FLOW REQUIREMENTS

IN THE JAMES

RIVER BASIN

Water Supply and [illegible]

[illegible] Control

TABLE OF CONTENTS

I. INTRODUCTION

This report was prepared at the request of the U.S. Army Corps of Engineers, Norfolk District under authority of the Federal Water Pollution Control Act (33 U.S.C. 466 et.seq). The report presents results of studies made to determine stream flow requirements for water supply and water quality control in the James River. These stream flows will be discussed with State and Federal agencies participating in the James River Study in order to establish a base from which pollution control measures can be evaluated and a basin wide water quality management program developed.

A. Purpose and Scope

The purpose of this report is to determine need for stream flow augmentation in the Jackson and James Rivers to meet water supply needs and water quality standards. Stream flow needs are presented for various degrees of waste treatment ranging from conventional secondary treatment of 85% Biochemical Oxygen Demand (BOD) removal to advanced waste treatment (95% BOD removal). Future needs through year 2020 are determined based on Economic projections of population and industrial output.

The study is limited to the main stem of the James and Jackson Rivers from Covington to the estuary below Hopewell. Consideration is also given to the Maruy River below Lexington.

The four principal areas considered were Covington, Lynchburg, Richmond and Hopewell. Future studies will evaluate cost of advanced waste treatment versus cost of providing flow augmentation; other methods for achieving water quality standards and meeting water supply needs will also be considered.

B. Acknowledgements

The assistance of many individuals and agencies in supplying information for this report is gratefully acknowledged. Special mention is made of the following agencies:

U. S. Geological Survey

U. S. Army Corps of Engineers, Norfolk District

Virginia Division of Industrial Planning and Development

Virginia Division of Water Resources

Virginia State Water Control Board

Virginia Department of Health

Virginia Institute of Marine Science

VMI Research Laboratories

National Council for Stream Improvement (Of the Pulp, Paper, and Paperboard Industries), Inc.

II. SUMMARY AND CONCLUSIONS

Stream flow needs for the James River in major urban and industrial areas have been determined through year 2020. These flow needs for water supply and water quality controls are based on economic projections of population and industrial output. Mathematical models, verified by field data were used to compute stream flows needed to maintain a monthly average dissolved oxygen of 5.0 mg/l.

The following conclusions were reached:

1. Existing minimum stream flows are adequate for all projected water supply requirements except at Covington. Industrial requirements at Covington will require storage for water supply, additional reuse of process waters, or development of other sources of supply.
2. A combination of storage for low flow augmentation and waste treatment beyond secondary treatment (85% BOD removal) will be needed to maintain water quality standards.
3. At Covington, the proposed Gathright Reservoir is designed for a minimum flow release of 305 cfs during the critical summer months. This flow will be sufficient through year 1980 with secondary treatment. By year 2000, 90% treatment or additional flow (555 cfs) will be needed. By year 2020 either 95% treatment or higher flows (up to 830 cfs) with treatment between 90 and 94% BOD removal will be needed.

4. At Lynchburg, the two reservoirs now being planned will provide a minimum flow of about 1100 cfs, which is adequate for the present with 90% BOD removal (only primary treatment exists at present); by year 2020 over 95% treatment will be necessary unless additional flow can be provided. At least 1650 cfs would be desirable as a minimum to meet needs both at Lynchburg and Hopewell. Flow requirements at Lynchburg and Hopewell are shown in Table II - 1.

5. In the Richmond-Hopewell area, the chemical industry at Hopewell is the controlling waste discharge. Through year 1980, 90% removal will be adequate if minimum flow of 2050 cfs is maintained (1650 cfs at Lynchburg plus 400 cfs added below Lynchburg). By year 2020 a flow of 4350 cfs would be needed at Hopewell even with 95% BOD removal. Thus after 1980 additional storage will be desirable at sites either above Lynchburg (if available) or on tributaries between Lynchburg and Hopewell. After costs of storage are calculated, the optimum costs of flow augmentation versus advanced waste treatment will be determined.

TABLE II - [illegible]

JAMES RIVER FLOW REQUIREMENTS AT HOPEWELL AND LYNCHBURG

D.O. OBJECTIVE [illegible]

YEAR	TREATMENT LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	LOCATION
1980	85%	(1)	(1)	900	2000	2750	4200	4600	4600	3900	2600	1300	750	Hopewell
		570	640	720	1260	1590	2730	2730	2730	2100	1050	[illegible]	700	Lynchburg
	90%	(1)	(1)	(1)	400	800	1750	2050	2050	1550	[illegible]	(1)	(1)	Hopewell
		360	430	[illegible]	80	990	1570	1570	1570	1300	[illegible]	[illegible]	[illegible]	Lynchburg
	95%	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	Hopewell
2000	85%	1050	2250	3700	5150	6200	100	3450	[illegible]	7550	5950	4200	3200	Hopewell
		900	1020	1320	2170	2150	2[illegible]0	1260	200	3400	2300	1410	1090	Lynchburg
	90%	(1)	400	1200	2700	1700	1500	[illegible]00	5600	5000	3500	1500	1000	Hopewell
		500	570	720	[illegible]	1340	2270	2270	2270	1 20	1240	7 0	100	Lynchburg
	95%	(1)	(1)	(1)	(1)	400	1500	1700	1700	1200	350	(1)	(1)	Hopewell
		230	310	390	10	690	1100	1100	1100	900	[illegible]50	410	330	Lynchburg
2020	85%	5100	5300	[illegible]00	8200	9300	11200	11300	11500	11000	9100	7000	[illegible]200	Hopewell
		1500	1720	2200	3640	4100	[illegible]	[illegible]	[illegible]	[illegible]	3590	2520	[illegible]	Lynchburg
	90%	2250	2650	3750	5100	[illegible]500	[illegible]150	[illegible]600	[illegible]50	7800	6200	1300	3550	Hopewell
		680	960	1230	2120	2420	4200	4200	[illegible]200	33[illegible]0	2200	1330	1040	Lynchburg
	95%	(1)	(1)	[illegible]50	1900	2500	4000	4350	4350	3500	2350	2150	700	Hopewell
		360	420	220	850	960	1540	1540	1540	1240	390	550	[illegible]50	Lynchburg
		1025(2)	3417	3455	1975	1523	774	803	600	331	2[illegible]	602	952	

(1) Water quality control flow requirements are less than minimum daily flow recorded.

(2) Flow [illegible] between Lynchburg and Richmond (minimum monthly)

III - ECONOMIC PROJECTIONS

The population of the James Basin was estimated at 1,800,000 in 1968, an increase of 200,000 from 1960. A medium projection for the entire river basin would increase the population to 2,000,000 in 1980, 2,800,000 in 2000, and 4,000,000 in 2020. This is more than a twofold increase from 1968 to 2020. The growth rate is about the same as the nation's medium growth rate. This seemingly average growth rate for the entire James River Basin camouflages the declining rural areas and the above average grwoth rate of the urban centers in the James River Basin. Richmond-Petersburg-Hopewell are part of the urban crescent that will extend from Washington, D.C., to Norfolk, Virginia. Virginia's greatest growth will occur in this urban corridor and the urban areas of Richmond and Petersburg-Hopewell are projected to increase more than 3 times from now to 2020. Table III-1 shows population projections for each area of the Basin.

The overall view of employment for the basin is 30% manufacturing and agriculture, and 70% spread among the services--24% in business service, 15% in retail trade, 5% in wholesale trade, and 9% in Government. The above distribution is similar to the national distribution.

Within the manufacturing sector, the James River Basin has many large water users and pollutors. The only large employment group that is not considered a large water user is transportation equipment with over 5% of the basin's employment. Food processing is 3%, chemicals are 2 1/2%, primary metal is 1%, and pulp and paper under 2%. The

TABLE III - 1

POPULATION PROJECTIONS

JAMES RIVER BASIN

	YEAR					
	1950	1960	1967	1980	2000	2020
Covington Area						
Covington	5,860	11.062	10,055	11,500	16,000	19,000
Water Service Area		7,200				
Clifton Forge	5,795	5,745	6,052	7,600	11,000	15,000
Water Service Area		8,350	8,350	10,000	14,000	21,000
Sub-total		16,330	16,107	19,100	27,000	34,000
Total Water Service Area		15,550	15,300	19,500	28,000	38,000
Alleghany County	23,139	12,128	13,207	12,000	12,000	11,000
Total Area	34,794	28,458	29,314	31,100	39,000	45,000
Lexington Area						
Buena Vista	5,214	6,300	6,869	8,300	10,600	13,500
Water Service Area		6,500				
Lexington	5,976	7,537	8,454	10,900	14,000	18,500
Water Service Area		10,115				
Sub-total	11,190	13,837	15,323	19,200	24,600	32,000
Total Water Service Area		16,615		21,000	25,000	35,000
Rockbridge County	17,383	16,502	16,631	17,300	15,400	13,000
TOTAL AREA	28,573	30,339	31,954	36,500	40,000	45,000

TABLE III - 1

POPULATION PROJECTIONS

JAMES RIVER BASIN

(CONTINUED)

	1950	1960	1967	1980	2000	2020
Petersburg-Hopewell-Colonial Heights Area						
Colonial Heights	6,280	9,587	14,100	20,200	32,600	40,000
Prince George Co. and Hopewell	29,800	38,200	48,600	79,300	144,000	320,000
Petersburg	35,100	36,700	37,300	40,600	45,000	50,000
Dinwiddie County	18,800	22,200	25,900	33,900	81,400	253,500
Total Area	89,980	106,637*	125,900*	174,000*	303,000*	663,500*
Lynchburg Area						
Lynchburg	48,100	54,800	56,298	69,000	69,000	69,000
Amherst County	20,300	23,000	25,953	44,600	68,000	170,500
Campbell County	28,500	33,000	41,053	67,000	104,500	268,100
Total Area	96,900	110,800	123,304	180,600	241,500	507,600
Water Service Area		67,185	81,400	135,000	193,000	457,000
Charlottesville Area						
Charlottesville and Albemarle Co.	52,600	60,400	74,766	107,700	130,000	150,000
Water Service Area		39,000	60,000	92,000	104,000	118,000

* To be used as Water Service Area

TABLE III - 3

POPULATION PROJECTIONS

JAMES RIVER BASIN

(CONTINUED)

	1950	1960	1967	1980	2000	2020
Richmond Area						
Richmond and Henrico County	287,600	337,300	373,500	431,000	506,400	606,900
Chesterfield County	40,220	71,213	105,100	218,000	350,000	378,000
Hanover County	22,000	27,500	35,100	58,300	129,600	233,000
Powhatan County	5,600	6,700	7,800	14,600	28,000	75,000
Goochland County	8,900	9,200	10,400	20,100	32,000	50,000
Total Area	364,320	451,913	531,900	742,000	1,046,000	1,342,900
Water Service Area		368,555	452,000	645,000	930,000	1,275,000

projection of employment in chemicals is to increase threefold for 1960 to 2020; pulp, paper and allied products are to have a two-fold increase; primary metals will double; food and kindred products will have only a small increase. The above do not seem to be significant increases, but when the outputs associated with the employment in these large water-using industries are considered, they are large. While food and kindred products show little rise in employment, the output per employee will increase six times. In chemical the increase will be over ten times; pulp and paper, three times; and primary metals, six times. Indexes of output for each major industry are shown in Table III-2.

It is the combination of increases in employment and output per employee that will add tremendously to the water used and waste produced in the future. This increase is in additinn to the population increase already mentioned. To further compound the size of the problem, both the industrial output and population increases will be concentrated in the four areas of Covington-Clifton Forge, Lynchburg, Richmond, and Petersburg-Hopewell.

TABLE III - 2

PROJECTED INDEXES OF INDUSTRIAL OUTPUT

Plant Location	Name of Plant	S.I.C.	Index of Output* 1980	2000	2020
Covington	WESTVACO	2621	200	300	500
Glasgow	James Lee and Sons (Burlington Industries)	2271	350	500	700
Big Island	Owens-Illinois Co.	2631	300	400	600
Lynchburg	Mead Corporation	2631	200	300	500
Richmond	Standards Paper Mfg.	2621	200	300	500
	Federal Paper Board Co.	2621	200	300	400
	E.I. duPont de Nemours - (Film Plant)	2821	400	900	1400
	E.I. duPont de Nemours - (Fibers Plant)	2824	400	900	1400
Chesterfield	American Tobacco Co.	2141	200	300	500
	Allied Chemical Co. (Fibers)	2824	500	1100	1500
Hopewell	Continental Can Co.	2631	200	300	400
	Allied Chemical Co. (Nitrogen Div.)	2818	350	700	1100
	Allied Chemical Co. (Fibres Div.)	2819	350	700	1100
	Hercules, Inc.	2821	350	700	1100

* Index of Output - 100 for year 1967

IV. WATER SUPPLY

Water supply values in the James River Basin for the year 1967 are shown in Table IV - 1. The water use figures and water service populations were obtained from an inventory by the Virginia Department of Health. The municipal water uses in gals/cap/day were calculated for projection purposes.

The projected water use values in the James River Basin for the years 1980, 2000, and 2020 are shown in Tables IV - 2, 3, 4.

Municipal water needs were calculated by adding 1% per year to the reported 1967 water use and multiplying the results by the projected water service populations. The value of 1% per year increase in gal/cap/day was obtained from statistical evaluation of municipal water systems in the Nation.[2/] In cases where municipalities did not have water meters in 1967, the 1967 gal/cap/day use was decreased by 35% and the resulting value was used in 1980. The 35% decrease in gal/cap/day use was an average obtained from records in various areas.[1/] The assumption that all the municipalities would have water meters by 1980 was made.

Industrial water uses, which are more unpredictable than municipal uses, were estimated using a combination of many information sources. The sources include the State of Virginia, Dr. Howard Edde of the National Council for Stream Improvement (of the Pulp, Paper, and Paperboard Industries) Inc., industrial waste inventories,[3/] conversations with industrial representatives, and several others. After assembling

TABLE IV - 1

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

JAMES RIVER BASIN - 1967

Water Service Area	Water Service Population	Municipal* gal/cap/day Use	Municipal* (MGD)	Industrial (MGD)	Total (MGD)
Covington	10,055	214**	2.0	50.0	52.0
Clifton Forge	8,350	217**	2.0	---	2.0
Lexington	8,450	70	1.0	---	1.0
Glasgow	---	---	---	2.0	2.0
Big Island	---	---	---	9.0	9.0
Lynchburg	56,300	100	5.5	14.5	20.0
Richmond	373,500	101	38.0	40	78
Petersburg	37,300	93	4.0	2.0	6.0
Hopewell	48,600	100	5.0	265	270
Chesterfield	60,000	90	6.0	12	12

* - Includes commercial and light industries

** - High because of no water meters

TABLE IV - 2

PROJECTED MUNICIPAL AND INDUSTRIAL WATER SUPPLY REQUIREMENTS

JAMES RIVER BASIN - 1980

Water Service Area	Water Service Population	Municipal* gal/cap/day	Municipal* (MGD)	Industrial (MGD)	Total (MGD)
Covington	11,500	139**	1.5	100	101.5
Clifton Forge	10,000	141**	1.5	---	1.5
Lexington	10,900	79	1.0	---	1.0
Glasgow	---	---	---	7.0	7.0
Big Island	---	---	---	25.0	25.0
Lynchburg	69,000	113	8.0	17.0	25.0
Richmond	431,999	114	49	150.0	199.0
Petersburg	40,600	105	4.0	10.0	14.0
Hopewell	79,300	113	9.0	720.0	729.0
Chesterfield County	150,320	102	15	12.0	27.0

* Includes commercial and light industries
** Assumes installation of Household water meters.

TABLE IV - 3

PROJECTED MUNICIPAL AND INDUSTRIAL WATER SUPPLY REQUIREMENTS

JAMES RIVER BASIN - 2000

Water Service Area	Water Service Population	Municipal* gal/cap/day	Municipal* (MGD)	Industrial (MGD)	Total (MGD)
Covington	16,000	167	2.5	100	102.5
Clifton Forge	14,000	169	2.5	---	2.5
Lexington	14,000	95	1.5	---	1.5
Glasgow	---	---	---	8.5	8.5
Big Island	---	---	---	27.0	27.0
Lynchburg	139,000	136	19	20.0	39.0
Richmond	506,400	137	69	175.0	244.0
Petersburg	45,000	126	5.5	12.0	17.5
Hopewell	144,000	136	20	730.0	750.0
Chesterfield County	255,920	122	31	14.0	45.0

* Includes commercial and light industries

TABLE IV - 4

PROJECTED MUNICIPAL AND INDUSTRIAL WATER SUPPLY REQUIREMENTS

JAMES RIVER BASIN - 2020

Water Service Area	Water Service Population	Municipal* gal/cap/day	Municipal* (MGD)	Industrial (MGD)	Total (MGD)
Covington	19,000	200	4.0	100	104
Clifton Forge	21,000	203	4.0	---	4
Lexington	18,500	114	2.0	---	2
Glasgow	---	---	---	10.0	10
Big Island	---	---	---	30.0	30
Lynchburg	334,000	163	54	23.0	77
Richmond	606,900	164	100	200.0	300
Petersburg	50,000	151	7.5	15.0	23
Hopewell	320,000	163	52	750.0	802
Chesterfield County	278,300	146	41	17.0	58

* Includes commercial and light industries

All the available information on the industrial water uses in the Basin, each industry was considered separately. The general procedure was to directly apply the 1980 index of output projections for each industry to obtain the 1980 water use projection. For the years 2000 and 2020, the industrial water supply needs were attenuated to reflect such factors as expected process changes, availability of water, and greater reuse of waste water.

The major industries considered in the determining water requirements were Westvaco (formerly West Virginia Pulp and Paper Company) at Covington; James Lee and Sons Co. at Glasgow; the Mead Corporation at Lynchburg; E.I. du Pont de Nemours, Federal Paper Board Co., and Standard Paper Manufactures Co., Inc. at Richmond; Allied Chemical Corps. and Continental Can Company at Hopewell; and American Tobacco Co. in Chesterfield County.

For comparative purposes the recorded mean and minimum stream flows and the calculated 7-day 10-year low flows are shown below.

Area	River Gaged	Mean Flow MGD	Minimum MGD	7-day 10-Year Low Flow MGD
Covington-Clifton Forge	Jackson	412	42	[illegible]
[illegible]	Maury	[illegible]	[illegible]	[illegible]
Big Island-Lynchburg	James	[illegible]	[illegible]	[illegible]
[illegible]	James	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] stream flows appear to be adequate for all municipal and industrial water requirements in the Basin through year 2020 (Table IV - 4), except for Covington. For municipal and industrial [illegible] Covington, sufficient [illegible] Gathright reservoir. However, [illegible] Gathright [illegible] quality [illegible], [illegible] water supply requirements [illegible] supply [illegible].

The [illegible] water supply [illegible] requirements in the Gathright Reservoir [illegible] industrial and municipal [illegible] Covington would reach about 30 MGD in year 2020. New information indicates that present usage is about 50 MGD which is the 7-day 10-year low flow; without Gathright the entire Jackson river flow may be diverted for water supply on occasion.

If Westvaco increases water usage in the future, as the projections suggest, the company will need to purchase storage in the Gathright Reservoir or develop other sources to meet the additional requirements.

At Hopewell, most of the industrial water supply can be reused 3 - 4 times as the river flow passes downstream since industries are widely spaced along the River. Natural flow plus reservoir flows already planned appear adequate for water supply needs.

V. JAMES RIVER WATER QUALITY STANDARDS

The James River is considered [illegible] state stream above the [illegible] line at Richmond. Below Richmond, the tidal portion of the James is an interstate stream.

Water quality standards have been adopted for both portions, and the interstate standards have been approved by the Secretary of the Interior, with exceptions noted on some items including maximum temperature.

Above Covington, the Jackson River is classified for water supply and [illegible] fishing. Dissolved oxygen (D.O.) standard is 5.0 mg/l minimum - temperature 70° F maximum. Below Covington, on the Jackson and James Rivers, including the estuary, the minimum D.O. is [illegible].0 mg/l and maximum temperature is 95° F (at present).

Coliform standards have been adopted for portions of the river classified for public water supply and/or recreation. The river between [illegible] and a point 5 miles above Hopewell has no coliform standard at present. Most of the remainder below Hopewell is classified for recreation, with coliforms not to exceed 2,400/100 ml as a monthly average.

VI. UPPER JAMES RIVER

Flow Requirements

In the Upper James River Basin, the principal sources of waste water are three pulp and paper mills, one at Covington and two in the Lynchburg area. These pulp and paper mills are expected to increase their output tonnage by a factor of 2-[illegible] by 1980 and by a factor of [illegible] by the year 2020. Waste loadings to the River will also increase, but by a smaller factor due to improved processes within the plants, and additional treatment of waste water prior to discharge.

In order to determine means of maintaining the adopted water quality standards, a mathematical model constructed by J.L. Worley[4] was utilized to calculate stream flow requirements. This model is a digital computer application of the Streeter-Phelps equation for dissolved oxygen. A water quality survey and cross sections were taken on the James River by Virginia Military Institute Research Laboratories[2] in 1966 in order to construct and verify the mathematical model.

Year 1967 waste loadings and flow used in the Worley Math Model[4] for the Upper James River are shown in Table IV - 1. Waste flows for year 1967 were obtained from an inventory supplied by the State of Virginia Department of Health. Municipal waste loads were calculated from sewer service populations and the population equivalent of [illegible] (lbs./cap./day) 5-day BOD. Industrial waste loads were obtained from the State of Virginia, Dr. Howard Edde of the National Council

March 18, 1969

TABLE VI - 1
UPPER JAMES RIVER, YEAR 1967 LOADS
PRIOR TO TREATMENT

Source of Pollution	Reach Number	Daily Loads	Daily[1] Loads (lbs. BOD_u)	Flow[2] (gal/cap/day)	Waste Flow (MGD)	Waste Flow (CFS)	Loads BOD_L (ppm)
West Va. Pulp and Paper Co.	198	56,250 (lbs. BOD_5)	82,720		50.000	77.350	198
City of Covington outfall	197	10,055 (P.E.)	2,956	213	2.149	3.325	165
Community of Low Moor outfall	196	600 (P.E.)	176	87	0.052	0.080	406
Community of Selma outfall	194	850 (P.E.)	250	106	0.090	0.13[illegible]	333
Clifton Forge outfall	192	6,052 (P.E.)	1,779	200	1.814	2.806	118
Iron Gate outfall	190	715 (P.E.)	210	109	0.078	0.121	323
Buchannan outfall	150	1,350 (P.E.)	397	90	0.200	0.309	238
Lexington outfall	135	8,454 (P.E.)	2,486	83	0.6[illegible]	1.080	427
Buena Vista outfall	132	6,869 (P.E.)	2,020	88	0.6[illegible]	0.930	430
James Lee and Sons Co. & Glasgow	130	26,200 (lbs. BOD_5)	38,529		2.019	3.123	2,287
Owens-Illinois Paper Co.	118	123,500 (lbs. BOD_5)	181,617		9.000	13.923	2,418
Madison Heights outfall	102	3,000 (P.E.)	882	90	0.494	0.764	214
Mead Corporation	100	61,250 (lbs. BOD_5)	90,073		8.200	12.685	1,316
Lynchburg outfall	90	56,300 (P.E.)	16,550	104	5.50	8.514	361

1/ Using 0.200 lb/cap/day BOD_5 and 0.294 lb/cap/day BOD_u.

2/ Based on present water usage

for Stream Improvement (Of the Pulp, Paper, and Paperboard, Industries) Inc., industrial waste inventories,[3/] and conversations with industrial representatives. All flows were converted to cubic feet per second (cfs) and all loads were converted to ultimate BOD in ppm for use in the math model.

Projected waste loadings (prior to treatment) and flows used in the the Worley Model for the years 1980, 2000, and 2020 are shown in Tables VI - 2, 3, and 4. Basically the waste flows are the same as the water supply needs discussed in section IV. The waste flows were considered approximately equal to water supply flows, less industrial cooling water. It was assumed that consumptive losses were offset by infiltration into the sewerage system. Municipal waste loads were computed using the population equivalents of 0.21 (lbs/cap/day) 5-day BOD in 1980, 0.23 (lbs/cap/day) 5-day BOD in 2000, and 0.25 (lbs/cap/day) 5-day in 2020 in conjugation with projected water service populations. Industrial waste loads in pounds of BOD were computed using the projected indexes of output and the reported waste loads in 1967 for each industry.

The loads shown in Tables VI - 1 through VI - 4 were then applied to the Worley Math Model and dilution flows necessary to maintain three, four, five and six mg/l dissolved oxygen were calculated for 85%, 90%, and 95% BOD removal at eight, twelve, twenty, twenty-five, twenty-eight, and thirty-two degrees centigrade. Table VI - 5 shows the flow requirements obtained from the Worley Model runs necessary to maintain a monthly average of 5.0 ppm D.O. at Covington and Lynchburg

TABLE VI - [illegible]
UPPER JAMES FIVER, YEAR 1980 PROJECTED LOADS

Waste Source	Reach Number	Daily Loads	Daily[1] Loads (lbs. BOD_u)	Flow[2] (gal cap/day)	Waste Flow (MGD)	Waste Flow (CFS)	Loads BOD_u (ppm)
West Virginia Pulp and Paper Co.	198	107,000 (lbs. BOD_5)	157,355		100.0	155.0	189
Covington	197	11,500 (P.E.)	3,554	138[3]	1.587	2.457	268
Low Moor	196	600 (P.E.)	185	98	0.054	0.091	376
Community of Selma	194	850 (P.E.)	263	120	0.102	0.158	309
Clifton Forge	192	7,600 (P.E.)	2,348	130[3]	0.988	1.529	285
Iron Gate	190	715 (P.E.)	221	123	0.088	0.136	301
Buchannan	150	1,350 (P.E.)	417	102	0.138	0.213	362
Lexington	135	10,900 (P.E.)	3,368	94	1.025	1.588	394
Buena Vista	132	8,300 (P.E.)	2,565	99	0.822	1.272	374
Glasgow	130	1,100 (P.E.)	340	100	0.110	0.170	370
James Lee and Son Co.	120	95,600 (lbs. BOD_5)	140,590		7.0	10.8	2,407
Owens-Illinois Paper Co.	118	137,000 (lbs. BOD_5)	201,470		25.0	38.7	966
Madison Heights	102	6,000 (P.E.)	1,854	102	0.612	0.947	363
Mead Corporation	100	42,000 (lbs. BOD_5)	61,765		10.0	15.5	740
Lynchburg	90	69,000 (P.E.)	21,321	118	8.142	12.604	314

1/ Using 0.210 lb/cap/day BOD_5 and 0.309 lb/cap/day BOD_u.

2/ Using 1 percent increase in gal/cap/day per year.

3/ Using 35 percent decrease of gal/cap/day for use of water meters.

TABLE VI - 3
UPPER JAMES RIVER, YEAR 2000 PROJECTED LOADS

Waste Source	Reach Number	Daily Loads	Daily Loads[1] (lbs. BOD_u)	Flow[2] (gal/cap/day)	Waste Flow (MGD)	Waste Flow (CFS)	Loads BOD_u (ppm)
West Va. Pulp & Paper Co.	198	171,000 (lbs. BOD_5)	251,370		100.	155.0	301
Covington	197	16,000 (P.E.)	5,408	166	2.656	4.111	244
Low Moor	196	600 (P.E.)	203	118	0.071	0.110	343
Selma	194	850 (P.E.)	287	144	0.122	0.189	282
Clifton Forge	192	11,000 (P.E.)	3,718	156	1.716	2.656	260
Iron Gate	190	715 (P.E.)	242	148	0.106	0.164	274
Buchannan	150	1,500 (P.E.)	507	122	0.183	0.283	332
Lexington	135	14,000 (P.E.)	4,732	113	1.582	2.450	358
Buena Vista	132	10,600 (P.E.)	3,583	119	1.261	1.952	340
Glasgow	130	1,100 (P.E.)	372	120	0.132	0.204	338
James Lee & Son Co.	120	130,000 (lbs. BOD_5)	191,100		8.5	13.16	2,694
Owens-Illinois Paper Co.	118	182,000 (lbs. BOD_5)	267,540		27.0	41.80	1,187
Madison Heights	102	6,000 (P.E.)	2,028	122	0.732	1.133	332
Mead Corporation	100	63,000 (lbs. BOD_5)	92,610		12.0	18.58	925
Lynchburg	90	139,000 (P.E.)	46,982	142	19.738	30.624	285

[1] Using 0.230 lb/cap/day BOD_5 and 0.338 lb/cap/day BOD_u.

[2] Using 1 percent increase in gpcd per year.

TABLE VI - 4

UPPER JAMES RIVER, YEAR 2020 PROJECTED LOADS

Waste Source	Reach Number	Daily Loads	Daily Loads [1] (lbs. BOD_u)	Flow [2] (gal/cap/day)	Waste Flow (MGD)	Waste Flow (CFS)	Loads BOD_u (ppm)
West Va. Pulp and Paper Co.	198	285,000 (lbs. BOD_5)	418,950		100.	155.0	502
Covington	197	19,000 (P.E.)	6,992	199	3.781	5.853	221
Low Moor	196	600 (P.E.)	221	142	0.085	0.132	311
Selma	194	850 (P.E.)	313	173	0.147	0.228	255
Clifton Forge	192	15,000 (P.E.)	5,520	187	2.805	4.342	236
Iron Gate	190	715 (P.E.)	263	178	0.127	0.197	248
Buchannan	150	1,350 (P.E.)	497	146	0.197	0.305	302
Lexington	135	18,500 (P.E.)	6,808	136	2.516	3.895	324
Buena Vista	132	13,500 (P.E.)	4,968	143	1.930	2.988	308
Glasgow	130	1,100 (P.E.)	405	144	0.158	0.245	340
James Lee and Son Co.	120	182,000 (lbs. BOD_5)	267,540		10.	15.480	3,206
Owens-Illinois Paper Co.	118	273,000 (lbs. BOD_5)	401,310		30.	46.440	1,603
Madison Heights	102	6,000 (P.E.)	2,208	146	0.876	1.356	302
Mead Corporation	100	105,000 (lbs. BOD_5)	154,350		14.	21.672	1,321
Lynchburg	90	334,000 (P.E.)	122,900	170	56.780	37.895	259

1/ Using 0.250 lb/cap/day BOD_5 and 0.368 lb/cap/day BOD_u.

2/ Using 1 percent increase in gpcd per year.

(the two most critical areas in the Upper James River) for the various years, BOD removals, and temperatures. Figures VI - 1 through VI - [illegible] show the graphical representations of Table VI - [illegible]. From these Figures the flow requirements presented in Tables VI - [illegible] and VI - 7 were obtained.

Covington-Clifton Forge Area

In the Covington area, the principal waste source is Westvaco (formerly West Virginia Pulp and Paper Company). This plant is now providing secondary treatment of its wastes, but two towns downstream (Covington and Clifton Forge) need to add additional treatment to their present primary plants.

Minimum river flow at Covington is 65 cfs; average flow is [illegible]37 cfs. Secondary treatment (85 percent BOD removal) will be adequate for conditions expected in 19[illegible]0, with a flow release of 365 cfs at the proposed Gathright reservoir during the critical summer period. Flow requirements, shown in Table VI - 6, are based on maintaining an average dissolved oxygen concentration of 5 milligrams per liter (mg/1). Stream standards require a D.O. of 4 mg/1 minimum. Flow needs are also based on a maximum river temperature of 27° C due to controlled releases from Gathright Reservoir now under construction.

By year 2000, additional flow (555 cfs) or higher degree of treatment (90 percent removal) will be needed. By year 2020, 95% BOD removal will be needed or a combination of additional flow and degree of treatment somewhere between 90 and 95% BOD removal. Cost studies

TABLE VI - 2

FLOW REQUIREMENTS - CFS (ft^3/sec)

Upper James River, - Virginia

DO Objective - 5.0 mg/l Average

Place Year	% BOD Removal	Temperature °C 8	12	20	25	28	32
Covington - (Reach 197)							
1967	85	89	93	116	159	206	300
	90	89	93	100	113	142	198
	95	89	93	100	107	113	128
1980	85	181	186	239	336	435	613
	90	181	186	201	234	296	405
	95	181	186	201	214	227	258
2000	85	181	216	360	512	662	927
	90	181	186	249	354	459	648
	95	181	186	201	214	254	338
2020	85	257	332	553	858	1057	1557
	90	188	233	393	586	714	1062
	95	181	186	216	321	364	544
Lynchburg - (Reach 90)							
1967	85	374	488	786	1037	1255	1581
	90	257	335	546	730	882	1112
	95	142	182	290	386	471	594
1980	85	529	698	1119	1587	2011	2731
	90	358	457	733	989	1219	1573
	95	225	254	397	528	644	868
2000	85	844	1089	1795	2475	3157	4266
	90	473	604	962	1341	1693	2273
	95	266	331	518	691	848	1092
2020	85	1400	1804	2984	4155	5661	8416
	90	820	1063	1759	2425	3113	4201
	95	354	449	714	963	1190	1538

Revised March 17, 1969

TABLE VI -

JAMES RIVER

Year	% BOD Removal	Flow Requirements in CFS at Covington[1]												
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Present	85	90	90	90	115	125	160	160	160	150	125	95	90	121
	90	90	90	90	100	100	125	125	125	110	100	95	90	103
	95	90	90	90	100	100	105	105	105	105	100	95	90	98
1980	85	180	180	185	240	250	365	365	365	310	250	190	180	255
	90	180	180	185	200	205	250	250	250	220	205	185	180	208
	95	180	180	185	200	200	215	215	215	210	200	185	180	197
2000	85	185	180	225	360	385	555	555	555	475	385	230	195	357
	90	185	180	185	250	265	385	385	385	325	265	190	180	265
	95	180	180	185	200	205	225	225	225	210	205	185	180	200
2020	85	270	270	330	553	600	910	910	910	770	600	360	290	564
	90	200	200	230	400	430	630	630	630	540	430	250	210	398
	95	180	180	190	216	230	330	330	330	280	230	190	180	239
Temp °C		9	8	12	20	21	26[2]	26[2]	26[2]	24	21	13	10	

DO Objective = 5.0 mg/l

(1) Including industrial water supply for WESTVACO.

(2) Assumes water temperature controlled by Gathright.

will be made to determine the optimum combination of advanced waste treatment (beyond 85% BOD removal) and flow augmentation; other possible methods of maintaining water quality include alternate sources of water supply for Westvaco, and additional reuse of process and cooling waters.

A BOD removal of 85% is considered the minimum acceptable level of treatment, and flow augmentation is to be used as an alternate only to additional waste treatment giving removals above 85%.

Present problems in the Covington area include recurrent low dissolved oxygen during the summer months due to high waste loadings even after about 80% BOD removal, high temperatures and low stream flow.

Lexington-Buena Vista Area

The Maury River in the Lexington and Buena Vista area has sufficient flow for present needs. By 1980, additional flows will probably be needed to maintain water quality. VEPCO is planning a pumped storage hydro-electric project on the headwaters on the Maury, and negotiations are underway to include storage for water supply and water quality.

Lynchburg Area

At Lynchburg, the minimum stream flow observed is 234 cfs; average flow is 3,500 cfs. The two proposed reservoirs, Gathright and Hipes, will provide a minimum stream flow of 1,100 cfs during the summer months.

There are several run-of-the-river hydroelectric projects in the Lynchburg area. These projects have limited storage and are used for peaking power, which causes periods of little or no flow in the James during drought seasons. In order to obtain maximum benefit from the flow augmentation, arrangements should be made to pass augmented flows without storage for peaking.

Flow required for various treatment levels is summarized in Table VI - 7. It appears that a combination of treatment beyond 85 percent BOD removal and additional reservoir storage will be needed. For example, by year 1980, 90 percent removal and 1,540 cfs would also satisfy the need.

Costs of various combinations of treatment levels and flow releases will be studied to determine an optimum.

However, minimum summer flows in excess of the average stream flow of 3,500 cfs will be difficult to attain, and a practical limit will dictate that treatment levels between 90 and [illegible] percent BOD removal will be needed after 1980 if growth of the paper industry and the City of Lynchburg continues as our projections indicate.

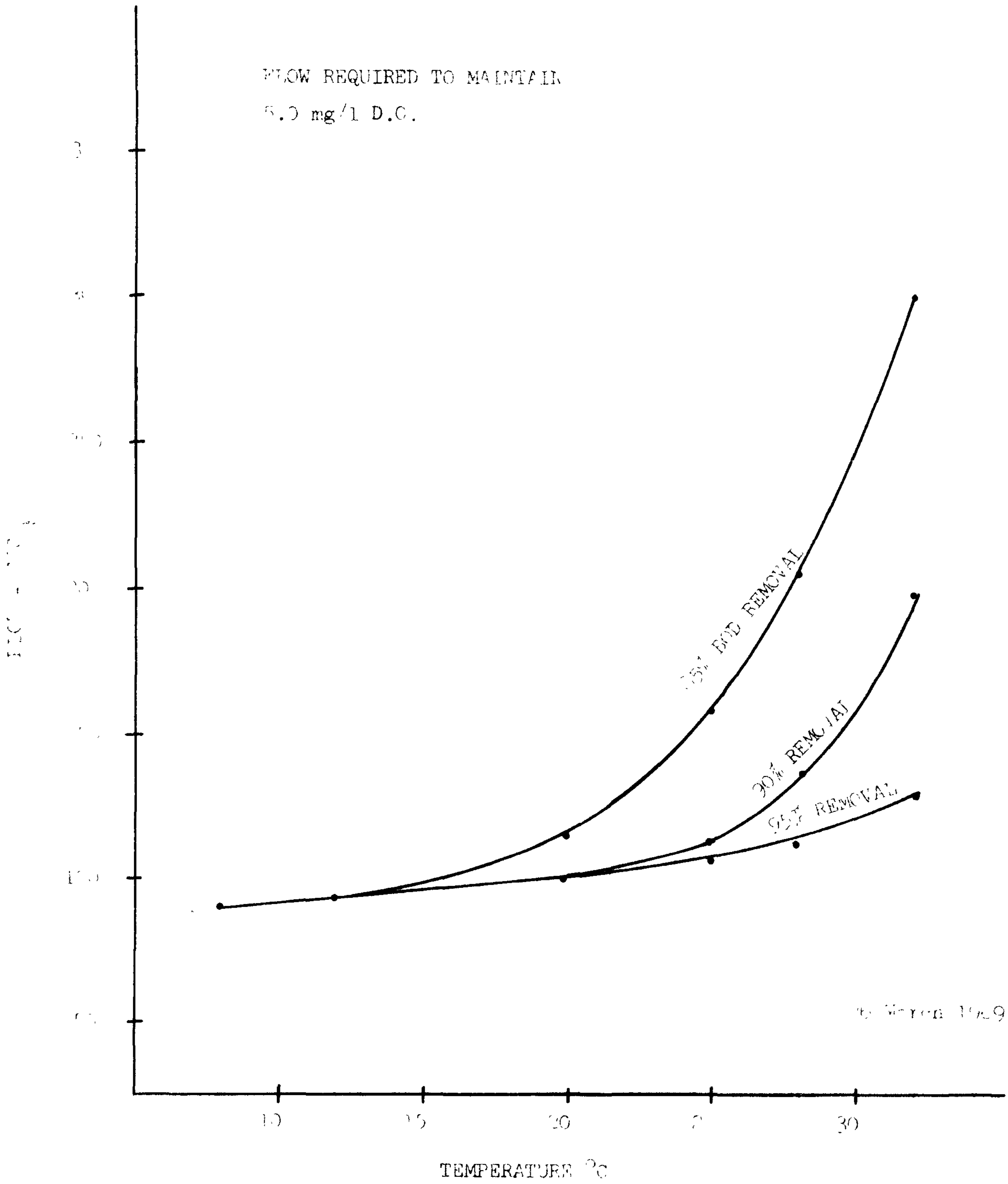
Lynchburg now has a primary waste treatment plant and the two paper mills in the area have "in plant" treatment processes. Secondary treatment or its equivalent should be provided for these major waste sources as soon as possible to correct existing degraded conditions in the James River.

TABLE VI - 7

JAMES RIVER

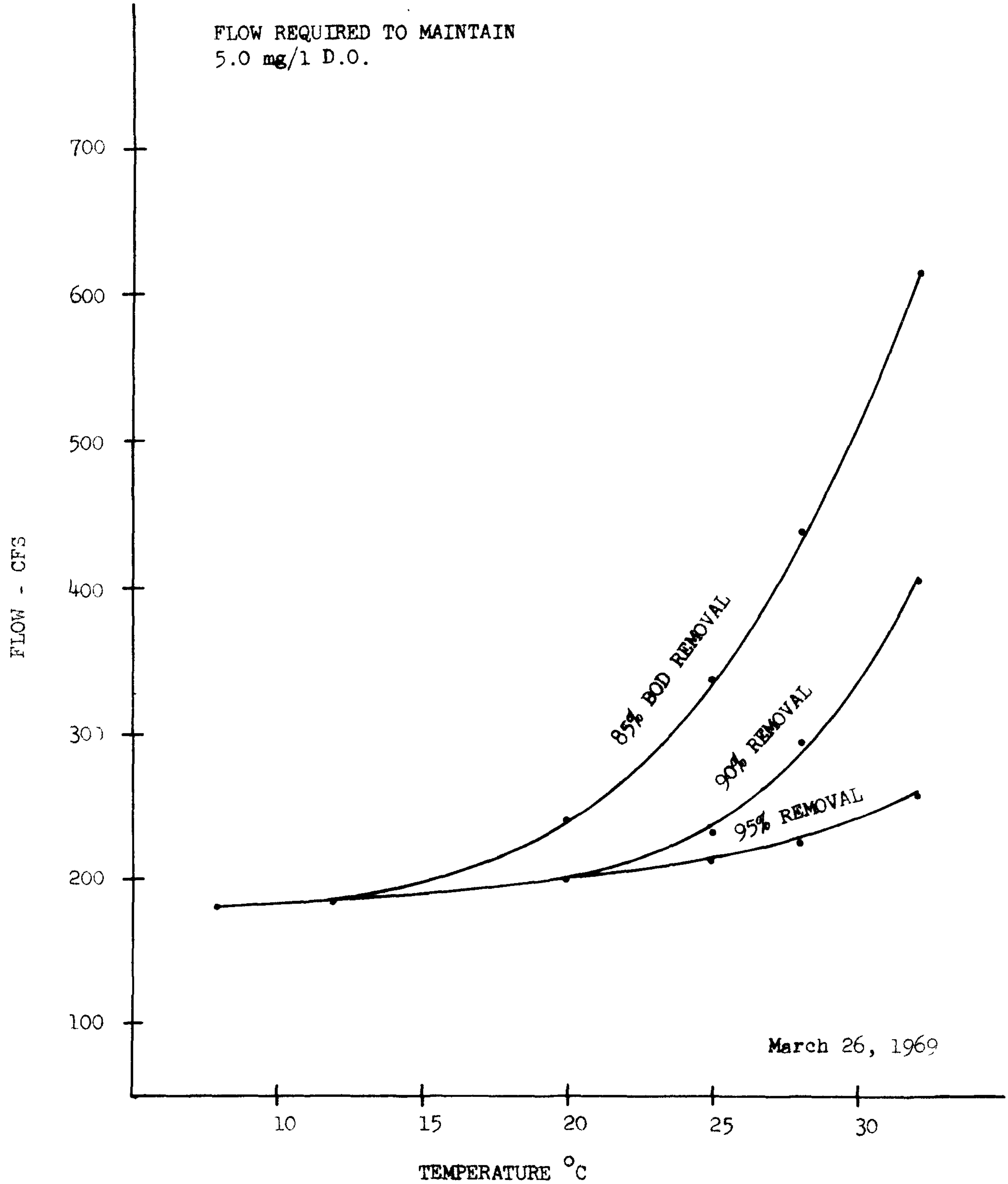
Year	% BOD Removal	Flow Requirements in CFS at Lynchburg												
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Present	85	400	460	590	930	1040	1580	1580	1580	1335	980	625	488	966
	90	275	315	410	645	730	1110	1110	1110	940	685	435	335	675
	95	155	175	220	345	386	590	590	590	500	365	235	182	361
1980	85	570	640	820	1360	1590	2730	2730	2730	2180	1470	870	700	1530
	90	380	430	540	880	990	1570	1570	1570	1300	930	580	460	9330
	95	200	240	290	470	530	870	870	870	680	500	310	250	508
2000	85	900	1020	1320	2170	2480	4260	4260	4260	3400	2300	1410	1090	2410
	90	500	570	720	1160	1340	2270	2270	2270	1820	1240	760	600	1290
	95	280	310	390	610	690	1100	1100	1100	900	650	410	330	656
2020	85	1500	1720	2200	3640	4160	8416	8416	8416	6150	3890	2320	1800	4390
	90	880	980	1280	2120	2420	4200	4200	4200	3360	2280	1330	1060	2360
	95	360	420	520	850	960	1540	1540	1540	1240	890	550	450	905
Temp °C		9	11	15	23	25	32	32	32	29	24	16	12	

DO Objective = 5.0 mg/l



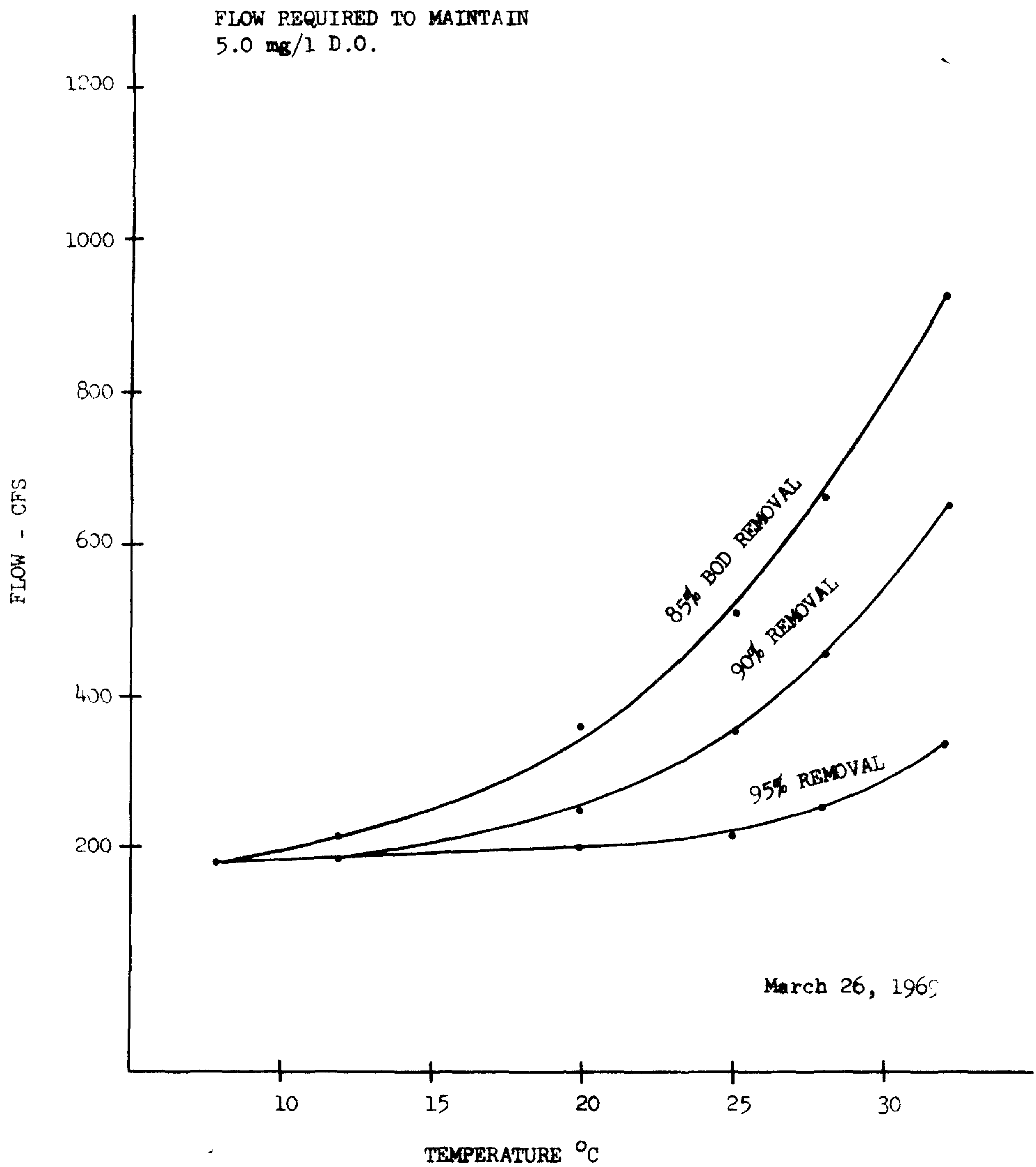
JAMES RIVER AT COVINGTON — 1967

FIGURE VI - 1



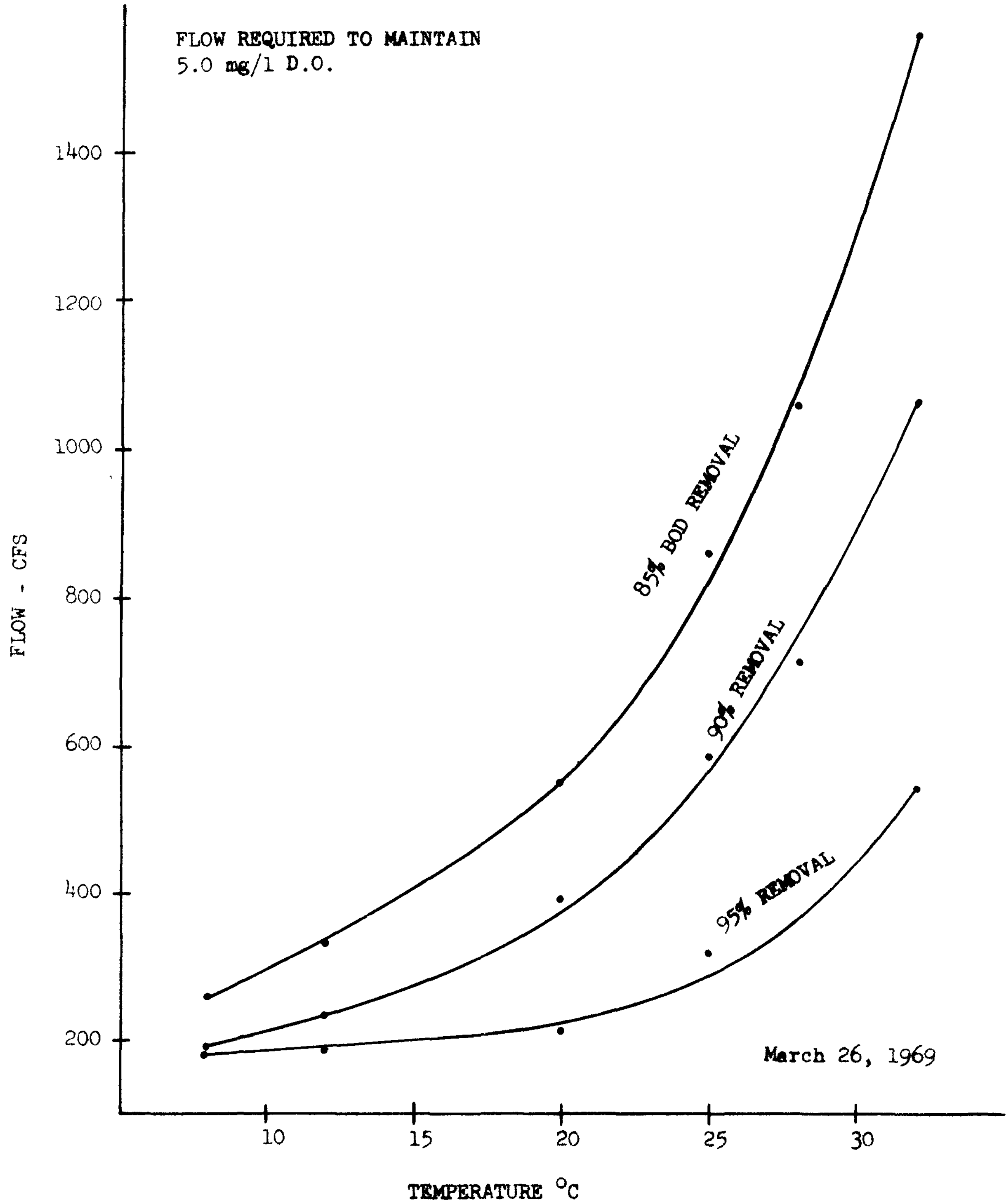
JAMES RIVER AT COVINGTON - 1980

FIGURE VI - 2



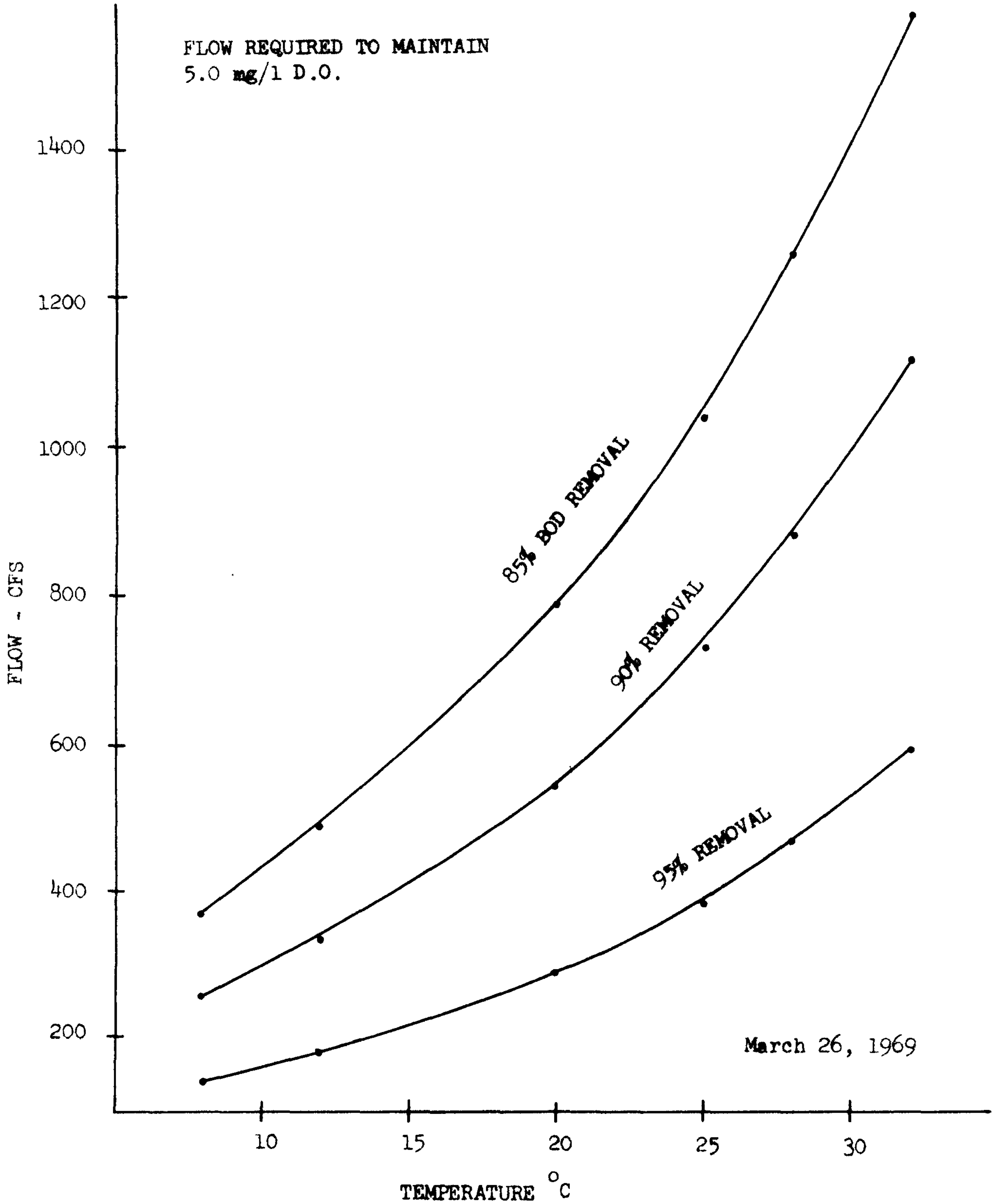
JAMES RIVER AT COVINGTON - 2000

FIGURE VI - 3



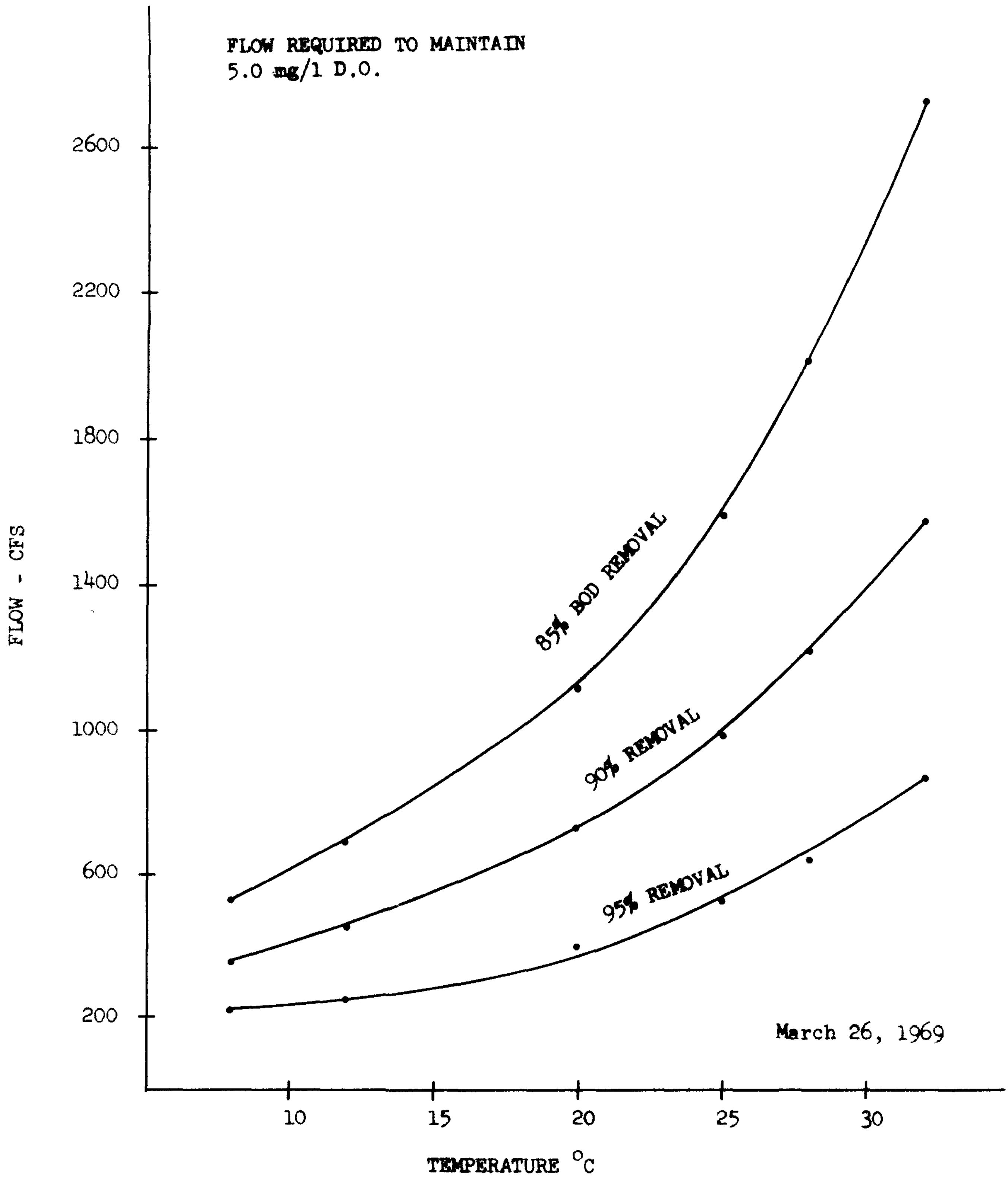
JAMES RIVER AT COVINGTON - 2020

FIGURE VI - 4



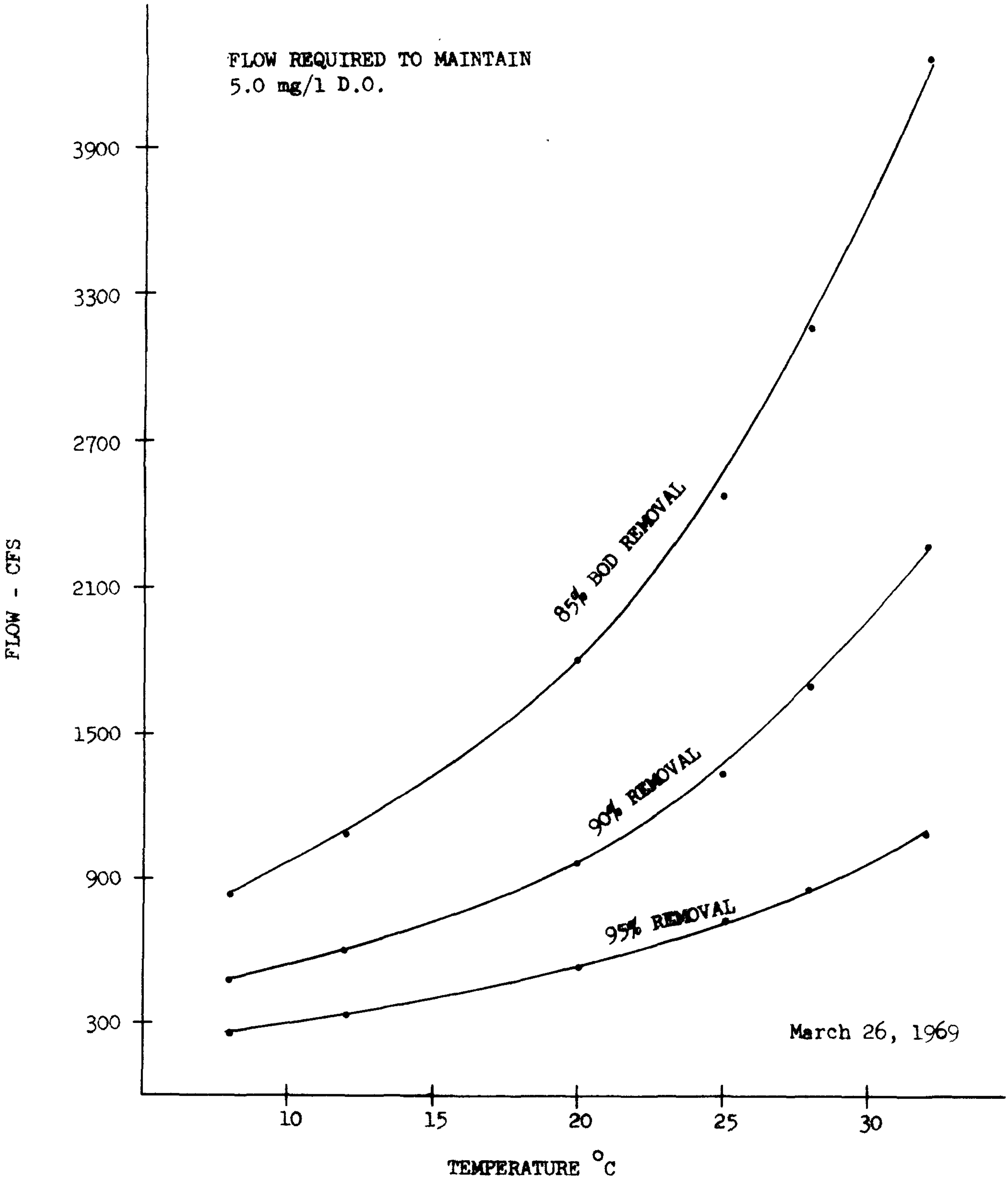
JAMES RIVER AT LYNCHBURG - 1967

FIGURE VI - 5



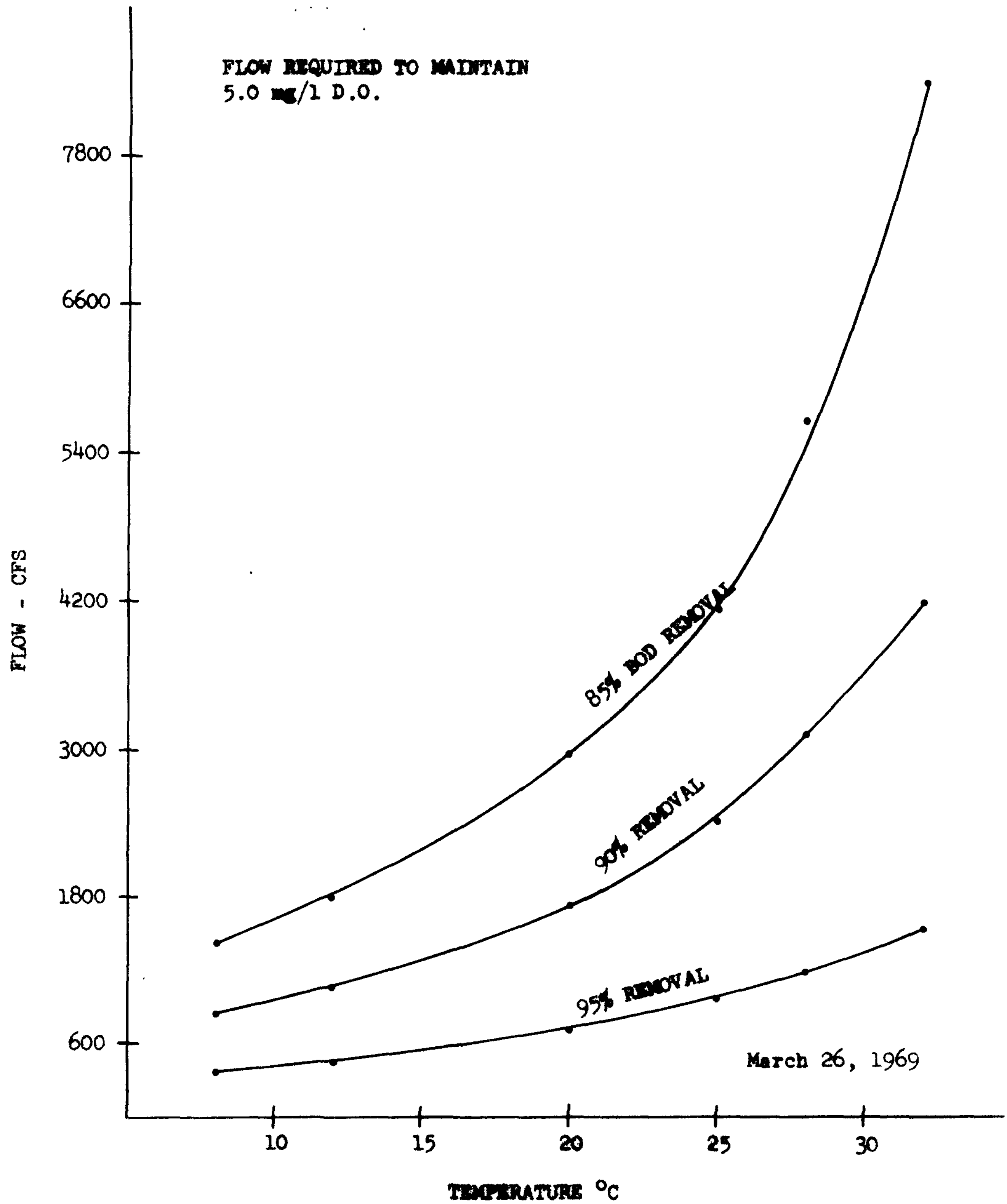
JAMES RIVER AT LYNCHBURG - 1980

FIGURE VI - 6



JAMES RIVER AT LYNCHBURG - 2000

FIGURE VI - 7



JAMES RIVER AT LYNCHBURG - 2020

FIGURE VI - 8

VII. JAMES RIVER ESTUARY

A. Flow Requirements

Domestic and industrial waste loads in the James River Estuary for 1980, 2000, and 2020 were computed from data shown in Table VII - 1 and the Waste Discharge Inventory of the Richmond-Petersburg-Hopewell Metropolitan Area compiled by the Virginia State Water Control Board.

DOMESTIC. A population equivalent factor, expressed as pounds of ultimate biochemical oxygen demand per capita, was applied to the projections to determine the quantity of domestic wastes requiring treatment and/or assimilation by the estuary during the selected time intervals. All discharge points were assumed to remain in their present locations with the exception of those in Chesterfield County. Wastes from this area, including the City of Petersburg, were predicted to be piped to the James for discharge by the year 1980.

INDUSTRIAL. Waste loads from industries, using the James as a receiving stream, were derived by escalating present output of ultimate BOD at the same rate as production. No allowances were made for advances in technology or change in processes to reduce the ratio of waste to finished product. Industrial wastes in this section of the estuary are primarily from chemical plants with approximately five percent from paper related operations.

In the future, the Hopewell industrial complex will continue to contribute [illegible] percent of the wastes being discharged to the estuary. The balance will come from industries and population centers located upstream. Domestic wastes will comprise approximately 17.5 percent of the total load.

Table VII - 1 shows the projected waste production for the design period. They are expressed as pounds of ultimate BOD to reflect their effect in the estuary as a result of tidal action.

WATER QUALITY. To maintain an average of 5 mg/l dissolved oxygen concentration in the James below the waste discharges at Richmond and Hopewell, the flows shown in Table VII - 2 will be needed. They were obtained by applying the projected loads to the estuarine math model and operating it at the treatment levels indicated. Figures VII - 1, 2, and 3 may be employed to determine required flows for temperatures other than the mean maximum monthly values chosen for the preapration of the table. For flows less than those called for in the table, Figures VII - 4 and VII - 5 can be consulted for the degree of treatment necessary to satisfy the established standards. The practical and economical feasibility of providing the required flows was not considered in this analysis.

Lynchburg flow requirements corresponding to 85 and 90 percent treatment are shown in Table VII - 7. With 85 percent treatment at Lynchburg and 90 percent treatment in the estuary, the stream standards can reliably be maintained in 1980. Maximum flows for the critical months of June, July, and August during this period will

TABLE VII - 1

WASTE LOADING: JAMES ESTUARY-RICHMOND TO HOPEWELL

Location	Contributor	1980 BOD_u #/Day (1)	2000 BOD_u #/Day (1)	2020 BOD_u #/Day (1)
Richmond	City of Richmond	129300	152000	182000
	Federal Paper	8520	12790	17060
	Standard Paper	4710	7060	11760
Chesterfield	Chesterfield County	65400	105000	113400
	DuPont Chemical	50000	112500	176000
	American Tobacco	22940	34410	57350
Hopewell	Allied Chemical	99850	199700	428000
	Continental Can Co.	191200	286600	382350
	Hercules, Inc.	422700	854400	1342600
	City of Hopewell	22170	43200	96000

(1) Loading prior to waste treatment

TABLE VII - [illegible]

FLOW REQUIREMENTS TO MAINTAIN [illegible].0 MG/L AT HOPEWELL

YEAR	TREATMENT LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	85%	(1)	(1)	900	2000	2750	4200	4600	4600	3900	2500	1300	750
1980	90%	(1)	(1)	(1)	400	800	1750	2050	2050	1550	650	(1)	(1)
	95%	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
	85%	1850	2250	3700	5150	6200	8100	6450	6450	7550	5950	4200	3200
2000	90%	(1)	400	1200	2700	3700	5300	5600	5600	5000	3500	1800	1000
	95%	(1)	(1)	(1)	(1)	400	1500	1700	1700	1200	350	(1)	(1)
	85%	5100	5300	6400	8200	9300	11200	11500	11500	11000	9100	7000	6200
2020	90%	2350	2650	3750	5400	6500	8150	8650	8650	7800	6200	4300	3550
	95%	(1)	(1)	850	1900	2500	4000	4350	4350	3500	2350	1250	700
TEMPERATURE °C		8	9	13	20	24	29	30	30	28	23	16	12

(1) Water quality control flow requirements are less than minimum daily flow recorded.

be 2730 and 2050 cfs respectively. By the year 2000, removal efficiencies may need to be increased above 90 percent in the estuary, during several months of the year to maintain the DO minimum. Without this procedure, flows of 4260 and 5600 cfs must be provided. If flows of 8416 and 8650 cfs cannot be furnished at Lynchburg and Hopewell for the period beginning in the year 2020, treatment in excess of 90 percent for discharges to the estuary during the critical months must be considered.

B. Mathematical and Physical Models

It is difficult to predict the reaction, of any estuary, to the addition of oxygen demanding constituents in municipal and industrial waste discharges. Accurately describing the physical, chemical, and biological processes in its dynamic environment is a formidable task. When rational simplifying assumptions are applied, it is often possible to approximate the dissolved oxygen concentration and biochemical oxygen demand remaining in any section by employing mathematical modelling techniques. As the tide and the proximity of the ocean varies with each estuary, it is necessary to estimate their effect with diffusion coefficients for the math model and then compare the results with sampling data from the field and/or a physical model. This process, known as verification, is some times lenghty and frustrating.

__Mathematical__. Two mathematical models were employed in the James River estuary investigation. The first was the DECS III model developed, under contract, by the General Electric Corporation. With it, the time-dependent characteristics of the tide are simulated in the input data. Its primary function was to determine the mixing coefficients throughout the estuary. A number of trial and error solutions were needed before attaining a reasonable match between the math model calculations and the physical dye data from the model at Vicksburg, Mississippi.

The derived coefficients were then applied in the Steady-State Segmented model developed by the Middle Atlantic Region's staff. This model is similar in theory to the DECS III with the exception of the time increment chosen. The Steady-State Model assumes a time period of sufficient length for all elements in the estuary to have reached relative equilibrium. Using data from the economic projections, waste loadings for 1980, 2000, and 2020 were computed and used in the model along with the geometric and hydraulic data to predict the flow requirements needed to maintain a minimum monthly average dissolved oxygen concentration of 5 mg/l at different levels of treatment. Previous studies of the James by the FWPCA Chesapeake Field Station at Annapolis, Maryland, indicated a monthly average value of 5 mg/l of dissolved oxygen was comparable to a minimum daily of 4.0 mg/l on which the water quality standards are based.

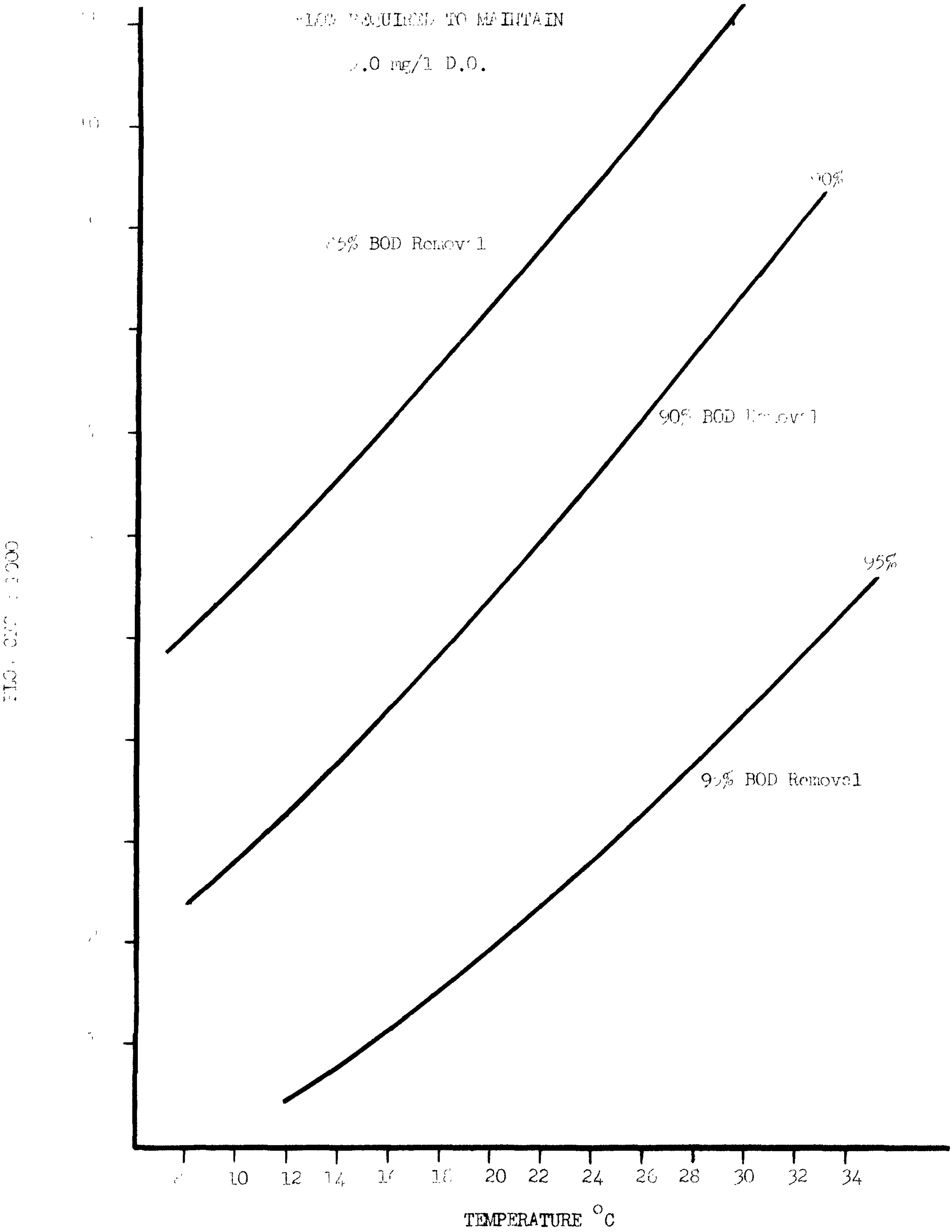
Physical. Data from the physical model at Vicksburg, Mississippi was used almost exclusively in this investigation as there was very little reliable data from field studies. Prior work in the James estuary was usually confined to a limited area of interest and conducted during different periods of the year. As much prototype data of significance that could be obtained was applied or reviewed for possible application. Primarily this was of a nature that could not be duplicated or simulated in the model i.e., oxygen uptake rates, benthal demand, and photosynthesis.

The physical model of the James River estuary, from the fall zone to the Atlantic Ocean, was constructed and is operated by the U.S. Army Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi. Two tests model studies were conducted for the FWPCA in addition to those for other state and federal agencies.

The first, using dye as a tracer, attempted to measure the diffusion rates. Loadings and discharge points were simulated for existing conditions. Dye concentrations were determined at selected stations for time intervals equivalent to 2.5 days in the prototype. The model was operated 120 tidal cycles for each flow condition. Flows simulated were 1000, 3200, and 11500 cfs as well as the hydrograph as measured at Richmond for July and August, 1966. The data gathered was presented in tabular and graphical form to be used to verify the math model.

Radioactive tracers were employed in the second test to establish the reaeration rate for each reach of the estuary. The activities of a conservative tracer, Tritium, and a non-conservative tracer, Krypton-85, were monitored for a number of tidal cycles. The appropriate laws of nuclear physics were then applied to determine the rate of mass transfer from the model to the atmosphere. This has been found to be proportional to the transfer of oxygen from the atmosphere through the air-water interface. The reaeration rates from this experiment appeared to be lower than those previously computed with hydraulic and geometric parameters of the estuary.

The math and physical models have precluded the need for an expensive and possibly inconclusive time-consuming field survey.



JAMES RIVER AT HOPEWELL - 2020

Figure VII - 3

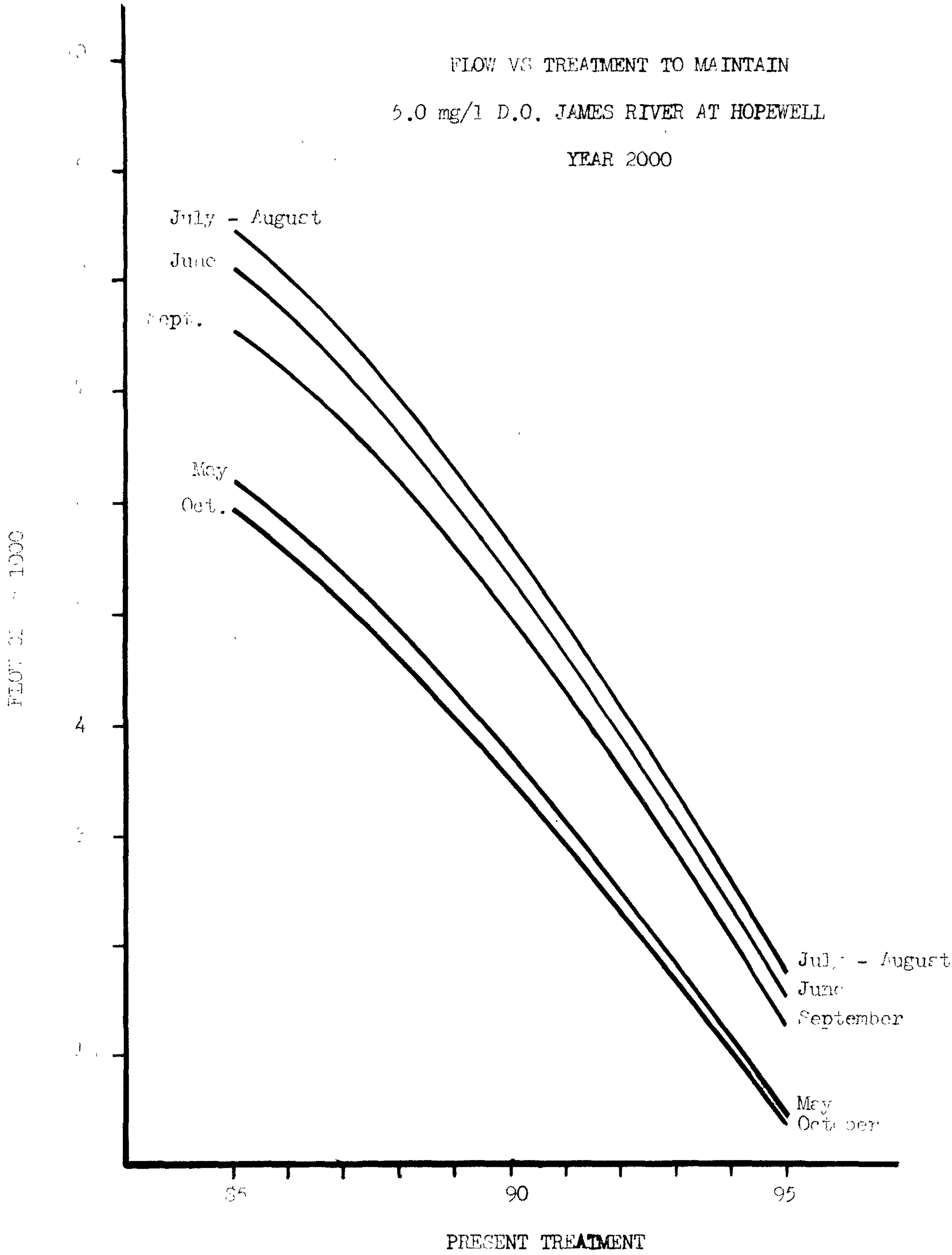

FLOW VS TREATMENT TO MAINTAIN
5.0 mg/1 D.O. JAMES RIVER AT HOPEWELL
YEAR 2000
July - August
June
Sept.
May
Oct.
July - August
June
September
May
October
4
90
95
PRESENT TREATMENT

Figure VII - 4

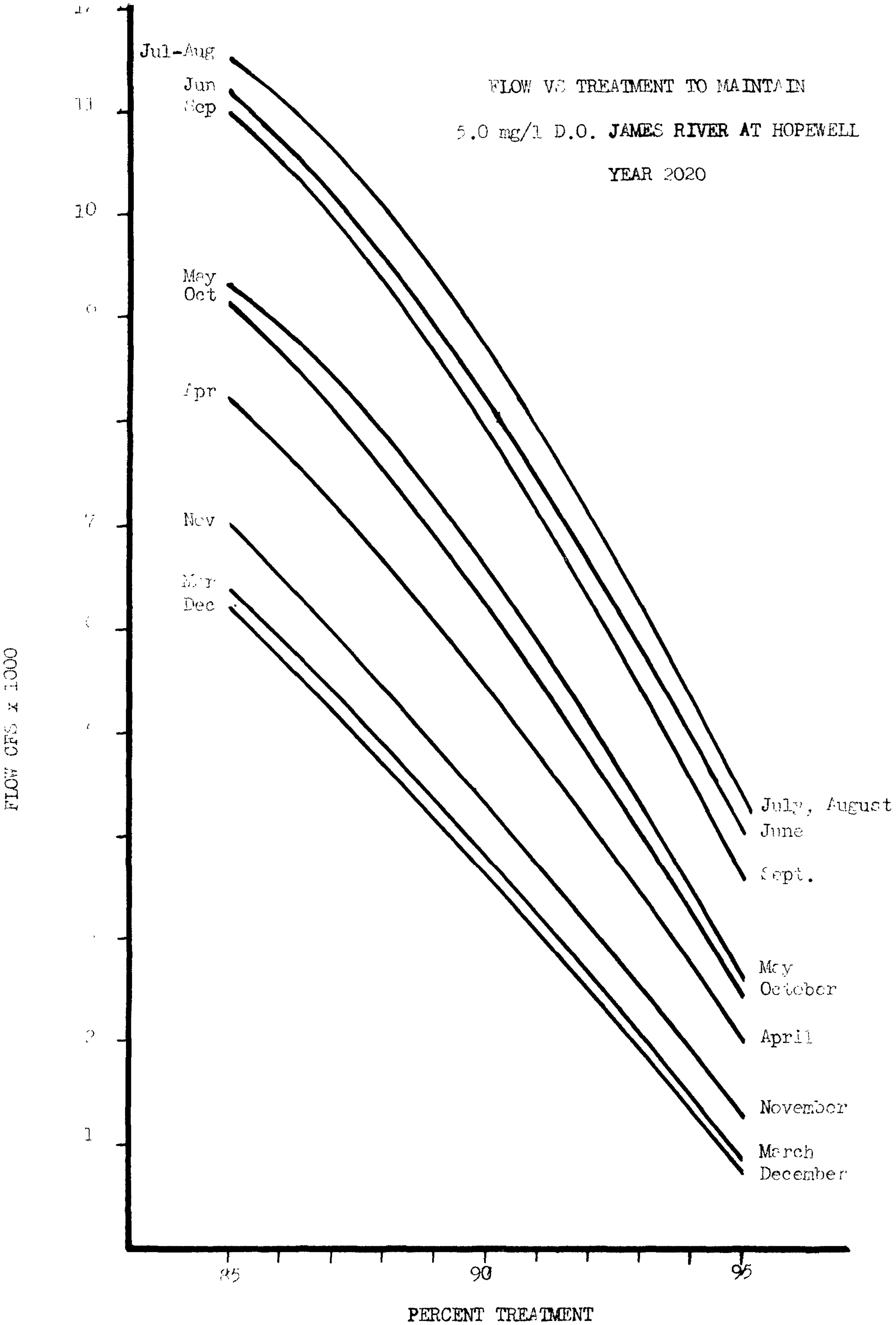
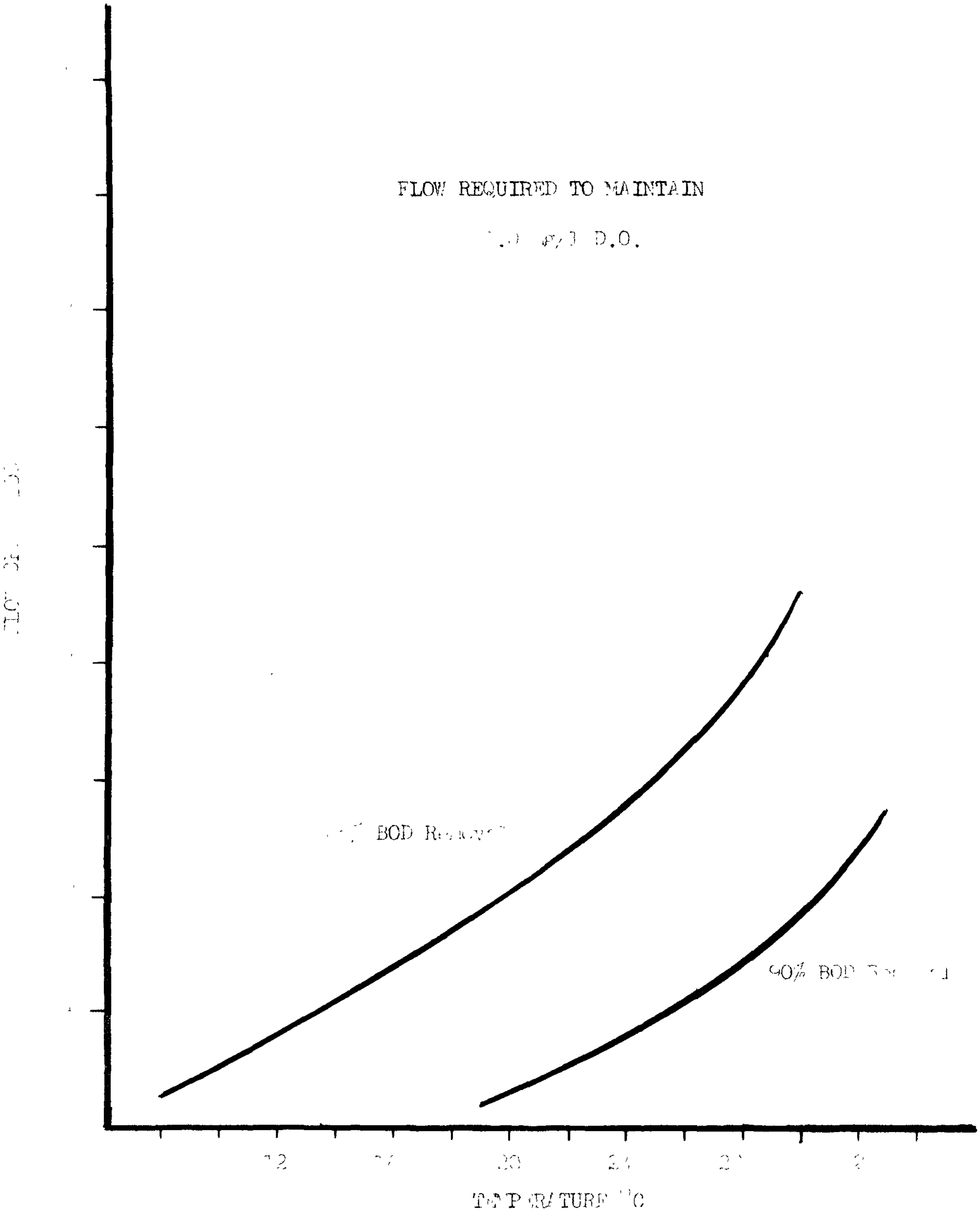

FLOW VS TREATMENT TO MAINTAIN
5.0 mg/1 D.O. JAMES RIVER AT HOPEWELL
YEAR 2020
FLOW CFS x 1000
10
7
2
1
Jul-Aug
Jun
Sep
May
Oct
Apr
Nov
Dec
July, August
June
Sept.
May
October
April
November
March
December
85
90
95
PERCENT TREATMENT

Figure VII - 5



JAMES RIVER T HOPEWELL - 1980

Figure VII - 1

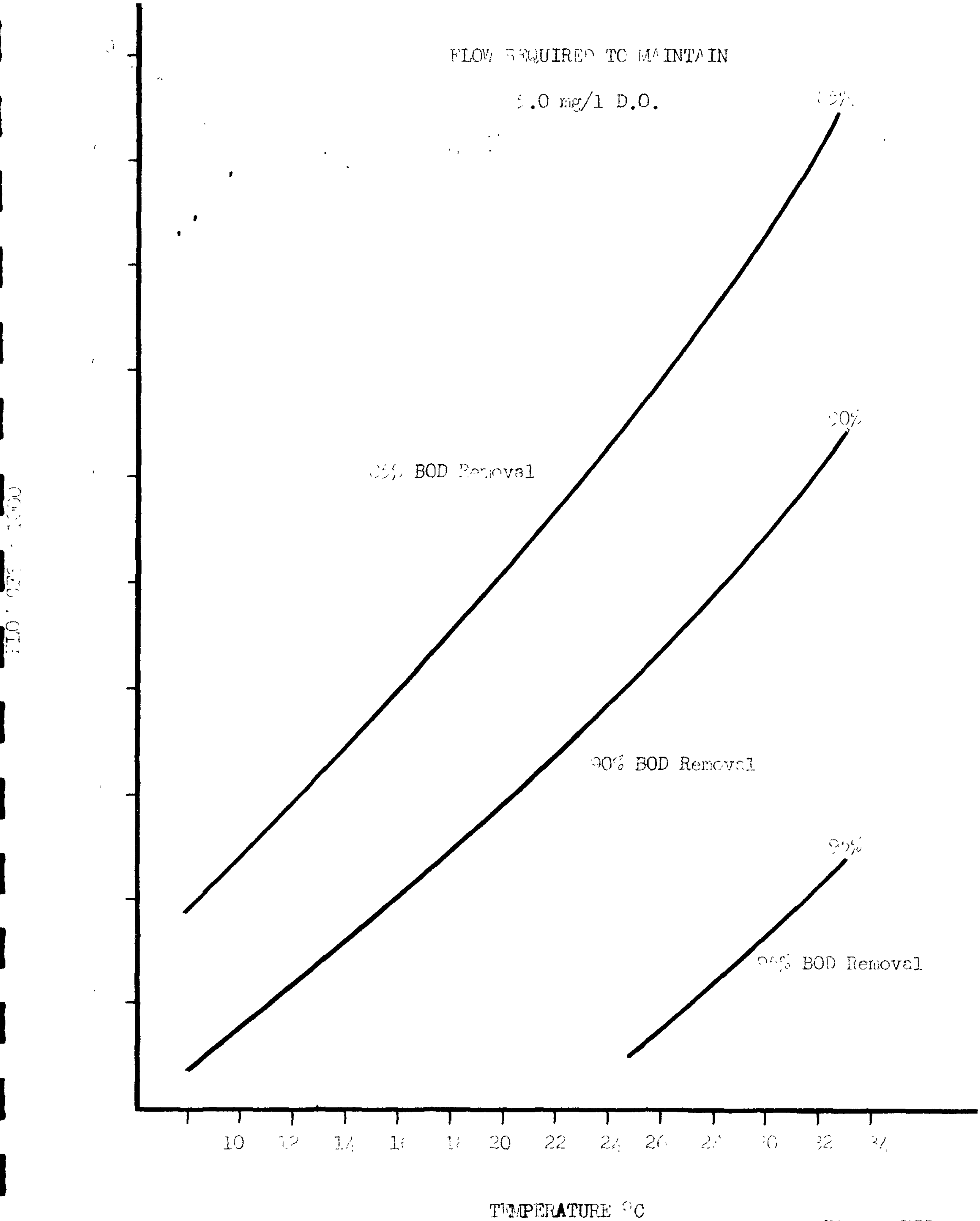


Figure VII -

JAMES RIVER AT HOPEWELL - 2000

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