on a review of the available information, four one-month periods were selected for model calibration (October, 1984 and September, 1986) and validation (September 1985 and July 1987). Each of these periods represents a period of stable flow. Although discharge is relatively steady during these periods, daily variation in flow is still significant and a representative flow value will be developed for steady state calibration. Two of these periods precede the 1986 phosphorus ban in Maryland, allowing a comparison of pre and post-ban conditions. For the calibration and validation periods selected, sufficient point source and tributary monitoring data are available to account for all the major loadings for steady state simulation.

Miscellaneous Data

Miscellaneous data required are solar radiation, water temperature, kinetic rate constants, and river flow. River flow will be taken from U.S. Geological Survey stations along the entire river and tributaries, whereas kinetic rate constants are taken from an extensive review of the literature (see Chapter 6).

Direct measurements of solar radiation are not available. Instead solar radiation was estimated by reducing the daily theoretical clear sky radiation by a factor based on NOAA's daily cloud cover number. Comparison of this method with solar radiation observations from 1977 to 1980 show percent standard deviations of approximately 5 to 20% in the estimate of the % of clear sky radiation actually received. Higher errors are associated with higher cloud cover. Due to the geographic extent of the basin and the lack of sufficient sampling stations, significant temporal and spatial variations can occur and will not be accounted for by the model. During calibration, sensitivity tests will be performed to estimate value of accounting for cloud cover using one meteorological station for the entire basin.

Water temperature data obtained for 1985 show statistically significant differences in temperature between, upper, middle and lower reaches of the river. There is a general trend toward cooler summer water temperatures in the upper river. A sensitivitiy analysis will be performed to assess the significantce of longitudinal variation in water temperature. Up to four temperature functions will be developed for the model using daily temperature data, based on the results of the sensitivity analysis.

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Appendix A. Concentration Ratios for the Different Nitrogen and Phosphorus Forms from WWTPs

Year	TKN/TN	NH_4^+/TN	NO_3^-/TN	NH_4^+/TKN	DIP/TP
A. Seneca Creek WWTP					
1985 (n=12)	0.100±0.014	0.006±0.001	0.898±0.014	0.064±0.014	NA
1988 (n=12)	0.052±0.015	0.012±0.001	0.948±0.005	0.169±0.026	NA
1989 (n=12)	0.065±0.022	0.015±0.005	0.925±0.022	0.206±0.040	NA
1990 (n=5)	0.075±0.010	0.014±0.001	0.924±0.024	0.186±0.025	NA
Avg. (n=41)	0.075±0.025	0.011±0.005	0.924±0.024	0.151±0.064	
B. Damascus WWTP					
1985 (n=12)	0.339±0.164	0.192±0.146	0.661±0.165	0.501±0.193	NA
1988 (n=12)	0.324±0.260	0.162±0.161	0.678±0.261	0.414±0.221	NA
1989 (n=12)	0.420±0.121	0.211±0.131	0.579±0.121	0.470±0.191	NA
1990 (n=5)	0.152±0.048	0.057±0.039	0.848±0.048	0.340±0.204	NA
Avg. (n=41)	0.339±0.201	0.178±0.166	0.661±0.201	0.454±0.204	
Pre-1990	0.365±0.200	0.195±0.200	0.635±0.201	0.470±0.207	
C. Leesburg WWTP					
1989-90 (n=14)	0.142±0.069	0.081±0.045	0.858±0.069	0.588±0.152	0.577±0.184
D. Frederick WWTP					
1989 (n=3)	0.039±0.030	0.024±0.002	0.950±0.010	0.267±0.208	0.921±0.061
E. Halfway WWTP					
1989 (n=3)	NA	NA	NA	0.750±0.131	NA

n - number of samples
NA - no data availabled

Appendix B.1. Median Summer (July-September) Nutrient Concentration, All Mainstem Stations Combined

Concentration, mg/L

YR	NH3	NO3	TON	TN	DIP	TP	BOD
83	.07	.87	.58	1.55	.07	.125	1.85
84	.04	.95	.6	1.74	.04	.1	1.6
85	.04	.66	.555	1.22	.05	.1	2.1
86	.03	.38	.595	1.16	.017	.08	5.1
87	.04	.98	.68	1.88	.046	.11	1.85
88	.03	.9	.56	1.43	.03	.07	2.8
89	.03	1.515	.47	1.995	.04	.08	.5
83-89	.04	.84	.56	1.5	.04	.09	1.9

Number of Observations

YR	NH3	NO3	TON	TN	DIP	TP	BOD
83	106	107	105	101	107	106	36
84	76	76	76	73	71	75	34
85	66	69	66	63	66	75	15
86	52	48	52	43	52	52	18
87	59	58	59	53	59	59	18
88	63	63	61	55	61	62	17
89	58	40	56	38	53	55	18
83-89	480	461	475	426	469	484	156

Appendix B.2. Median Summer (July-September) Nutrient Concentration by Mainstem River Mile, Across All Year

Concentration, mg/L

SEG	RM	NH3	NO3	TON	TN	DIP	TP	BOD
47	115.9	.04	.96	.53	1.56	.04	.09	1.5
47	117.4	.05	.825	.77	1.7	.044	.1	3
43	133.3	.01	1.17	.63	1.7	.04	.08	NA
41	147.1	.025	1.28	.72	2.005	.067	.125	1.5
39	159.1	.03	1.145	.68	1.89	.053	.11	1.95
33	183.0	.04	1.28	.525	1.9	.04	.08	NA
26	238.6	.03	.61	.49	1.12	.028	.07	3.90
22	276.6	.03	.43	.43	.96	.0205	.085	NA
18	287.4	.04	.74	.49	1.29	.053	.11	2.00
17	295.4	.04	.775	.51	1.31	.05	.1	NA
10	317.3	.04	.59	.55	1.23	.02	.08	NA
5	332.7	.05	.605	.53	1.225	.02	.09	NA
1	341.1	.11	.65	.28	1.05	.01	.04	NA

Number of Observations

SEG	RM	NH3	NO3	TON	TN	DIP	TP	BOD
47	115.9	133	130	130	110	130	132	33
47	117.4	22	22	22	21	22	22	21
43	133.3	7	7	7	7	7	7	0
41	147.1	46	46	46	46	46	46	40
39	159.1	67	66	67	65	68	67	60
33	183.0	31	31	30	19	31	30	0
26	238.6	23	23	22	22	22	22	1
22	276.6	27	24	27	24	26	28	0
18	287.4	27	24	27	24	26	27	1
17	295.4	19	16	19	16	19	19	0
10	317.3	27	25	27	25	25	29	0
5	332.7	26	24	26	24	24	27	0
1	341.1	25	23	25	23	23	28	0

Appendix B.3. Median Summer (July-September) Nutrient Concentration by Station, Across All year

A. Observed Median Concentrations, mg/L: Mainstem Stations

STATION	RM	NH3	NO3	TON	TN	DIP	TP	BOD
01646580	115.9	.06	.965	.555	1.36	.025	.065	NA
PR01	115.9	.03	.96	.525	1.57	.045	.09	1.5
01646500	117.4	.13	.20	.77	NA	.01	.06	NA
POT1184	117.4	.05	.85	.77	1.7	.048	.11	3
PR04	133.3	.01	1.17	.63	1.7	.04	.08	NA
POT1471	147.1	.07	1.28	.75	2.29	.09	.16	2
POT1472	147.1	.02	1.13	.735	1.93	.047	.1	1.65
PR02	147.1	.01	1.37	.58	1.95	.07	.12	1.3
01638500	159.1	NA	1.20	NA	NA	.03	NA	NA
POT1595	159.1	.04	1.335	.69	2.165	.06	.13	2.3
POT1596	159.1	.03	.8	.77	1.675	.054	.12	2.7
PR03	159.1	.01	1.1	.61	1.78	.05	.1	1.5
01618000	183.0	.06	1.3	.53	NA	.04	.07	NA
POT1830	183.0	.04	1.28	.52	1.9	.04	.09	NA
POT2386	238.6	.03	.61	.49	1.12	.028	.07	3.90
POT2766	276.6	.03	.43	.43	.96	.0205	.085	NA
NBP0023	287.4	.04	.74	.49	1.29	.053	.11	2.00
NBP0103	295.4	.04	.775	.51	1.31	.05	.1	NA
NBP0326	317.3	.04	.59	.55	1.23	.02	.08	NA
NBP0461	332.7	.05	.605	.53	1.225	.02	.09	NA
NBP0534	341.1	.11	.65	.28	1.05	.01	.04	NA

B. Observed Median Concentration, mg/L: Tributary Stations								
STATION	RM	NH3	NO3	TON	TN	DIP	TP	BOD
CJB0005	119.0	.02	.765	.505	1.24	.016	.045	2.4
01645000	133.9	NA	4.60	NA	NA	.33	NA	NA
SEN0008	133.9	.02	3.5	.58	4.095	.21	.25	1.9
1ABRB002.15	139.1	.1	.3	.5	.91	.04	.1	2
1AGOO002.38	142.2	.15	1.4	.7	2.37	.06	.1	2.5
MON0020	153.1	.04	2.825	.76	3.73	.2	.24	2.1
MR01	153.1	.01	2.65	.7	3.32	.12	.2	1.6
1ACAX004.57	159.5	.1	.77	.36	1.24	.03	.1	1
CAC0031	163.5	.05	1.02	.72	1.79	.102	.16	NA
01636500	171.5	.035	.715	.68	NA	.055	.12	NA
550471	171.5	.07	.68	.385	4.56	NA	.12	1.4
01619500	179.3	NA	4.70	NA	NA	NA	.64	NA
ANT0044	179.3	.04	4.88	.585	5.51	.27	.325	3.60
550462	200.3	.09	1.325	.23	NA	NA	.313	1.15
CON0005	210.8	.03	3.58	.62	4.415	.2	.23	NA
TOW0030	282.6	.03	.095	.42	.55	.01	.04	NA
550468	285.1	.065	.165	.25	NA	NA	.0205	.85
BDK0000	307.2	.025	.22	.275	.48	.006	.05	NA
WIL0013	307.2	.025	.21	.32	.61	.01	.045	NA
GEO0009	338.7	.1	1.09	.425	1.965	.02	.195	NA
SAV0000	341.0	.02	.7	.3	1	.01	.03	NA

C. Number of Observations: Mainstem Stations								
STATION	RM	NH3	NO3	TON	TN	DIP	TP	BOD
01646580	115.9	18	18	18	1	18	18	0
PR01	115.9	115	112	112	109	112	114	33
01646500	117.4	1	1	1	0	1	1	0
POT1184	117.4	21	21	21	21	21	21	21
PR04	133.3	7	7	7	7	7	7	0
POT1471	147.1	21	21	21	21	21	21	21
POT1472	147.1	12	12	12	12	12	12	12
PR02	147.1	13	13	13	13	13	13	7
01638500	159.1	0	1	0	0	1	0	0
POT1595	159.1	21	20	21	20	21	21	21
POT1596	159.1	21	20	21	20	21	21	21
PR03	159.1	25	25	25	25	25	25	18
01618000	183.0	11	11	11	0	11	11	0
POT1830	183.0	20	20	19	19	20	19	0
POT2386	238.6	23	23	22	22	22	22	1
POT2766	276.6	27	24	27	24	26	28	0
NBP0023	287.4	27	24	27	24	26	27	1
NBP0103	295.4	19	16	19	16	19	19	0
NBP0326	317.3	27	25	27	25	25	29	0
NBP0461	332.7	26	24	26	24	24	27	0
NBP0534	341.1	25	23	25	23	23	28	0

D. Number of Observations: Tributary Stations								
STATION	RM	NH3	NO3	TON	TN	DIP	TP	BOD
CJB0005	119.0	12	12	12	12	12	12	11
01645000	133.9	0	1	0	0	1	0	0
SEN0008	133.9	21	20	21	20	17	21	21
1ABRB002.15	139.1	19	19	19	19	19	19	19
1AGOO002.38	142.2	19	19	19	19	19	19	18
MON0020	153.1	21	20	21	20	21	21	21
MR01	153.1	25	25	25	25	25	25	20
1ACAX004.57	159.5	19	19	19	19	19	19	18
CAC0031	163.5	19	19	18	18	18	18	0
01636500	171.5	12	12	11	0	12	11	0
550471	171.5	6	17	6	1	0	17	6
01619500	179.3	0	1	0	0	0	1	0
ANT0044	179.3	23	23	22	22	22	22	1
550462	200.3	6	6	6	0	0	6	6
CON0005	210.8	20	19	19	18	20	19	0
TOW0030	282.6	19	16	19	16	19	19	0
550468	285.1	6	16	6	0	0	16	6
BDK0000	307.2	6	3	6	3	6	6	0
WIL0013	307.2	26	23	26	23	25	28	0
GEO0009	338.7	25	23	24	22	23	26	0
SAV0000	341.0	26	24	26	24	24	28	0