CHAPTER IV

SINGLE RESERVOIR OPERATION STUDIES

Introduction

An evaluation of the water supply capabilities of each reservoir of the New York City Delaware System is presented in this chapter. Detailed knowledge of the individual capabilities of the reservoirs is useful for comprehensive plan formulation. Several alternative regulation schemes for each reservoir were studied using a single reservoir operation model to screen out the schemes which are not promising and to develop information for use in the system operation studies. Since single reservoir analysis does not consider the U.S. Supreme Court Decree's flow requirement at Montague, New Jersey, the system yield determined here is higher than it actually would be.

General

Several operation studies were made separately for Cannonsville, Pepacton and Neversink Reservoirs using a single reservoir simulation model. Inflow data consisted of average monthly discharges for the period October 1922 to September 1967. However, to study the significance of the recent drought, studies were made separately using data for the 38-year period from October 1922 to September 1960 and for the 45-year period from October 1922 to September 1967. The basic hydrologic data were developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers for use in the Northeastern United States Water Supply (NEWS) Study. For use in the present study the data were adjusted to correct discrepancies observed. The development of inflow data is detailed in Appendix A (on file). The outflows from each City reservoir consist of diversion to New York City for water supply and downstream conservation releases. The present and proposed conservation releases are detailed in Chapter III. Evaporation losses from reservoir surfaces are taken into consideration. The model performs a sophisticated analysis of reservoir operation and maintains a continuous account of the monthly water budget. The model output consists of annual shortage data, shortage index calculations, probable monthly means, 80 and 90 percent exceedence stages and monthly mean releases. The scope of single reservoir operation studies is presented in Table IV-1.

Theory and concept of the single reservoir operation study model, principles of reservoir regulation, the computer program for the model and printout for three typical runs are presented in Appendix B (on file). Summaries of various operation studies detailing shortage data, shortage index data, average end of September stage data, and average release for July data are also included in Appendix B.

Operation Studies

I. Cannonsville Reservoir

The basic runs (Series I) include study of 25 operation schemes assuming that the total capacity of the reservoir between the spillway crest level and the minimum operating level is available for use. The downstream releases were at the present level in Series I(a) and at the proposed level in Series I(b). In all of these runs, diversion to New York City for water supply (D_1) was varied over a wide range from 50 cfs to 1,000 cfs.

Shortage deficiencies are expressed in terms of the shortage index (SI)[9]. This is an important term used throughout the remainder of the report to indicate the capability of the reservoirs, both singularly and as a system, to satisfy requirements. The shortage index is useful because it reflects the magnitude of the shortage as well as the number of shortages both of which are important factors that need to be considered in evaluating reservoir capability. Although the computed numerical values are usually low and expressed as decimals, they provide a common base for evaluating and comparing operation capabilities. If, for example, a run is made to determine the capability of Cannonsville Reservoir operated to meet a diversion requirement of 600 cfs and the proposed conservation release of 125 cfs, it would probably be found that the total requirement of 725 cfs could not be met every year during the 45-year period being tested. In other words, shortages would occur during certain years. If shortages occurred during four separate years and if the average shortage per year was 73 cfs, the shortage index would be 0.089 1/. If the same average shortage per year occurred for 10 separate years, the shortage index would be 0.222; if for only one year, the shortage index would be 0.022. The smallest numerical value represents the best reservoir operation.

The shortage index (SI) is shown as a function of diversion demand (D_1) in Figure IV-1 for Series I(a) and I(b). The reservoir has the capability of meeting the following diversion demands with no shortages:

Series	Downstream Releases	Diversion Demand (D_1) 45-Year Data (1923-1967)	38-Year Data (1923-1960)
I(a)	Present Level	500 cfs (323 mgd)	600 cfs (388 mgd)
I(b)	Proposed Level	400 cfs (259 mgd)	550 cfs (356 mgd)

Prior to 1960, the drought within the period 1929 to 1935, which has a frequency of occurrence of once in 12 years, was considered as the most critical of any that occurred during the period 1905 to 1954. As the above table indicates the 60's drought, which has a frequency of occurrence of once in over 400 years, is more limiting, and it is selected

1/ $$\left[4 \times \left(\frac{73}{725}\right)^2\right] \frac{100}{45} = 0.089$$

as the design criterion. However, analyses are made for both the 38-year (1923-1960) and 45-year (1923-1967) data separately to study the effect of the recent drought.

The basic diversion capability of the reservoir is defined as the diversion demand it can meet without any shortages while downstream releases are made at the proposed level. The basic diversion capability of Cannonsville Reservoir is 400 cfs for the 45-year data and 550 cfs for the 38-year data.

The monthly variation of average, 80 percent and 90 percent exceedence stages for the two sets of data for the operation scheme with a diversion demand of 400 cfs and downstream releases at the proposed level of 125 cfs are shown in Figure IV-2.

Yield-drawdown curves for the 10, 20 and 50 percent exceedence probabilities for Series I(a) and I(b) are presented in Figure IV-3 for the present and proposed downstream release operations. The analysis is based on the inflow data for the period October 1922 to September 1967. The drawdown is calculated as the difference between the end of September stage and the spillway crest level. The minimum operating level set by the City for the reservoir is considered as the lowest level to which the reservoir could be drawn down. The yield-drawdown data for various operation schemes are given in Table IV-2. For the basic diversion rate of 400 cfs, the drawdown increases by 7.7 feet for the 50 percent exceedence probability, 14.8 feet for the 20 percent exceedence probability and 18.5 feet for the 10 percent exceedence probability when the downstream releases are increased from the present level to the proposed level.

II. Pepacton Reservoir

The basic runs (Series II) consist of study of 28 operation schemes assuming that the total capacity of the reservoir between the spillway crest level and the minimum operating level is available for use. The downstream releases were at the present level in Series II(a) and at the proposed level in Series II(b). In all of these runs, diversion to New York City for water supply (D_1) was varied over a wide range from 50 cfs to 1,000 cfs.

The shortage index (SI) is shown as a function of diversion demand (D_1) in Figure IV-4 for Series II(a) and II(b). The reservoir has the capability of meeting the following diversion demands with no shortages:

Series	Downstream Releases	Diversion Demand (D_1) 45-Year Data (1923-1967)	Diversion Demand (D_1) 38-Year Data (1923-1960)
II(a)	Present Level	600 cfs (388 mgd)	750 cfs (485 mgd)
II(b)	Proposed Level	550 cfs (356 mgd)	700 cfs (453 mgd)

The basic diversion capability of Pepacton Reservoir is 550 cfs for the 45-year data and 700 cfs for the 38-year data.

Figure IV-5 presents the monthly variation of average, 80 percent and 90 percent exceedence stages for the two sets of data for the operation scheme with a diversion demand of 550 cfs and downstream releases at the proposed level of 70 cfs.

Yield-drawdown curves for the 10, 20 and 50 percent exceedence probabilities for Series II(a) and II(b) are presented in Figure IV-6 for the present and proposed downstream release operations. The analysis is based on the inflow data for the period October 1922 to September 1967. The yield-drawdown data for various operation schemes are given in Table IV-2. For the basic diversion rate of 550 cfs, the drawdown increases by 5.1 feet for the 50 percent exceedence probability, 9.8 feet for the 20 percent exceedence probability and 13.2 feet for the 10 percent exceedence probability when the downstream releases are increased from the present level to the proposed level.

III. Neversink Reservoir

The basic runs (Series III) consist of the study of 16 operation schemes assuming that the total capacity of the reservoir between the spillway crest level and the minimum operating level is available for use. The downstream releases were at the present level in Series III(a) and at the proposed level in Series III(b). In all of these runs, diversion to New York City for water supply (D_1) was varied over a wide range from 50 cfs to 500 cfs.

The shortage index (SI) is shown as a function of diversion demand (D_1) in Figure IV-7 for Series III(a) and III(b). It is seen that the reservoir has the capability of meeting the following diversion demands with no shortages:

Series	Downstream Releases	Diversion Demand (D_1) 45-Year Data (1923-1967)	Diversion Demand (D_1) 38-Year Data (1923-1960)
III(a)	Present Level	175 cfs (113 mgd)	200 cfs (129 mgd)
III(b)	Proposed Level	150 cfs (97 mgd)	170 cfs (110 mgd)

The basic diversion capability of Neversink Reservoir is 150 cfs for the 45-year data and 170 cfs for the 38-year data.

The monthly variation of average, 80 percent and 90 percent exceedence stages for the above sets of data for the operation scheme with a diversion demand of 150 cfs and downstream release at the proposed level of 50 cfs are shown in Figure IV-8.

Yield-drawdown curves for the 10, 20 and 50 percent exceedence probabilities for Series III(a) and III(b) are presented in Figure IV-9 for the present and proposed downstream release operations.

The analysis is based on the inflow data for the period October 1922 to September 1967. The yield-drawdown data for various operation schemes are given in Table IV-2. For the basic diversion rate of 150 cfs, the drawdowns increase by 9.7 feet for the 50 percent exceedence probability, 16.8 feet for the 20 percent exceedence probability and 18.1 feet for the 10 percent exceedence probability when the downstream releases are increased from the present level to the proposed level.

Flexible Operation Scheme

The analyses discussed so far considered the total reservoir capacity between the minimum operating level and the crest level as available for use. The ideal operation of the reservoirs for public water supply is to maintain the water level as near to the crest level as possible. By using the total reservoir capacity down to the minimum operating level, water levels might be drawn down so low during the drought years that shortages would occur. To reduce this hazard, a flexible operation scheme, in which the reservoir releases would consist of primary and secondary releases, was studied. The primary releases are at the present rate and the secondary releases are equal to the difference between proposed and present releases. During the drought years, only primary releases are provided. Both primary and secondary releases are provided during normal year operations. For purposes of this analysis, the 80 percent exceedence stage curves of the corresponding basic runs (Series I, II and III), were introduced as the sub-rule or criteria rule curves. Both primary and secondary releases would be made only when the reservoir stage is above the elevation defined by the criteria rule curve. These criteria rule curves were adopted for the system operation studies.

Several runs were made to study the flexible operation scheme for the City reservoirs (Series IV). Monthly variations of diversions during the year were also introduced by multiplying the basic diversion capability by a set of ratios. Four sets of ratios obtained from different sources were tested. In Series IV(a), a constant diversion demand were used. Ratios adopted in the NEWS Study [1] were used in Series IV(b). For Series IV(c), ratios obtained by analyzing the total diversion from the three City reservoirs for the period October 1964 to September 1972 were used. Ratios obtained by analyzing the diversion from each reservoir of the system for the same period were used in Series IV(d). These runs are detailed in Appendix B (on file). Average and 80 percent exceedence stages of Series IV (a,b,c,d) are compared in Figures IV-10 to 12 for diversion demands of 400 cfs for Cannonsville Reservoir, 550 cfs for Pepacton Reservoir and 150 cfs for Neversink Reservoir. It is seen that average and 80 percent exceedence stage curves for Series IV(a),(b) and (c) are practically the same and only the curves for Series IV(d) differ considerably. Results of Series IV(a) are used for further analysis.

Figures IV-13 to 15 present comparisons of average, 80 and 90 percent exceedence stage curves for the basic runs (Series I, II and III) and Series IV(a) for Cannonsville, Pepacton and Neversink Reservoirs.

It is seen that curves for Series IV(a) are above the corresponding curves for the basic runs indicating the advantage of the flexible operation scheme. The City can choose to operate according to the flexible operation scheme meeting the demands of diversion, and primary and secondary downstream releases when the reservoir stage is above the elevation defined by the criteria rule curve. When the reservoir stage falls below this elevation, the City can cut off the secondary releases and thus aim at continuing to maintain primary water supply diversion and primary downstream releases.

System Water Supply Capability

The system water supply capability is the sum of basic diversion capabilities of Cannonsville, Pepacton and Neversink Reservoirs. The basic diversion capability of a reservoir has been defined in the earlier sections as the diversion demand it can meet without any shortages while downstream releases are made at the proposed level.

The system water supply capability is about 1,100 cfs (711 mgd) for the 45-year data (1923-1967) and 1,420 cfs (918 mgd) for the 38-year data excluding the severe 60's drought (1923-1960). Since single reservoir analysis does not consider the U.S. Supreme Court Decree's flow requirement at Montague, New Jersey, the system yield determined here is higher than it actually would be.

TABLE IV-1 SCOPE OF OPERATION STUDIES

Series	Reservoir	Diversion to New York City D_1		Downstream Releases	
		cfs	mgd	Primary Release (D_2)	Secondary Release (D_3)
I	Cannonsville	50	32.4	Nov. 1-April 7: 7.7 cfs(5 mgd) and April 8-Oct.31: 23.1 cfs (15 mgd)	Zero
		100	64.8	"	"
		200	129.6	"	"
		300	194.4	"	"
		400	259.2	"	"
		500	324.0	"	"
		600	388.9	"	"
		700	453.7	"	"
		800	518.5	"	"
		900	583.3	"	"
		1000	648.0	"	"
		50	32.4	Jan. 1 - Dec. 31: 125 cfs(81 mgd)	"
		100	64.8	"	"
		150	97.2	"	"
		200	129.6	"	"
		300	194.4	"	"
		400	259.2	"	"
		450	291.6	"	"
		500	324.0	"	"
		550	356.5	"	"
		600	388.9	"	"
		700	453.7	"	"
		800	518.5	"	"
		900	583.3	"	"
		1000	648.0	"	"

TABLE IV-1 (cont'd)

Series	Reservoir	Diversion to New York City D_1 cfs	mgd	Downstream Releases: Primary Release (D_2)	Downstream Releases: Secondary Release (D_3)
II	Pepacton	50	32.4	Nov. 1-April 7: 6.2 cfs(4 mgd) and April 8-Oct. 31: 18.5 cfs (12 mgd)	Zero
		100	64.8	"	"
		200	129.6	"	"
		300	194.4	"	"
		400	259.2	"	"
		500	324.0	"	"
		600	388.9	"	"
		700	453.7	"	"
		800	518.5	"	"
		900	583.3	"	"
		1000	648.0	"	"
				Jan. 1-Dec. 31: 70 cfs(45.4 mgd)	"
		50	32.4		
		100	64.8	"	"
		160	103.7	"	"
		200	129.6	"	"
		240	155.5	"	"
		300	194.4	"	"
		320	207.4	"	"
		370	239.8	"	"
		400	259.2	"	"
		500	324.0	"	"
		550	356.5	"	"
		600	388.9	"	"
		700	453.7	"	"
		750	486.0	"	"
		800	518.5	"	"
		900	583.3	"	"
		1000	648.0	"	"

TABLE IV-1 (cont'd)

Series	Reservoir	Diversion to New York City (D_1) cfs	Diversion to New York City (D_1) mgd	Downstream Releases: Primary Release (D_2)	Downstream Releases: Secondary Release (D_3)
III	Neversink	50	32.4	Nov.1-April 7: 4.5 cfs (3 mgd) and April 8-Oct. 31: 15.4 cfs (10 mgd)	zero
		100	64.8	"	"
		200	129.6	"	"
		300	194.4	"	"
		400	259.2	"	"
		500	324.0	"	"
		50	32.4	Jan. 1-Dec. 31: 50 cfs (32.4 mgd)	"
		100	64.8	"	"
		150	97.2	"	"
		200	129.6	"	"
		250	162.0	"	"
		285	184.7	"	"
		300	194.4	"	"
		322	208.7	"	"
		400	259.2	"	"
		500	324.0	"	"

TABLE IV-1 (cont'd

Series	Reservoir	Diversion to New York City D_1 cfs	Diversion to New York City D_1 mgd	Downstream Releases: Primary Release D_2	Downstream Releases: Secondary Release D_3
IV	Cannonsville	400xR	259.2xR	Nov.1-April 7: 7.7 cfs(5 mgd) and April 8-Oct.31: 23.1 cfs (15 mgd)	Nov.1-April 7: 117.3 cfs (76 mgd) and April 8-Oct.31: 101.9 cfs (66 mgd)
		450xR	291.6xR	"	"
		500xR	324.0xR	"	"
		550xR	356.5xR	"	"
	Pepacton	550xR	356.5xR	Nov.1-Apr.7:6.2 cfs(4 mgd) and April 8-Oct.31:18.5 cfs (12 mgd)	Nov.1-April 7:63.8 cfs (41.4 mgd) and April 8-Oct.31: 51 cfs(33.4 mgd)
		600xR	388.4xR	"	"
		700xR	453.7xR	"	"
	Neversink	150xR	97.2xR	Nov.1-April 7:4.5 cfs(3 mgd) and April 8-Oct.31: 15.4 cfs (10 mgd)	Nov.1-April 7:45.5 cfs (29 mgd) and April 8-Oct. 31:34.6 cfs(22.4 mgd)
		200xR	129.6xR	"	"
		250xR	162.0xR	"	"

TABLE IV-1 (cont'd)

DETAILS OF MULTIPLIER RATIOS

R in the Table is the multiplier ratio to account for monthly demand variation from the average demand. The following sets of ratios have been used in the series IV (a), (b), (c) and (d).

Series	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
IV (a)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
IV (b)	1.050	1.000	0.950	0.925	0.900	0.925	0.950	1.000	1.000	1.075	1.100	1.075
	(Ratio's adopted in the NEWS Study)											
IV (c)	1.027	0.956	0.698	0.903	0.955	0.934	0.733	1.164	1.081	1.177	1.196	1.175
	(Ratios obtained by using the total diversion from the 3 reservoirs based on historical operation of the reservoirs by New York City for the period 1965-72)											
IV (d) Pepacton	1.532	1.409	0.911	0.651	0.633	0.549	0.600	0.973	0.750	1.091	1.517	1.535
Cannons-ville	0.454	0.559	0.350	1.491	1.601	2.014	0.832	1.474	1.497	1.063	0.736	0.286
Neversink	1.411	0.999	0.826	0.537	0.666	0.401	0.258	0.717	0.764	1.360	1.917	2.090

(Ratios obtained by using the diversion from each reservoir based on historical operation of the reservoirs by New York City for the period 1965-72)

TABLE IV-2

Yield Drawdown Data
(Analysis of End of September Drawdown for the Period 1923-1967)

Series	Reservoir	Diversion to New York City(D_1) cfs	Diversion to New York City(D_1) (mgd)	Series (a) Exceedence Probability 50	Series (a) Exceedence Probability 20	Series (a) Exceedence Probability 10	Series (b) Exceedence Probability 50	Series (b) Exceedence Probability 20	Series (b) Exceedence Probability 10
I	Cannonsville			D_2: Nov.1-Apr.7:7.7 cfs (5 mgd)& Apr. 8-Oct.31: 231 cfs (15 mgd) D_3=0			D_2: Jan. 1-Dec.31;125 cfs (81 mgd) D_3=0		
		50	32.4	0.9	0.9	0.9	2.3	2.8	3.0
		100	64.8	1.4	1.4	1.4	3.3	4.9	5.8
		150	97.2				4.6	7.1	8.5
		200	129.6	3.3	5.0	5.8	6.1	9.6	11.4
		300	194.4	6.1	9.6	13.4	10.5	16.8	20.1
		400	259.2	10.3	16.5	19.7	18.0	31.3	38.2
		450	291.6	-	-	-	22.9	40.8	50.1
		500	324.0	17.5	29.9	36.3	28.3	48.9	59.5
		550	356.5	-	-	-	35.6	59.2	71.4
		600	388.9	27.7	47.8	58.1	45.1	71.0	84.3
		700	453.7	43.6	68.9	81.9	71.2	99.6	
		800	518.5	69.7	98.1		92.0		
		900	583.3	90.8			101.1		
		1000	648.0	109.8			106.5		

TABLE IV-2 (cont'd)

Series	Reservoir	Diversion to New York City (D_1) cfs	Diversion to New York City (D_1) (mgd)	Series (a) Exceedence Probability 50	Series (a) 20	Series (a) 10	Series (b) Exceedence Probability 50	Series (b) 20	Series (b) 10
II	Pepacton			D_2=Nov.1-Apr.7:6.2 cfs (4 mgd) & Apr.8-Oct.31: 18.5 cfs(12 mgd) D_3=0			D_2=Jan.1-Dec.31:70 cfs (45.4 mgd) D_3=0		
		50	32.4	0.4	0.4	0.4	0.6	0.6	0.6
		100	64.8	0.6	0.6	0.6	1.1	1.1	1.1
		160	103.7	-	-	-	2.0	2.0	2.0
		200	129.6	1.8	2.7	3.2	2.7	4.3	5.3
		240	155.5	-	-	-	3.5	5.9	7.2
		300	194.4	3.7	6.4	7.7	5.0	8.4	10.1
		320	207.4	-	-	-	5.6	9.2	11.0
		370	239.8	-	-	-	7.2	11.8	14.2
		400	259.2	6.5	10.7	12.7	8.4	13.6	16.3
		500	324.0	10.4	16.9	20.3	13.6	22.4	27.0
		550	356.5	13.3	23.0	27.0	18.4	32.8	40.2
		600	388.9	17.8	31.2	38.1	25.5	49.2	61.4
		700	453.7	31.8	57.1	70.4	45.0	73.4	88.1
		800	518.5	61.0	92.6	109.5	78.1	113.0	
		900	583.3	93.4	121.9		105.4		
		1000	648.0	111.4			116.6		

TABLE IV-2 (cont'd)

Series	Reservoir	Diversion to New York City (D_1) cfs	Diversion to New York City (D_1) (mgd)[1]	Series (a) Exceedence Probability 50	Series (a) Exceedence Probability 20	Series (a) Exceedence Probability 10	Series (b) Exceedence Probability 50	Series (b) Exceedence Probability 20	Series (b) Exceedence Probability 10
III	Neversink			D_2=Nov.1-Apr.7:4.5 cfs (3 mgd) & Apr.8-Oct.31: 15.4 cfs(10 mgd) D_3=0			D_2=Jan.1-Dec.31:50 cfs (32.4 mgd) D_3=0		
		50	32.4	0.1	1.5	2.2	2.7	5.9	7.5
		100	64.8	4.2	8.3	50.4	8.6	14.6	17.8
		150	97.2	12.4	23.2	31.5	22.1	40.0	49.6
		200	129.6	29.0	51.4	63.0	58.8	89.3	105.1
		250	162.0	-	-		93.4	120.0	
		285	184.7	-	-		104.2		
		300	194.4	96.6	120.5		106.5		
		322	208.7	-			108.7		
		400	259.2	110.8			112.3		
		500	324.0	113.3			113.5		

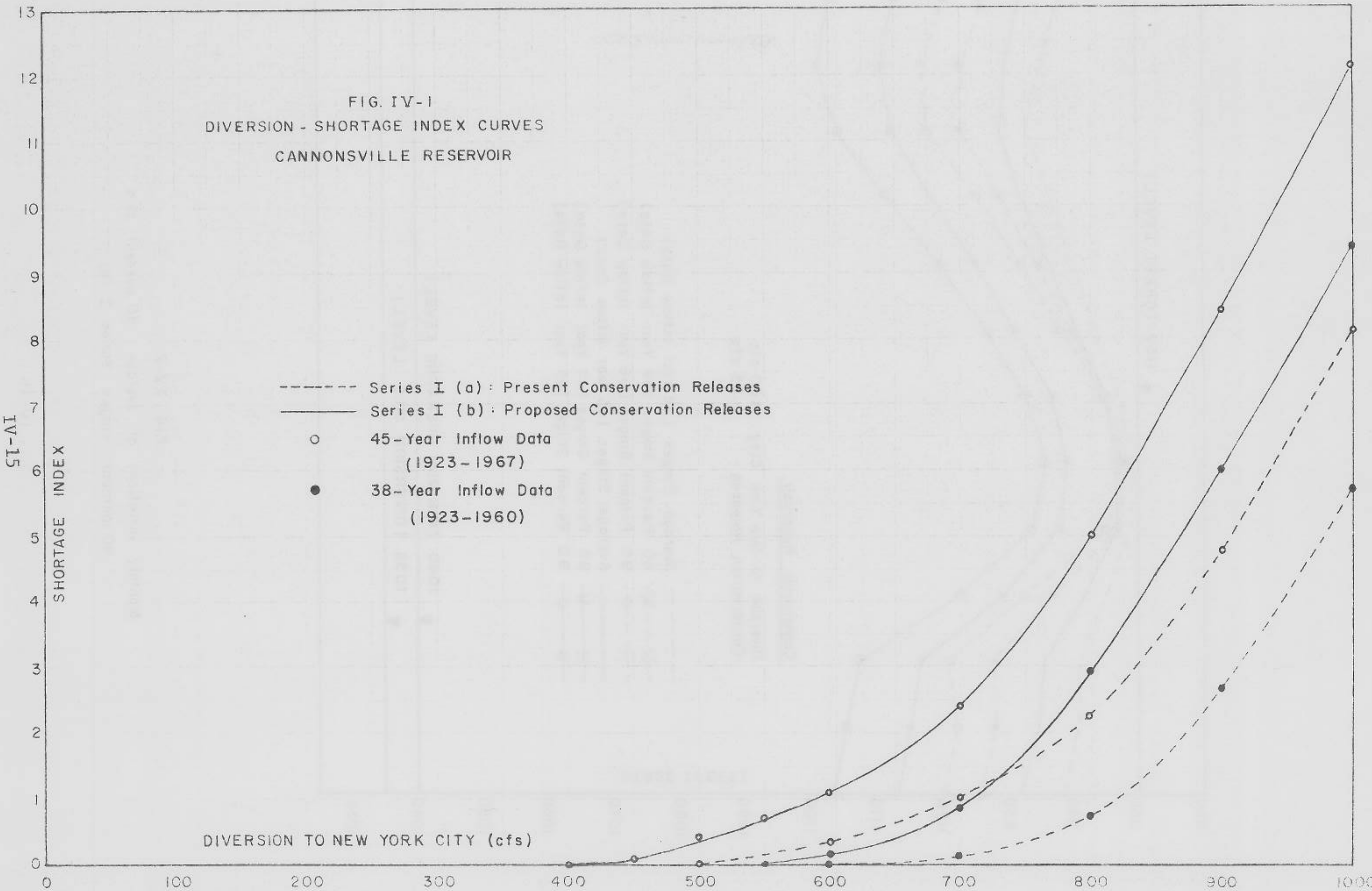
FIG. IV-1
DIVERSION - SHORTAGE INDEX CURVES
CANNONSVILLE RESERVOIR
Series I (a) : Present Conservation Releases
Series I (b) : Proposed Conservation Releases
45-Year Inflow Data
(1923-1967)
38-Year Inflow Data
(1923-1960)
SHORTAGE INDEX
DIVERSION TO NEW YORK CITY (cfs)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
0
100
200
300
400
500
600
700
800
900
1000

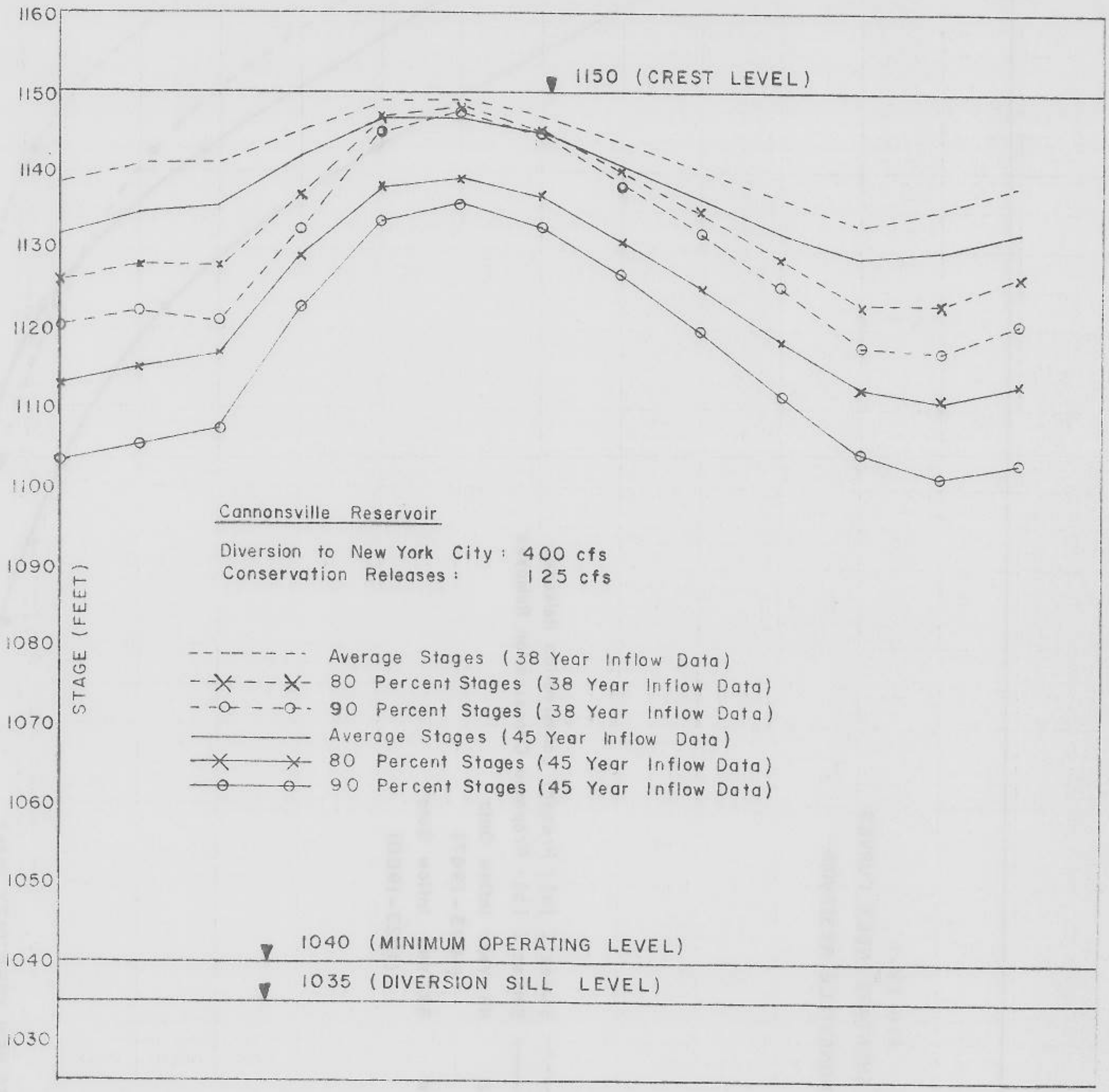

FIG. IV-2

Monthly variations of average, 80 percent and 90 percent stages Series I (b)

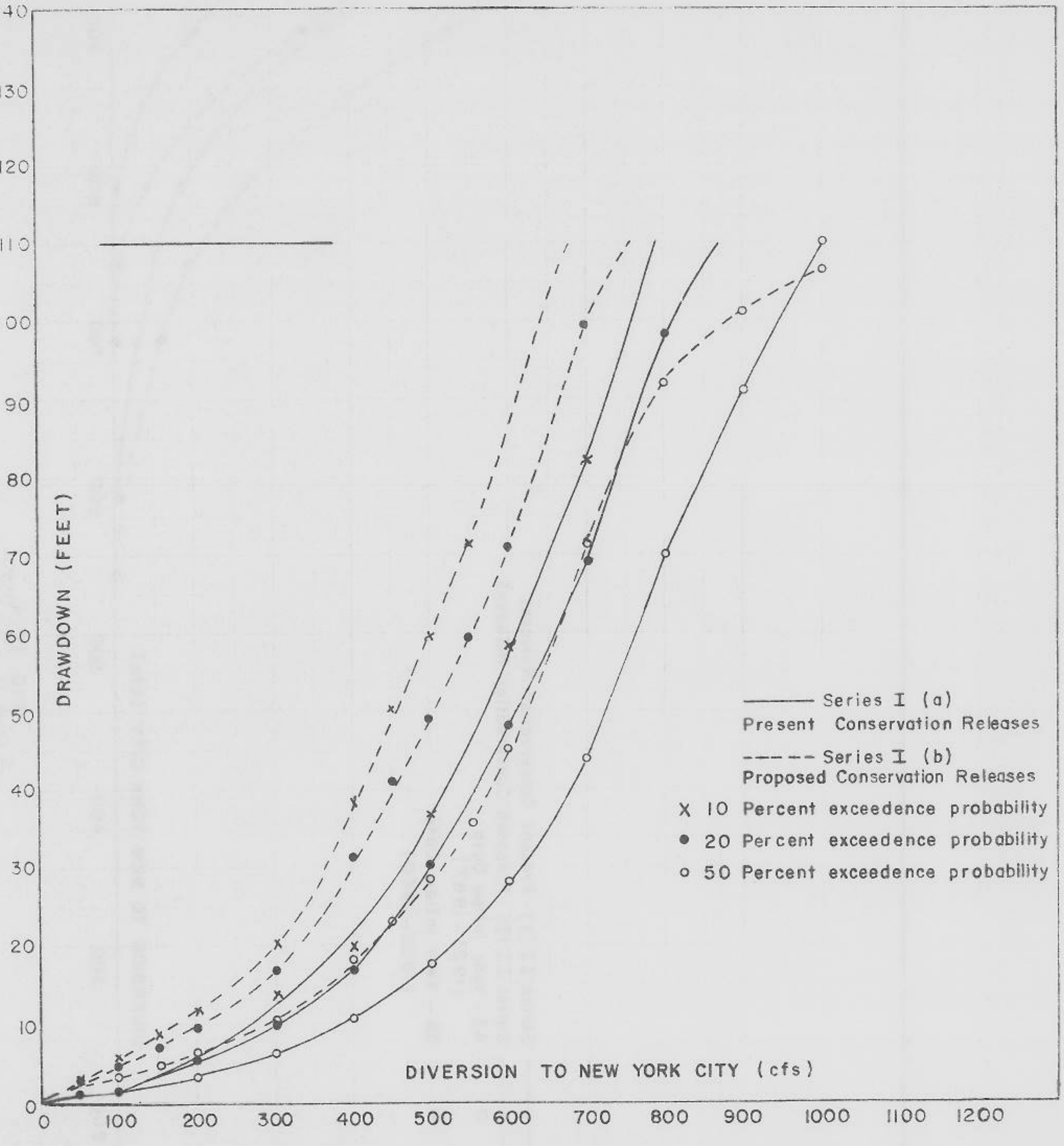

FIG. IV-3

YIELD-DRAWDOWN CURVES

CANNONSVILLE RESERVOIR

(Analysis of end of September mean stages for the 45-year inflow Data)

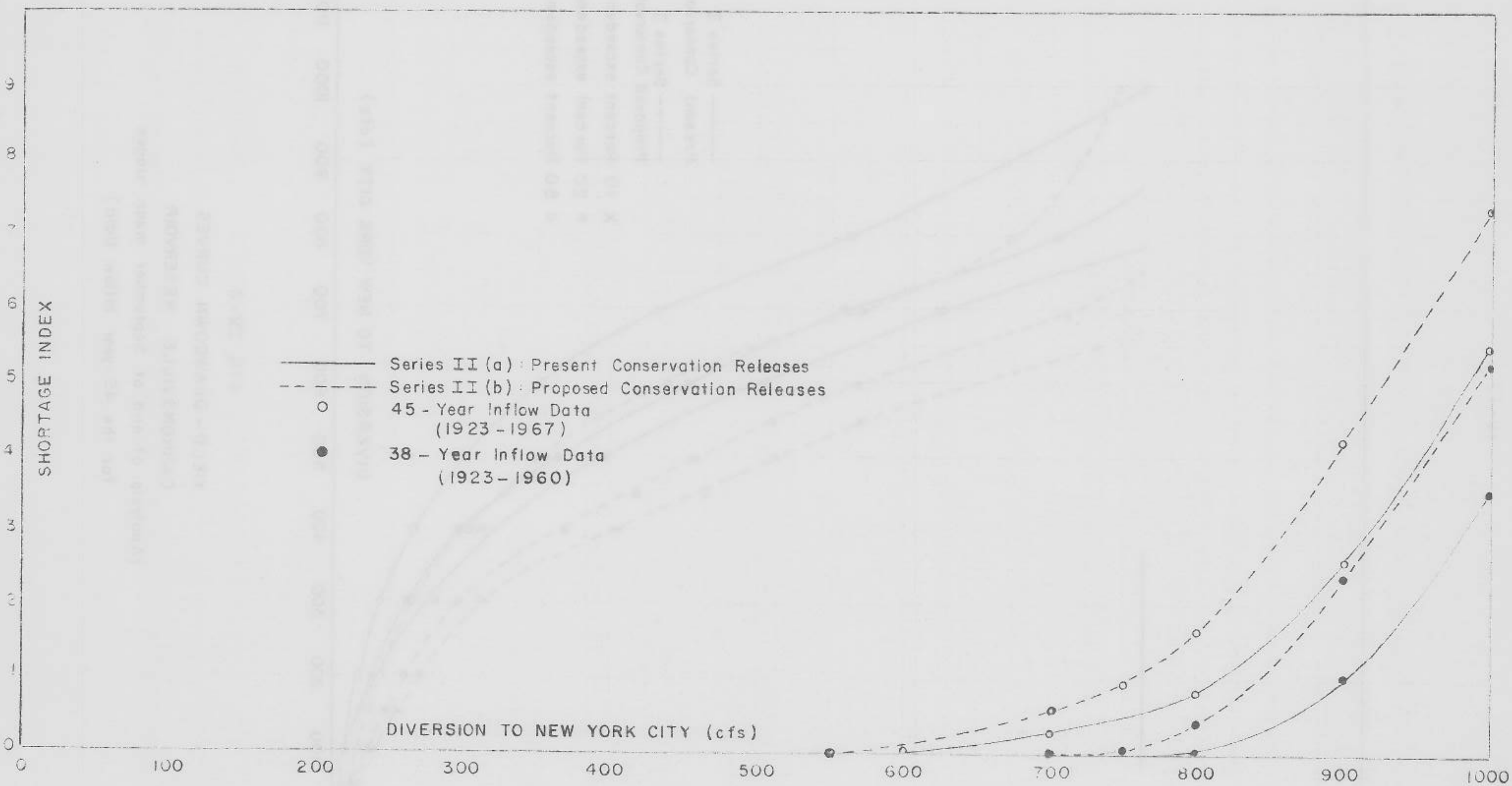

FIG. IV-4

DIVERSION - SHORTAGE INDEX CURVES

PEPACTON RESERVOIR

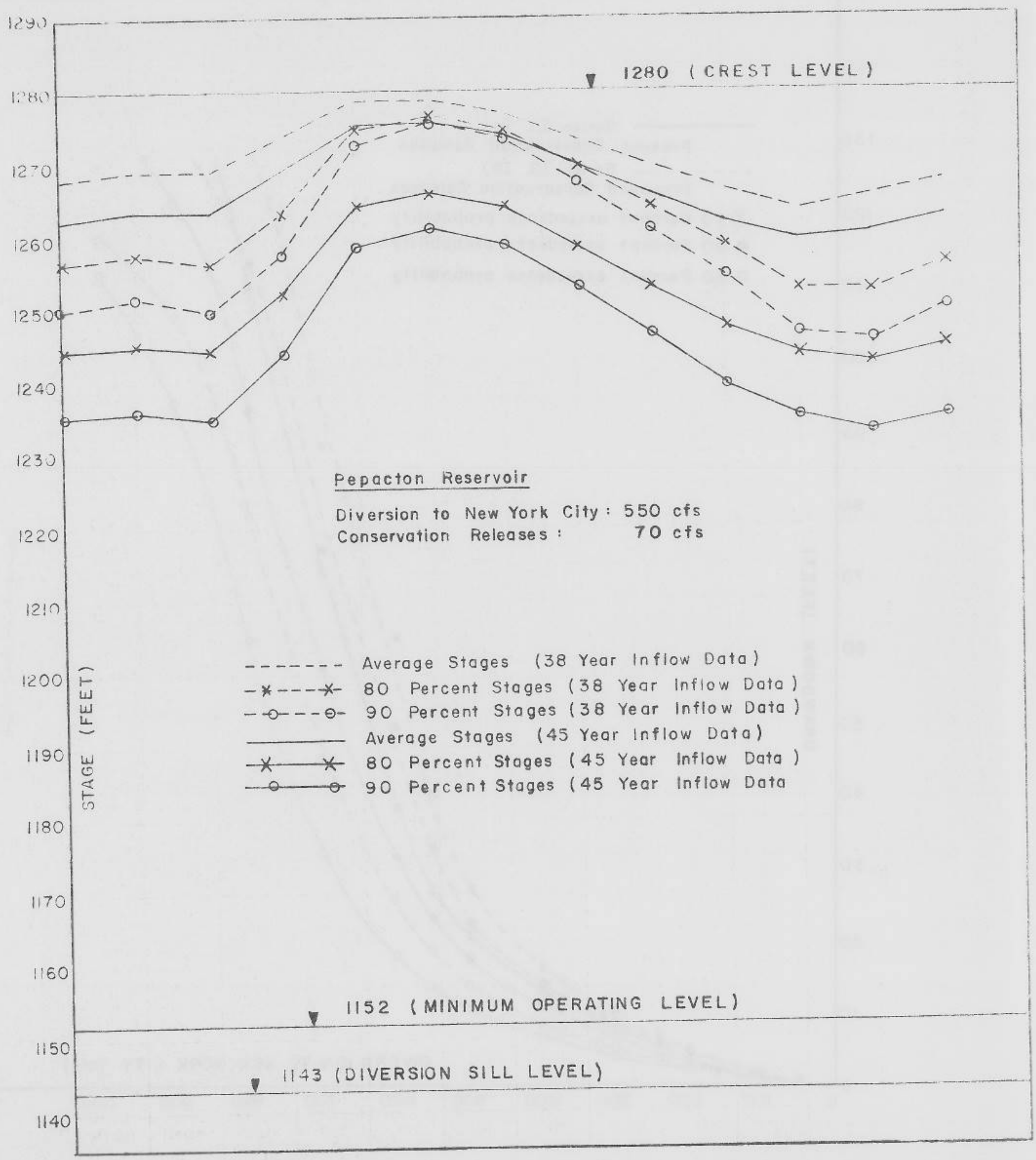

FIG. IV-5

Monthly variations of average, 80 percent and 90 percent stages Series II (b)

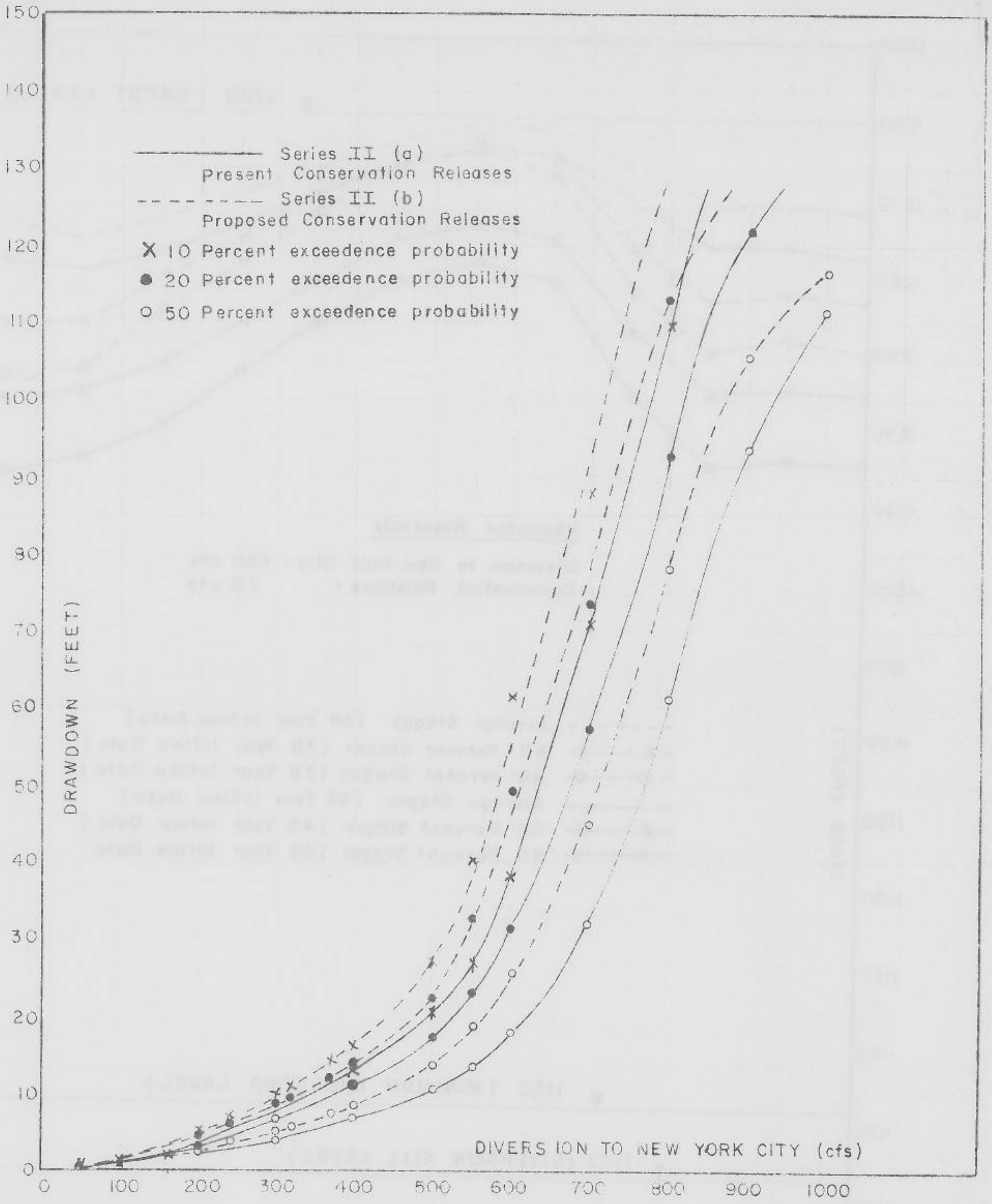

FIG. IV-6
YIELD-DRAWDOWN CURVES
PEPACTON RESERVOIR
(Analysis of end of September mean stages for the 45-year Inflow Data)

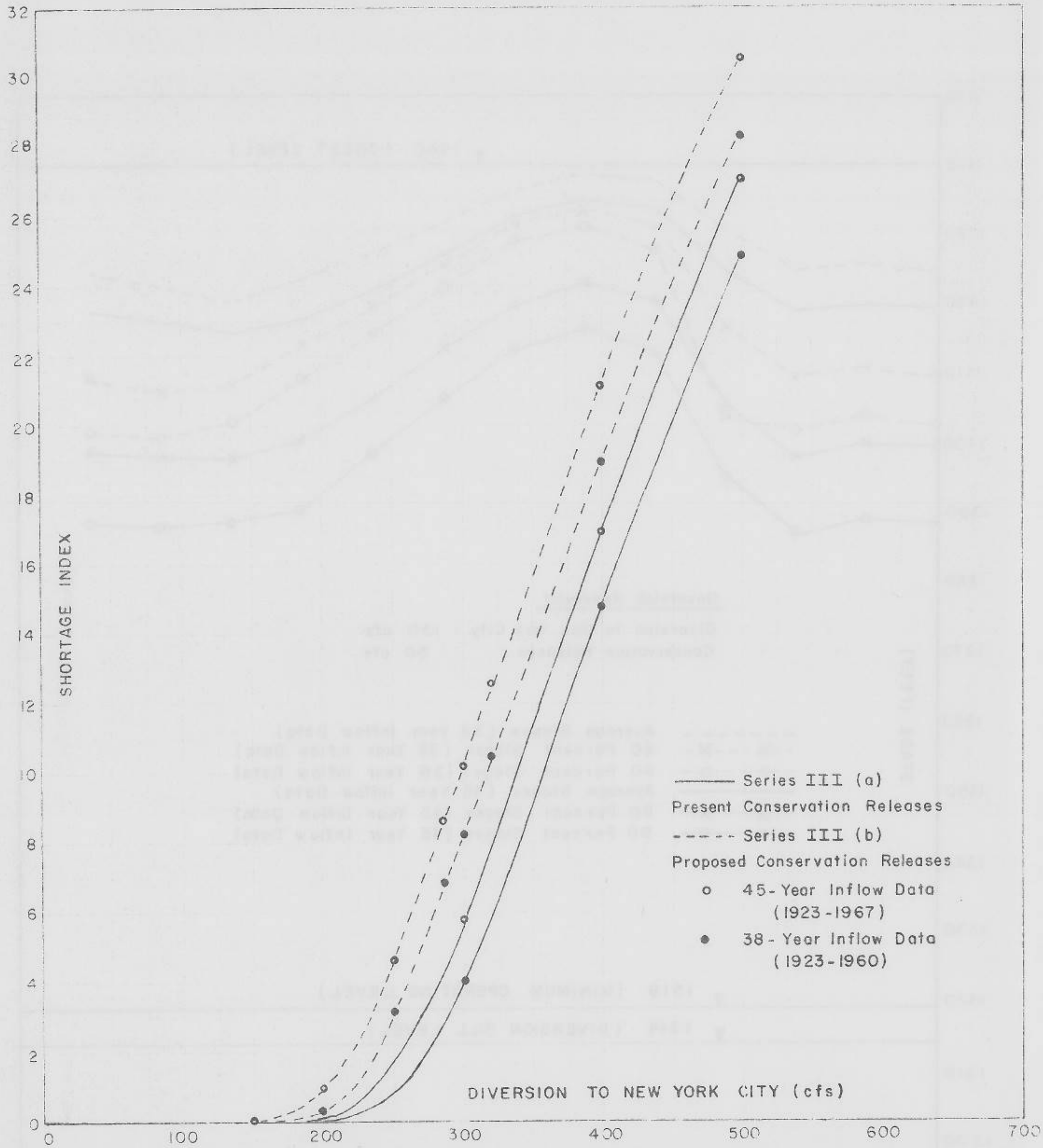

FIG. IV-7
DIVERSION - SHORTAGE INDEX CURVES
NEVERSINK RESERVOIR

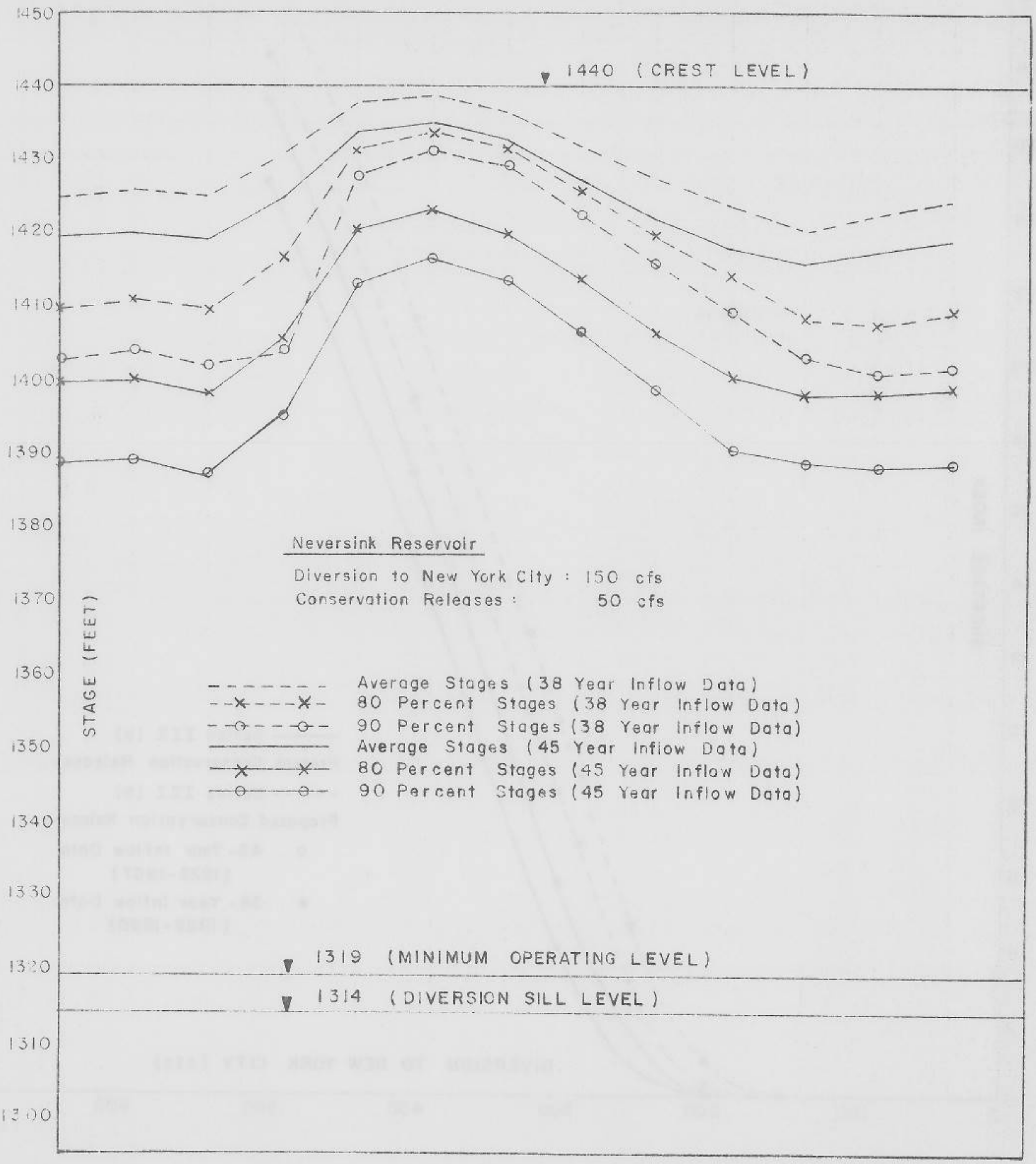

FIG. IV-8

Monthly variations of average, 80 percent and 90 percent stages Series III (b)

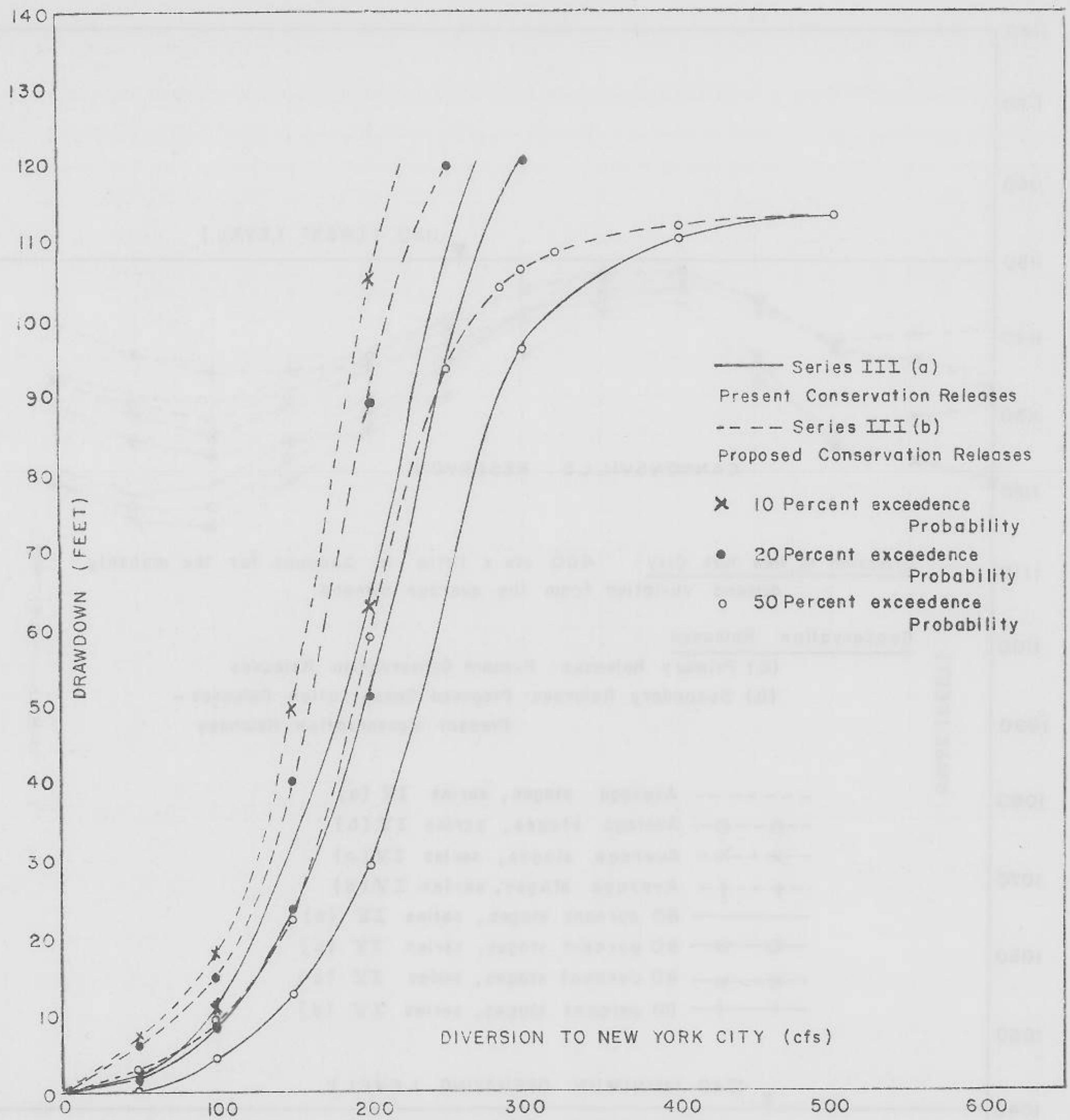

FIG. IV-9
YIELD-DRAWDOWN CURVES
NEVERSINK RESERVOIR
(Analysis of end of September mean stages for the 45-year inflow data)

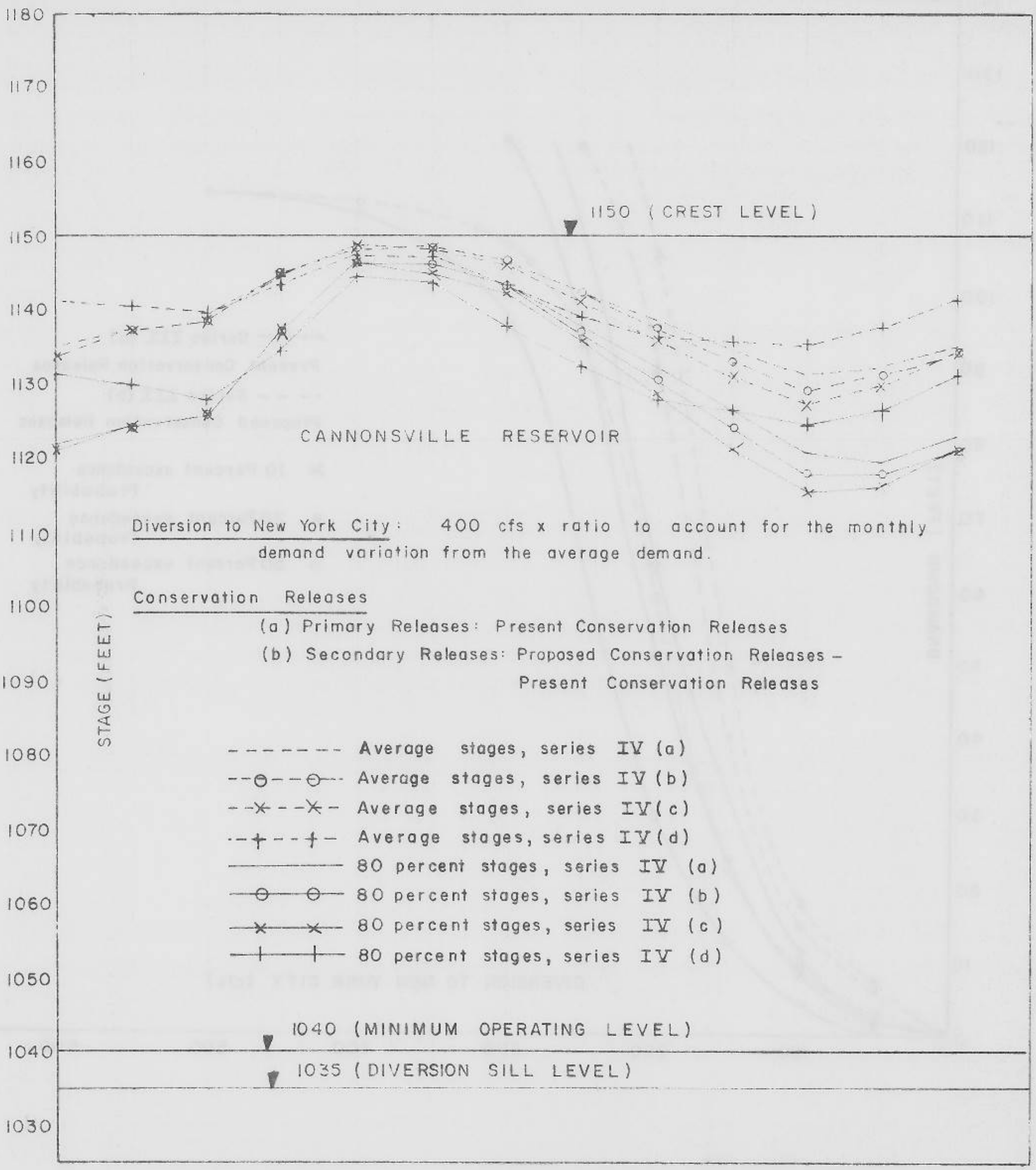

FIG. IV-10

Monthly variations of average and 80 percent stages for series IV

(Analysis based on the 45-year inflow data)

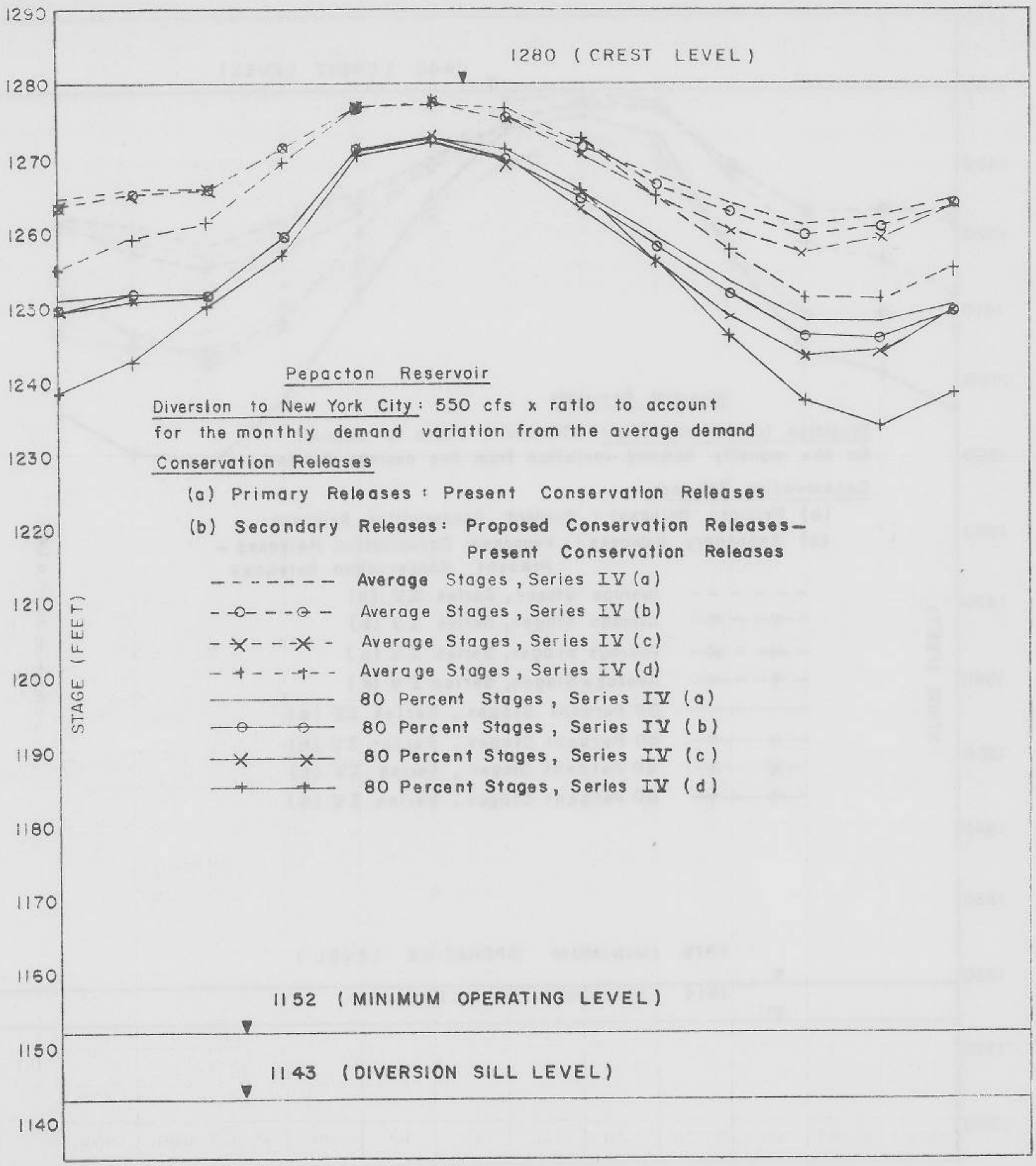

FIG. IV-11

Monthly variations of average and 80 percent stages for Series IV

(Analysis based on the 45-year inflow data)

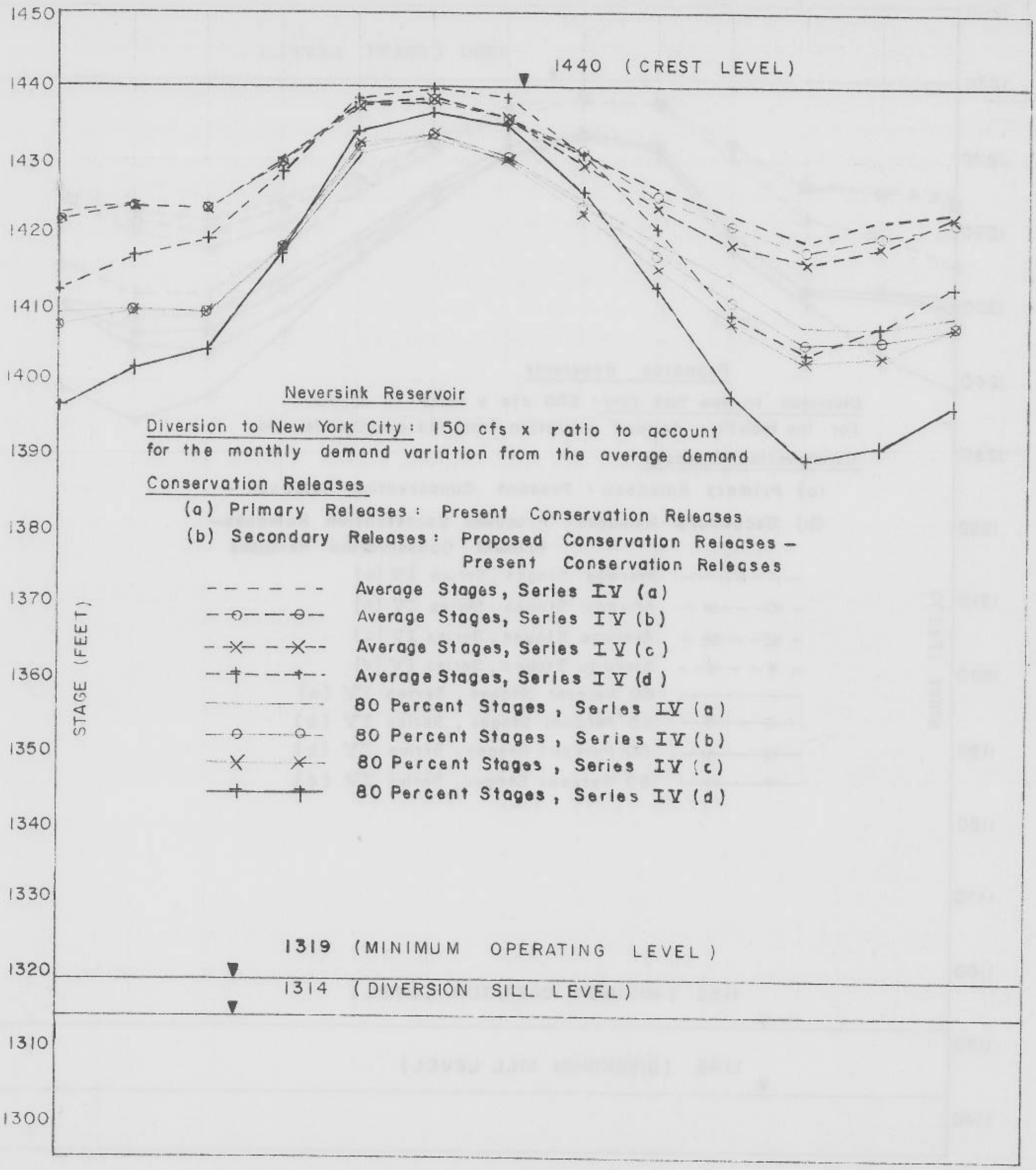

FIG. IV-12
Monthly variation of average and 80 percent stages for Series IV
(Analysis based on the 45-year inflow data)

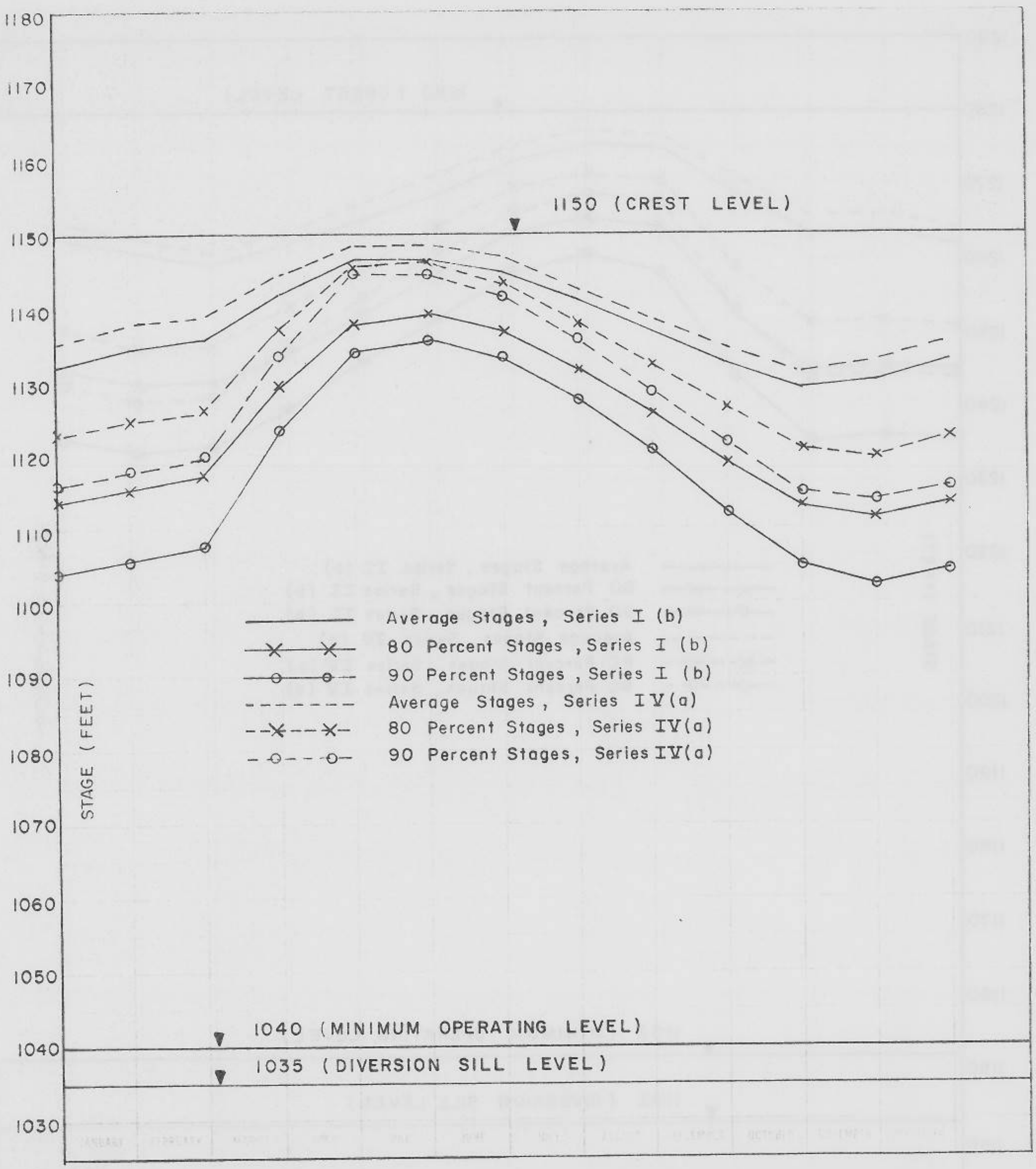

FIG. IV-13

Comparison of average, 80 percent and 90 percent stages for Series I (b) and IV (a) at 400 cfs diversion level, Cannonsville Reservoir (Analysis based on the 45-year inflow data)

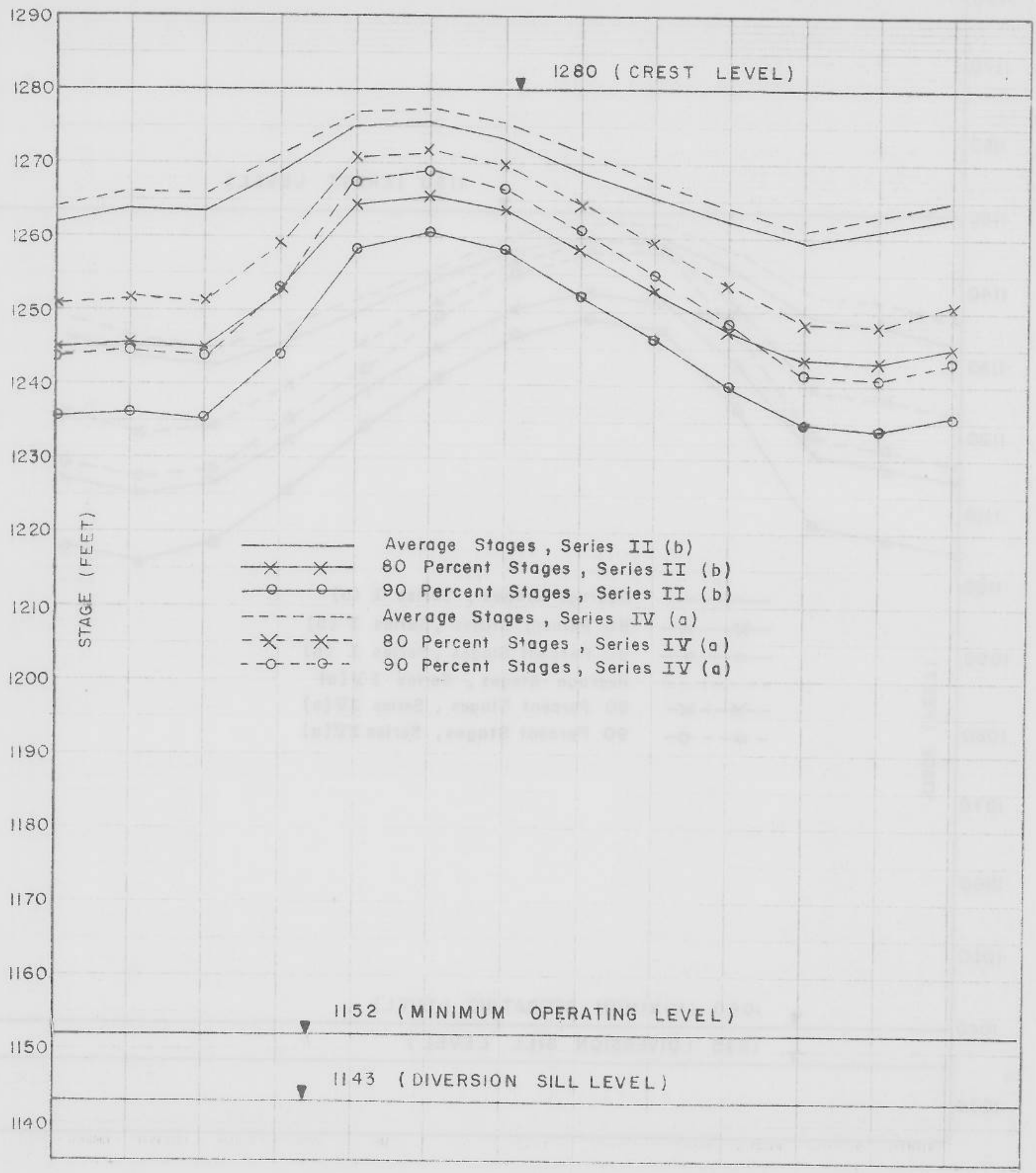

FIG. IV-14

Comparison of average, 80 percent and 90 percent stages for Series II (b) and IV (a) at 550 cfs diversion level, Pepacton Reservoir (Analysis based on the 45-year inflow data)

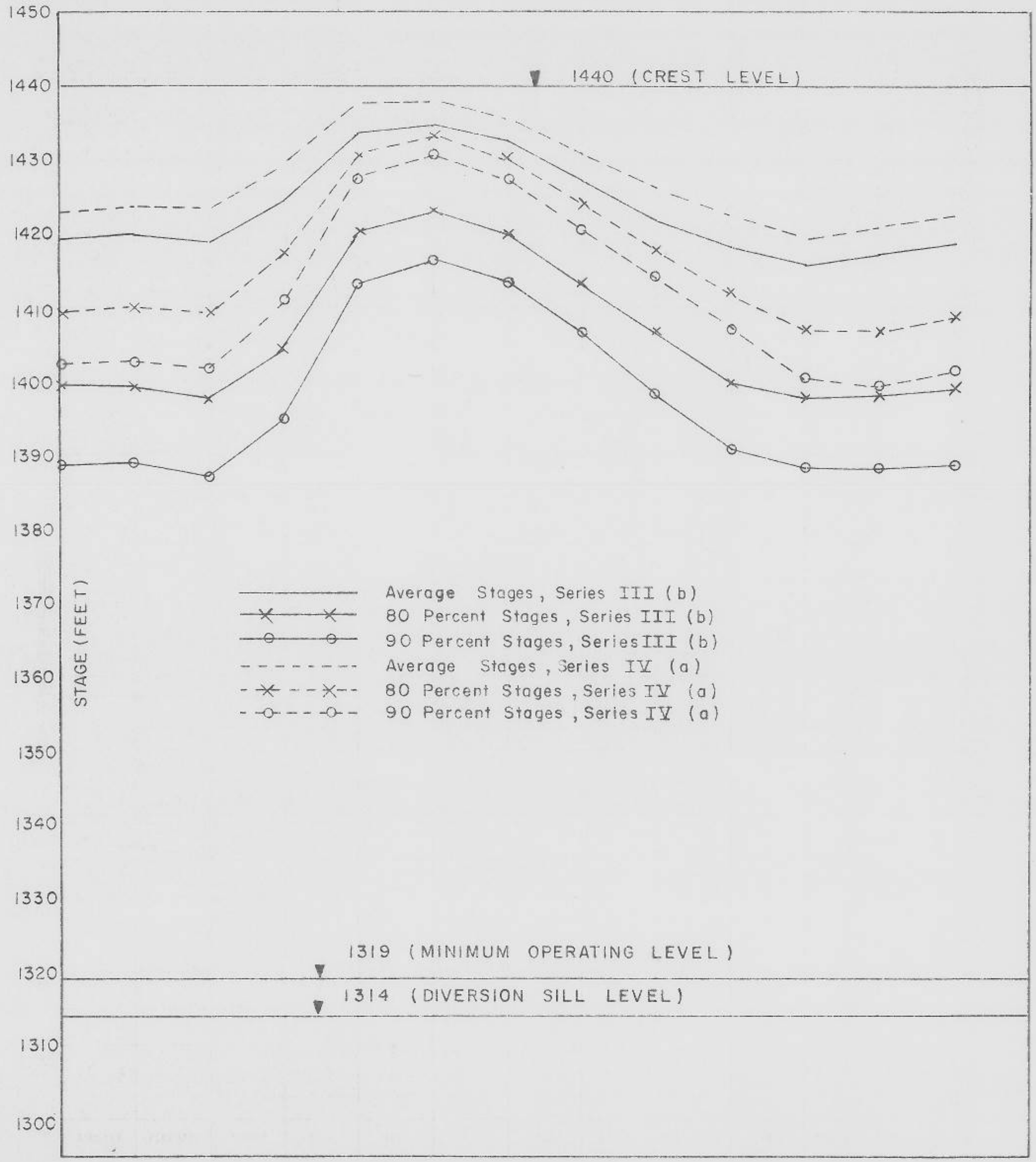

FIG. IV-15

Comparison of average, 80 percent and 90 percent stages for Series III (b) and IV (a) at 150 cfs diversion level, Neversink Reservoir

(Analysis based on the 45-year inflow data)

CHAPTER V

BASIC SYSTEM OPERATION STUDIES

Introduction

The water supply capabilities of Cannonsville, Pepacton and Neversink Reservoirs of the New York City Delaware System have been discussed in Chapter IV based on detailed studies of each reservoir by itself. Single reservoir operation studies are controlled by the diversion requirements of New York City for water supply and the conservation release requirements to maintain environmental quality of the rivers downstream from the dams. Since such analyses do not consider the flow requirements at Montague, the results need to be adjusted. This chapter discusses the water supply capabilities based on basic system operation studies which consider the flow requirements at Montague.

General

Typical yield-probability curves for a two-reservoir system are presented in Fig. V-1. The yield-probability relations for Reservoirs A and B, based on single reservoir analysis, are shown. The upper line of the shaded area denotes the system yield-probability relation for completely correlated inflows into the two reservoirs. The lower line of the shaded area denotes the system yield-probability relation for completely independent inflows into the two reservoirs. For partially correlated inflows under natural conditions, the system yield-probability relation will lie between the two lines. The figure also shows the system yield-probability curve for a combined reservoir system with storage capacity equal to the sum of individual reservoir capacities and inflows equal to the sum of individual reservoir inflows. The increase in yield of the combined reservoir system would be due to the effect of other facilities added to the system, such as interconnections between the reservoirs to reduce spills.

In this chapter, the system yield is determined by system-basis operation studies. The integrated operation of the three reservoirs with balancing rules and consideration of the flow requirements at Montague, New Jersey are the major differences between the system and single reservoir analyses. In the system-basis operation, the amounts of water released or diverted from each reservoir may not be constant, whereas they are constant in the single reservoir analysis. Their values are determined in tandem in proportion to the projected storage contents and other factors. The effect of partially correlated inflows upon the system's yield is accounted for by input of concurrent inflows, and with the tandem procedure maximum use of the system's potential is examined. Detailed development of the mathematical model used to carry out system-basis operation studies, the computer program for the model and a typical printout are included in Appendix C (on file).

System Operating Procedures

The present downstream releases from Cannonsville, Pepacton and Neversink Reservoirs are based on terms of the United States Supreme Court 1954 Amended Decree and the minimum conservation release requirements of the State of New York. The present operating procedures followed by New York City to meet these requirements and the associated problems have been discussed in chapter II. These result in local demands for increased conservation releases from each of the reservoirs and a more balanced operation of the system.

Operations based solely on the extremely severe drought years of 1965 to 1967 is unnecessarily conservative, especially for New York City which has other water supply sources to facilitate more flexible operation. During non-drought years this type of operation can result in waste of the available water by spilling over the dams and inefficient utilization of the available storages. If a severe drought occurred, reductions in operation, either in releases or diversions, or both, could be made to alleviate the water shortages. Thus, a flexible operating procedure which provides higher releases and diversions during wet periods and allows reduced operations during drought periods is a desirable alternative scheme of system operation. Such a scheme, however, requires criteria for defining the drought and non-drought conditions and for altering the operating procedures accordingly. Such criteria are discussed in the following sections.

Criteria for Defining Drought and Non-Drought Operations

A drought can be defined as a period of deficient precipitation and runoff extending over an indefinite number of months. The criteria to determine the deficiency that constitutes a drought are generally arbitrary. In this analysis, simple and convenient criteria are sought. It is recognized that the drought effect (or severity) is an accumulated value of flow deficiency, and that, for given operating conditions, the cumulative flow deficiencies correspond directly with the water levels in reservoirs. Based on this consideration, the water levels in different months which have an exceedence frequency of 80 percent are adopted as the drought criteria. When the water stage in reservoir falls below the criterion-level at any time, drought operations are undertaken.

Since the frequency distribution of water levels in each reservoir depends on the rates of releases and diversions and priorities of operation, separate criterion-level curves are proposed for diversion and release operations. The balancing rule of the reservoir, which controls the amounts of releases and diversions made, will also affect the frequency distribution. The allocation of the diversion and release requirements among the three city reservoirs may be made in proportion to the expected inflows, to the ratios of drainage area to storage capacity, simply to the storage capacities or to other factors.

The balancing rule based on maintaining the water level in each reservoir at an equal percentage of its own total storage is used in the system operation studies.

Levels of Drought and Non-Drought Operations

The existing conservation releases are the essential minimum flows and are considered as primary releases required at all times. The proposed conservation releases discussed in Chapter III are the desirable flows for maintaining the environmental quality of the rivers downstream of the reservoirs. The additional flows required to increase the existing releases to the proposed level are termed secondary releases. The additional releases may be reduced or eliminated during drought periods. Similarly, diversions to New York City for water supply are subdivided. The system safe yield, which is the level of diversion the system can sustain without major shortage, is the primary diversion. The additional diversion which may be undertaken by the city is the secondary diversion. Only the primary diversion is considered during drought periods while both the primary and secondary diversions are considered in non-drought periods.

Single-Level System Operation Studies

In these studies, release and diversion requirements were not subdivided into primary and secondary categories. Thus, the operation is termed as single-level system operation. Two schemes of allocating the New York City diversion requirement amongst the three reservoirs were examined. The first scheme is based on constant diversion from each reservoir according to sets of predetermined proportions. Three such sets were examined to select one set which provides better system performance. The second scheme is based on variable diversion from each reservoir determined by the reservoir balancing rules. This scheme yields better system performance than the first scheme. Criterion-level curves which indicate drought and non-drought operations were developed from this analysis.

I. Constant Diversion Scheme

The schematic diagram for the constant diversion scheme is shown in Fig. V-2. In this scheme, the diversions are prefixed for each run by a selected set of proportions. The scheme allows flexibility only in the release operations. The releases are determined following the reservoir balancing rules based on maintaining the water level in each reservoir at an equal percentage of its own total storage. Integer numbers are associated with various target levels and the balancing rules are conveniently presented by the reservoir level-number curves as shown in Fig. V-3. The crest level of the spillway (S MAX) and the minimum operating level (S MIN) define the limits of storage operation for each reservoir.

The levels of system diversion of 400, 600 and 800 mgd were examined. The scope of runs is presented in Appendix C (on file). To obtain the constant diversion from each reservoir, the system diversion was multiplied by the set of proportions. Three such sets of constant diversion proportions computed from the historic diversion records for the water years 1968 through 1972 (Proportion I), the ratios of drainage area to storage capacity (Proportion II) and the basic diversion capabilities of the reservoirs derived in the single reservoir operation studies (Proportion III) were used. The computed values of the above proportions and constant diversions using these proportions at the 600 mgd system diversion level are presented in Table V-1 which indicates large variations from set to set as well as from reservoir to reservoir.

Conservation releases at the existing and proposed rates, and variable releases at each reservoir as determined by the reservoir balancing rules to meet the flow requirement of 1750 cfs at Montague, New Jersey were considered in the analysis. The following summarizes the results of the computer simulation analyses, in which 45 years of historic streamflow records adopted from the NEWS study data were used.

A. Shortage Index - The functional relationship between system shortage index and system diversion is shown in Fig. V-4. For runs with Proportions I and II at system diversions of 600 and 800 mgd, the recorded shortage index is considerably higher than 0.1. Close examination of the analysis indicates that shortage at Neversink accounts for more than 85 percent of the system shortage, and that the increase in frequency of shortage occurrence is more than 50 percent for the proposed higher conservation releases and is more than 70 percent for the higher system diversion of 800 mgd. The high diversion rates at Neversink (a safe yield of 150 cfs without shortage is indicated by the single reservoir analysis while the diversion rates computed by Proportions I and II for Neversink Reservoir are above 200 cfs at the 600 mgd (928 cfs) system diversion level as shown in Table V-1) contribute greatly to the occurrence of shortages. The Proportion III runs have much better performance. Shortage indicies of 0.001 and 0.047 are recorded at the 600 mgd diversion level for the existing and proposed release levels, respectively. Based on single reservoir analysis the system has a yield of 711 mgd (1100 cfs) without shortages. The decrease in yield is essentially due to the flow requirements at Montague.

B. Reservoir Stages - The average monthly stages for Pepacton Reservoir at the 600 mgd system diversion level are plotted in Figure V-5. The reservoir stages computed for the low diversion level 241 cfs (Proportion II) are unaffected by the increase in release demands, but a decrease in stages of about five feet due to the increase in releases is indicated for the high diversion level of 548 cfs (Proportion I). The average stages of the low diversion level compare closely with results of the single reservoir analysis run at the 550 cfs diversion level shown by the dashed line. The average stages of the high diversion level are seen to be about 10 ft. lower than the above line of the comparable single reservoir analysis run. The use of the individual reservoir balancing rules may have effected the lowering of the computed reservoir stages. The weighting factors for the balancing as represented in Fig. V-3 are 0.52, 0.36 and 0.12 for Pepacton, Cannonsville and Neversink, respectively. When additional releases are called upon to meet the flow requirements at Montague, more than 50 percent of the supplements are provided by Pepacton. Frequent shortages at Neversink also affect the other reservoirs.

Table V-2 shows the comparison of cumulative storage and release frequencies of the three constant diversion proportions at the system diversion level of 600 mgd and the existing release requirements. For runs with Proportions I and II, Neversink is seen to be heavily tapped, with its storages falling below the 60 percent capacity about 42 and 64 percent of the time respectively and with minimum releases occurring 80 and 93 percent of the time respectively. Pepacton can sustain higher diversions and releases with Proportions I and II as only 23 and 13 percent of the time, respectively, does its storage ever go below the 60 percent level. Storage at Cannonsville would go below the 60 percent level only 14 and 17 percent of the time respectively. More than 40 percent of the time their releases are 10 times larger than the required minimum releases, even at the higher diversion proportions. For runs with Proportion III, the storage and the release frequency distributions among the reservoirs are seen to be relatively uniform. Thus Proportion III compares favorably with other proportions.

II. Variable Diversion Scheme

The constant diversion scheme examined in the previous section allows flexibility in the release operations only. The diversion operations are prefixed by a set of constant proportions. Since the diversion operations are generally much larger than the release operations, incorporation of flexibility into diversion operations would allow more opportunities to manipulate the storage operations. This will result in a more efficient use of the available storages, and thus the available water.

Incorporation of flexibility into the diversion operations can be made by a modified schematic diagram as shown in Fig. V-6. An additional activity point is added, between Montague and the three reservoirs, to the original four-activity point system. The diversion to New York City is undertaken there, allowing each reservoir to release variable amounts of water to provide the required sum. The reservoir balancing rules can now be applied to both the release and diversion operations. This mode of diversion operation is currently being practiced since the water from the three city reservoirs of the system is diverted through underground tunnels to Rondout Reservoir. Water is diverted from Rondout Reservoir to New York City. Thus, the additional activity point is comparable to Rondout Reservoir. The tunnel capacities are not considered to limit the size of allocations from each reservoir for the range of system diversions examined.

Three levels of system diversion of 400, 600 and 800 mgd at both the existing and the proposed levels of releases were investigated. The scope of runs is presented in Appendix C (on file). Analyses were made using uniform and non-uniform monthly diversion rates (computed based on the monthly records of total diversion to the city from the basin during the period 1965 through 1972[10]) to study the effect of such variation on the system yield. The results are summarized below.

A. Shortage Index - The system shortage index variation with diversion to the City is shown in Fig. V-7 for the present and proposed release levels using uniform and non-uniform monthly diversion rates. No shortages are recorded for the 600 mgd diversion level with the present release requirements, whereas shortages are recorded for runs similar to these with the constant diversion scheme discussed earlier. Less severe shortages as well as fewer shortage occurrences are observed for the 800 mgd diversion level with the existing release requirements as compared with similar runs of the constant diversion scheme. Increasing the conservation releases from existing to the proposed level increases the number of shortage-years from zero to three for the 600 mgd diversion and from 4 to 7 for the 800 mgd diversion levels. For Proportions I and II, shortage-years computed are 24 to 41. For Proportion III greater degrees of shortages with the same number of shortage-years occurred.

B. Reservoir Stages - The average monthly stages for Pepacton at the 600 mgd system diversion level are plotted in Fig. V-8. The resulting stages are seen to be more favorably distributed than the average monthly stages by the constant diversion scheme (as shown in Fig. V-5). Table V-3 shows the computer output of the summary tables for the end-of-period storages at the 600 mgd system diversion and the existing release levels. The frequency tally tables in Table V-3 indicate that equal relative reservoir stages are maintained among the three reservoirs. The cumulative stage frequencies are seen to lie between the results of Proportions I and II of the Constant Diversion Scheme (Table V-2) for Pepacton and Cannonsville, but stage frequencies for the Neversink Reservoir are generally improved. The stage frequencies compare closely with the results of Proportion III in which Pepacton is used more often than Cannonsville as shown in Table V-4.

C. Constant Diversion Proportions - As the performance of the system basis operation with variable diversion scheme is seen to be better than that with the constant diversion scheme, the data of this analysis are further analyzed to establish the resulting diversion proportions. Two operating methods are discussed. Method A is based on the diversion preferences in the following order of priority - Neversink, Pepacton, Cannonsville. In this method, all the available water from Neversink and Pepacton Reservoirs after making the required conservation releases is diverted to the City. Additional water required to make up for the total diversion allocation to the City and releases to meet the flow requirement at Montague are taken from Cannonsville Reservoir after making the required conservation releases. Method B assumes that there are no diversion preferences. In this method, the diversion allocation to the City is subdivided amongst the three reservoirs in proportion to the relative quantities of water available for diversion from each reservoir after making the required conservation releases. All the three reservoirs are used to meet the flow requirement at Montague. Table V-5 presents the computed average diversion proportions for Methods A and B along with Proportions I, II, and III discussed under the constant diversion scheme.

Comparing Proportion I (derived from historic diversion records for the period 1968 through 1972) with the proportion for Method A (systems basis operation study with variable diversion scheme using the diversion preferences in the order of priority as adopted by the city at present - Neversink, Pepacton and Cannonsville), it is seen that the amounts of water taken from Cannonsville and Neversink Reservoirs increase from 18 percent to 21 percent and 23 percent to 24 percent respectively, whereas the amount of water taken from the Pepacton Reservoir decreases from 59 percent to 55 percent. The changes appear to be too small to have any significance. Although the city currently takes an average of 18 percent from Cannonsville, it varies widely from month to month. Under the proposed scheme also, the city may continue to minimize withdrawals from Cannonsville Reservoir during certain months and increase withdrawals during other months to average the 21 percent withdrawal. In Method A, releases are made from Cannonsville Reservoir to meet the flow requirement at Montague as directed by the River Master. Since these demands vary depending upon several factors as discussed in Chapter II, the quantity and consequently the temperature of streamflow in the West Branch Delaware River and to some extent in the Delaware River will fluctuate considerably. In contrast, since releases are made from all three reservoirs to meet the flow requirement at Montague in Method B, non-uniform flows and temperatures would prevail in all the rivers downstream of the City reservoirs. This is not desirable since fish and wildlife interests prefer releases to be made up from Cannonsville Reservoir where possible. The City also might not consider Method B desirable since the proportion would mean increasing the amount of water diverted from Cannonsville Reservoir from 18 percent (Proportion I) to 47 percent.

D. Drought-Criterion - Levels - The system safe yield, defined as the yield to the City without any shortage is found to be 600 mgd under the present release requirements. For the proposed higher release requirements, shortages are recorded during the last three years of the 1960's drought, 1965 through 1967. The shortages might not have occurred if the releases were cut down to the present lower release levels before the storages became low.

Average, 80 percent and 90 percent end-of-month stage curves for the system diversion of 600 mgd and releases at the proposed levels are shown in Fig. V-9 based on analyses of the 45-year inflow data. Smooth broken lines are drawn to represent criterion - level curves for 80 percent (Curve A) and 90 percent (Curve B) exceedence frequencies. Curve A is adopted as the criterion-level curve for release operations. Average and 80 percent end-of-month stage curves for system diversion of 800 mgd and releases at the existing levels are shown in Fig. V-10 based on analysis of the 45-year inflow data. The smooth broken line is drawn to represent the criterion-level curve for the 80 percent exceedence frequency which is adopted as the criterion-level curve for diversion operation.

E. Uniform vs. Non-uniform Monthly Diversion Rates - The preceding analyses consider a uniform system diversion rate for each month. Non-uniform monthly diversion rates are next examined to study the effect of such monthly variations on the yield of the system. The monthly variations, derived based on the monthly records of total diversion to the city from the Basin during the period 1965 through 1972, are listed in Table V-6. The system is drawn upon more heavily during the low flow summer period than the high flow spring period.

Results of the operations study show that the shortage indices and the occurrences of shortage-years are practically the same, and that the reservoir-stage cumulative frequencies increase by only one to three percent over that of the uniform rate analysis. The effect on the stage frequencies is more pronounced when the reservoir stages are high. When the stages are low, which would occur during prolonged drought, the reduced diversion rates from November through April help alleviate the shortages. As a whole, the effect upon the system yield is considered negligible.

Multi-Level System Operation Studies

The diversion and release operations were divided into primary and secondary categories for these studies. The drought-criterion-level curves developed in the earlier section were used to specify the drought and non-drought operations. Primary operations were allowed when the reservoir stages were below the drought-criterion-levels (drought period). Otherwise (non-drought periods), both primary and secondary operations were allowed. Because of this flexibility, this operation may also be called the system flexible-operation scheme. The objective of the scheme is to insure adequate supplies at all times for the primary system operations and permit the secondary operations whenever possible without interruption of the primary operations. Several runs were made to study the basic system operations. The scope of runs is presented in Appendix C (on file).

The first set of runs was made to meet the primary operations of diverting 600 mgd to the city, maintaining the existing conservation releases and meeting the minimum flow requirement of 1750 cfs at Montague, and the secondary operation of releasing downstream an amount equal to the difference between the proposed and the existing conservation releases. The drought-criterion-level curve for release operations was used for these runs. The results show no diversion shortages whereas a one-year diversion shortage was recorded in the corresponding previous analysis under the variable diversion scheme at 600 mgd diversion and the proposed conservation release levels. Release shortages are reduced to a minimum. Montague shortages are reduced by 87 percent using the 80 percent criterion-level curve and by 22 percent using the 90 percent criterion-level rule curve.

For the second set of runs, the 800 mgd diversion to the city was sub-divided into a primary diversion of 600 mgd and secondary diversion of 200 mgd. This set of runs was made to meet the primary and secondary operations as before for the first set of runs and the additional secondary operation of diverting 200 mgd to the City. The drought-criterion-level rule curves for release and diversion operations were used for these runs. The results show great improvement in the system performance. The shortage index for primary operations reduced from 0.42 to 0.09. The primary diversion shortages are minimum, occurring once each in the 30's and 60's droughts. Primary release shortages are also minimum. The summary tables of system performance for the 38-year data (including the 30's drought) and the 45-year data (including the 30's and 60's drought) are presented in Tables V-7 and V-8. The long-term average diversions to the City are as follows:

	38-year Data (1923-60)	45-year Data (1923-67)
Primary Diversion (mgd)	600	599
Secondary Diversion (mgd)	188	172
Total Diversion (mgd)	788	771

The amount of water available for diversion to the City drops below 800 mgd only eight percent of the time for the 38-year data and only 17 percent of the time for the 45-year data (including the recent 60's drought). Since Cannonsville Reservoir became operational, the City has been diverting an average of about 600 mgd from the Delaware System. The proposed conservation releases of 50, 70 and 125 cfs at Neversink, Pepacton and Cannonsville Reservoirs respectively are met 75 percent of the time for the 38-year data and 66 percent of the time for the 45-year data. During the remaining time, the proposed conservation releases are reduced to the existing level.

The analyses indicate that the system yield can be increased to provide additional diversions and releases with the adoption of flexible operating procedures. The resulting system shortage index of 0.09 is tolerable. The criterion-level rule curves for diversion and release operations are shown together in Fig. V-11 to indicate the proposed flexible operation scheme. The 800 mgd diversion and proposed conservation releases can be met when the reservoir stage is above the level defined by the curve for release operations. The 800 mgd diversion and existing conservation releases can be met when the reservoir stage is between the levels defined by the curves for release and diversion operations. When the reservoir stage is below the level defined by the curve for diversion operations, 600 mgd diversion and existing conservation releases can be met. The figure indicates that the reduction in diversion or release is not gradual. Although more than one criterion-level rule curve can be employed to make gradual reductions in each operation as the water level falls, the foregoing monthly operation analysis may be considered to approximate the daily operation analysis with a gradual reduction scheme.

The relation between the percent storages indicated by the above figure and corresponding storages and stages for each of the three reservoirs of the system is presented in Table V-9. The 100 percent storage corresponds to the storage at crest level and zero percent storage corresponds to the storage at minimum operating level. This table used in conjunction with Fig. V-11 would enable the determination of the system operation according to the flexible operation scheme.

The amount of water available to the city during periods of severe drought, comparable to the one in 60's, would be 599 mgd under the proposed scheme. This is almost the same as the safe system yield with the existing release requirements for the 45-year data which includes the 60's drought. In essence, the city would be losing nothing in terms of safe system yield under the proposed operation scheme. They would be providing higher conservation releases only during non-drought periods. This amounts to the excess water which is lost over the spillways during periods of high spring runoff under the present operating procedures.

Summary

The present City operating procedures for the system are different from the procedures adopted prior to the completion of Cannonsville Reservoir in March 1967. Hence, the operation of the system during the water years 1968 through 1972 is analyzed to understand the present operation of the system. However, since the above years are basically wet, operation during these years may not truly represent the normal operation over a longer period. Diversion to the City at an average rate of 600 mgd and conservation releases at the existing level are made. Four basic system operation runs SD-1, SR-1, SD-5 and SD-7 are selected for comparison with the present operation. In run SD-1, diversion and release levels which are the same as in the present operation were examined with the 38-year and 45-year inflow data sets. In run SR-1, the diversion rate remained the same at 600 mgd but the conservation releases were varied from the proposed level to the existing level based on the drought criterion-level curve for release operations (Fig. V-11). This would be the case when the diversion to the city is continued at the present average rate of 600 mgd while making the downstream conservation releases at the proposed level. In run SD-5, diversion to the city at the rate of 800 mgd (maximum allowed by the Decree) and conservation releases at the existing level were made. This corresponds to a possible future operation if the conservation releases are continued at the existing level. In run SR-7, the diversion rates were varied from 800 mgd to 600 mgd and the downstream conservation releases were varied from the proposed level to the existing level following the drought criterion-level rule curves for diversion and release operations (Fig. V-11). This would be the case in future if the proposed flexible operation scheme is adopted.

Average monthly stage curves for the Pepacton, Cannonsville and Neversink Reservoirs, based on the 45-year data, for the above four basic system operation runs are presented in Fig. V-12. Average monthly mean stage curves for the present operation of the reservoirs are also shown. For the present operation and the above four runs, a comparison of the scheme of operation, primary shortage index, long-term yield to the City, chances of reservoirs' filling to the 90 percent storage level, and water level fluctuation of the reservoirs is presented in Table V-10. For this purpose, the fluctuation is defined as the difference in water levels at the beginning of June and November.

The effect of increasing the existing conservation releases to the proposed level during the non-drought operation and reducing back to the existing level during drought operation following the rule curve is noticed by comparing runs SD-1 and SR-1. The shortage index, long-term system yield to the City and chances of the reservoirs filling to the 90 percent storage level remain the same. The fluctuation increases by about one foot and the average monthly stages drop by about two feet for all three reservoirs. Similarly comparing runs SD-5 and SR-7, it is seen that modifying the diversions and releases according to the proposed flexible operation scheme reduces the long-term system yield and chances of the reservoirs filling to the 90 percent storage level. The fluctuation increases by less than one foot, but the monthly mean stages rise by about two feet for all the three reservoirs. The monthly mean stage curve for Pepaction Reservoir based on the recent five-year operation is about four feet above and has the same trend as the curve for comparable run SD-1. Both the curves for Cannonsville and Neversink Reservoirs based on the recent five-year operation have contrasting trends steeply falling-off in the summer and fall months. Cannonsville Reservoir is heavily drawn upon in these months, to meet the excess release requirement at Montague, and Neversink Reservoir is used to meet the diversion needs. The consequent fluctuation for Cannonsville and Neversink are large. The fluctuation for Pepacton Reservoir is more reasonable lying in the range of fluctuation computed for runs SD-1 and SR-1.

TABLE V-1 Comparison of computed reservoir diversions using different proportions at 600 mgd (929 cfs) system diversion level.

	Reservoir Diversion (cfs)		
Proportion	Pepacton	Cannonsville	Neversink
I *	548 (59)**	167 (18)	213 (23)
II	241 (26)	446 (48)	241 (26)
III	464 (50)	334 (36)	130 (14)

* Proportion I computed from the historic diversion records; II based on the ratios of the drainage area to the storage capacity; III based on the single reservoir analysis.

** The values in parentheses are the corresponding proportions as percentage of system diversion.

TABLE V-2. Comparison of frequencies of reservoir storages and releases (constant diversion scheme at system diversion level of 600 mgd and existing releases).

A. Reservoir storages

	Percent frequency			
Proportion	Pepacton	Cannonsville	Neversink	Remarks
I	(6,23,55)	(1,14,36)	(11,42,72)	See Note 1
II	(1,13,38)	(2,17,47)	(25,64,87)	
III	(2,19,47)	(2,16,41)	(2,18,43)	

B. Reservoir releases

	Percent frequency			
Proportion	Pepacton	Cannonsville	Neversink	Remarks
I	(50,43)	(16,75)	(80,13)	See Note 2
II	(22,78)	(43,41)	(93,3)	
III	(42,52)	(29,59)	(36,39)	

Note:

1. Values in parentheses are frequencies of storage equal to or less than 20, 60, and 90 percent of its own capacity.
2. The first value refers to the frequency of releases equal to or less than the required minimum release; the second is the frequency of releases ten times larger the required releases.

LAKE	MONTH	MEAN	STD DEV	MAX	MIN	FREQ TALLY IN PER CENT OF (SMAX-SMIN) 0	10	20	30	40	50	60	70	80	90	100
1 Pepacton Reservoir	10	1251.05	26.07	1278.92	1171.64	1	1	0	3	5	6	6	3	7	13	
	11	1251.89	30.78	1278.92	1152.69	2	0	2	1	6	5	3	5	4	17	
	12	1255.59	30.40	1278.92	1152.18	2	1	0	1	5	5	1	5	4	21	
	1	1258.33	30.15	1278.92	1146.01	1	1	2	0	3	3	4	3	5	23	
	2	1260.10	29.38	1278.92	1157.21	1	1	2	1	2	3	3	1	5	26	
	3	1267.11	21.71	1278.92	1202.51	0	0	2	1	1	4	1	2	2	32	
	4	1273.96	13.29	1278.92	1213.30	0	0	0	1	0	1	2	2	1	38	
	5	1275.23	10.67	1278.92	1222.45	0	0	0	0	1	0	2	1	2	39	
	6	1273.86	10.92	1278.92	1223.91	0	0	0	0	1	1	1	0	4	38	
	7	1269.02	13.40	1278.92	1213.95	0	0	0	1	1	0	1	6	10	26	
	8	1262.69	16.86	1278.92	1201.97	0	0	2	0	0	1	8	8	9	17	
	9	1256.13	21.68	1278.92	1187.19	0	2	0	0	2	7	7	9	5	13	
		PER CENT ACC. FREQUENCY				1	2	4	5	10	17	24	33	43	100	
2 Cannonsville Reservoir	10	1127.51	20.29	1148.87	1064.58	1	1	0	3	5	6	6	4	6	13	
	11	1128.05	24.55	1148.87	1044.38	2	0	2	1	6	5	3	5	4	17	
	12	1130.87	24.08	1148.87	1043.79	2	1	0	1	5	5	1	5	4	21	
	1	1132.98	24.00	1148.87	1036.51	1	1	2	0	3	3	4	3	5	23	
	2	1134.41	22.93	1148.87	1049.49	1	1	2	1	2	3	3	1	5	26	
	3	1140.10	16.47	1148.87	1090.74	0	0	2	1	1	3	2	2	1	33	
	4	1145.13	9.98	1148.87	1098.63	0	0	0	1	0	1	2	2	1	38	
	5	1146.08	8.00	1148.87	1105.30	0	0	0	0	1	0	2	1	2	39	
	6	1145.03	8.29	1148.87	1106.39	0	0	0	0	1	1	1	0	4	38	
	7	1141.46	10.11	1148.87	1099.10	0	0	0	1	1	0	1	6	10	26	
	8	1136.71	12.81	1148.87	1090.34	0	0	2	0	0	1	8	8	9	17	
	9	1131.62	16.55	1148.87	1078.71	0	2	0	0	2	7	7	9	5	13	
		PER CENT ACC. FREQUENCY				1	2	4	5	10	17	24	33	43	100	
3 Neversink Reservoir	10	1415.48	24.01	1442.18	1343.15	1	1	0	3	5	5	7	3	7	13	
	11	1416.58	28.20	1442.18	1328.95	2	0	2	1	6	5	3	5	3	18	
	12	1419.98	27.86	1442.18	1328.58	2	1	0	1	5	5	1	5	4	21	
	1	1422.56	27.69	1442.18	1324.20	1	1	2	1	2	3	4	3	4	24	
	2	1424.16	27.16	1442.18	1332.24	1	1	2	1	2	3	3	1	5	26	
	3	1430.79	20.55	1442.18	1370.38	0	0	2	1	1	4	0	3	2	32	
	4	1437.42	12.74	1442.18	1380.42	0	0	0	1	0	1	2	2	1	38	
	5	1438.46	10.32	1442.18	1388.87	0	0	0	0	1	0	2	1	2	39	
	6	1436.70	10.46	1442.18	1390.22	0	0	0	0	1	1	1	0	4	38	
	7	1431.65	12.52	1442.18	1381.01	0	0	0	1	1	0	1	6	11	25	
	8	1425.91	15.59	1442.18	1369.87	0	0	2	0	0	1	8	8	9	17	
	9	1420.11	20.05	1442.18	1356.11	0	2	0	0	2	7	7	9	4	14	
		PER CENT ACC. FREQUENCY				1	2	4	6	10	17	24	33	43	100	

TABLE V-3: Summary Tables for Storage Operations—VARIABLE DIVERSION SCHEME
(System operations study at 600 mgd diversion and existing release levels.
End-of-period storages. Operation duration—45 years.)

LAKE	MONTH	MEAN	STD DEV	MAX	MIN	FREQ TALLY IN PER CENT OF (SMAX-SMIN) 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
1 Pepacton Reservoir	10	1250.43	26.41	1278.92	1140.35	1	1	0	3	5	7	4	5	8	11
	11	1259.92	31.33	1278.92	1140.66	2	0	2	1	7	5	2	4	5	17
	12	1254.00	31.08	1278.92	1165.58	2	1	0	3	2	7	2	5	4	19
	1	1256.27	30.62	1278.92	1145.58	1	1	2	2	1	5	4	1	8	20
	2	1257.36	30.65	1278.92	1150.53	1	1	2	1	3	3	2	4	6	22
	3	1263.82	24.99	1278.92	1188.67	0	2	1	1	2	2	2	3	4	28
	4	1271.98	16.40	1278.92	1201.02	0	0	1	0	1	1	3	1	0	38
	5	1273.45	13.71	1278.92	1211.42	0	0	0	1	0	1	1	3	1	38
	6	1272.24	13.55	1278.92	1213.51	0	0	0	1	0	2	1	2	2	37
	7	1267.55	15.96	1278.92	1207.09	0	0	1	1	0	1	1	5	12	24
	8	1261.45	17.40	1278.92	1198.29	0	0	2	0	0	2	8	7	11	15
	9	1255.27	22.24	1278.92	1163.49	0	2	0	0	3	7	7	8	5	13
	PER CENT ACC. FREQUENCY					1	2	4	7	11	19	26	35	47	100
2 Cannonsville Reservoir	10	1126.89	20.78	1148.87	1054.27	1	1	0	3	5	7	4	5	6	12
	11	1128.05	25.13	1148.87	1036.10	2	0	2	0	8	4	1	8	3	17
	12	1131.40	24.55	1148.87	1036.10	1	2	0	2	4	2	4	5	4	21
	1	1134.30	23.69	1148.87	1036.10	1	0	3	1	2	3	1	3	5	26
	2	1136.59	21.29	1148.87	1062.49	1	0	3	0	2	4	2	0	3	30
	3	1142.64	13.09	1148.87	1103.25	0	0	0	2	1	2	2	2	1	35
	4	1146.69	6.66	1148.87	1112.03	0	0	0	0	1	0	0	3	1	40
	5	1147.39	5.49	1148.87	1118.42	0	0	0	0	0	1	1	0	1	42
	6	1146.03	6.49	1148.87	1113.63	0	0	0	0	0	2	0	0	2	41
	7	1142.08	9.32	1148.87	1102.11	0	0	0	1	1	0	0	5	12	26
	8	1136.97	12.55	1148.87	1090.04	0	0	1	1	0	1	7	8	11	16
	9	1131.33	15.62	1148.87	1075.57	0	2	0	0	2	6	8	8	7	12
	PER CENT ACC. FREQUENCY					1	2	3	5	10	16	22	30	41	100
3 Neversink Reservoir	10	1415.37	24.64	1442.18	1339.07	2	0	0	3	6	5	4	4	8	12
	11	1416.31	28.83	1442.18	1323.96	2	0	2	0	8	4	4	2	5	17
	12	1419.68	28.31	1442.18	1323.96	2	1	0	2	3	7	0	5	3	21
	1	1421.89	27.73	1442.18	1323.96	1	1	2	1	1	5	4	2	4	24
	2	1423.20	27.65	1442.18	1323.96	1	1	2	0	3	2	5	3	2	26
	3	1429.14	22.52	1442.18	1359.42	0	2	1	0	2	2	2	4	2	30
	4	1436.75	14.24	1442.18	1372.76	0	0	1	0	1	1	1	2	1	38
	5	1438.15	11.76	1442.18	1382.28	0	0	0	1	0	1	1	1	2	39
	6	1436.54	11.95	1442.18	1382.35	0	0	0	1	0	2	0	0	3	39
	7	1431.18	13.66	1442.18	1375.58	0	0	1	1	0	1	0	6	11	25
	8	1425.43	15.54	1442.18	1366.28	0	1	2	0	0	2	5	11	7	18
	9	1419.65	23.03	1442.18	1352.78	0	2	0	0	2	7	8	8	4	14
	PER CENT ACC. FREQUENCY					1	2	4	5	11	18	25	34	43	100

TABLE V-4: Summary Tables for Storage Operations–CONSTANT DIVERSION SCHEME
(System operations study at 600 mgd diversion and existing release levels.
End-of-period storages. Operation duration–45 years.)

TABLE V-5 - Comparison of computed average diversion proportions for the three New York City Reservoirs

Data Source	Diversion Proportions (Percent)		
	Pepacton	Cannonsville	Neversink
1. System basis operations study with variable diversion scheme			
Method A [1]	55	21	24
Method B [2]	40	47	13
2. Proportion I	59	18	23
3. Proportion II	26	48	26
4. Proportion III	50	36	14

Note: 1. Method A considers diversion preference in the order of Neversink, Pepacton, and then Cannonsville.

2. Method B is based on equal priorities

TABLE V-6 - Monthly Water Supply Diversion Variations from the Average Diversion

MONTH	MONTHLY VARIATION
January	0.903
February	0.955
March	0.934
April	0.733
May	1.164
June	1.081
July	1.177
August	1.196
September	1.175
October	1.027
November	0.976
December	0.699

LAKE	MONTH	MEAN	STD DEV	MAX	MIN	FREQ TALLY IN PER CENT OF (SMAX-SMIN) 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
1 Pepacton Reservoir	10	1242.05	25.14	1278.92	1195.04	0	0	5	6	1	5	5	8	3	5
	11	1243.91	29.95	1278.92	1184.29	0	2	4	5	1	2	6	6	5	7
	12	1248.23	29.12	1278.92	1173.59	0	2	3	1	4	4	5	5	2	12
	1	1250.64	29.93	1278.92	1147.68	1	1	1	3	4	2	7	2	4	13
	2	1251.53	30.42	1278.92	1145.68	1	1	2	2	1	5	5	4	3	14
	3	1260.73	24.03	1278.92	1172.29	0	1	0	2	2	3	3	5	4	18
	4	1272.48	11.76	1278.92	1221.36	0	0	0	0	1	0	2	3	6	26
	5	1274.39	8.24	1278.92	1240.24	0	0	0	0	0	1	0	4	4	29
	6	1272.13	7.95	1278.92	1243.39	0	0	0	0	0	0	1	3	9	25
	7	1265.50	10.79	1278.92	1243.41	0	0	0	0	0	0	4	11	8	15
	8	1257.06	14.42	1278.92	1226.16	0	0	0	0	1	6	8	9	7	7
	9	1249.20	19.90	1278.92	1215.21	0	0	0	3	10	2	3	9	6	5
	PER CENT ACC. FREQUENCY					0	1	5	10	15	22	32	48	61	100
2 Cannonsville Reservoir	10	1120.83	19.27	1148.87	1085.04	0	0	5	6	1	5	5	8	3	5
	11	1122.28	22.97	1148.87	1076.26	0	2	4	5	1	2	6	6	5	7
	12	1125.45	22.48	1148.87	1066.49	0	2	3	1	4	4	5	5	2	12
	1	1127.11	23.87	1148.87	1038.51	1	1	1	3	4	2	7	2	5	12
	2	1127.78	24.32	1148.87	1036.10	1	1	2	2	1	5	5	4	3	14
	3	1135.06	18.53	1148.87	1065.23	0	1	0	1	3	3	3	5	4	18
	4	1144.22	8.77	1148.87	1104.50	0	0	0	0	1	0	2	3	4	28
	5	1145.49	6.06	1148.87	1119.33	0	0	0	0	0	1	0	4	4	29
	6	1143.82	5.84	1148.87	1121.87	0	0	0	0	0	0	1	3	9	25
	7	1138.88	7.97	1148.87	1121.89	0	0	0	0	0	0	4	11	8	15
	8	1132.40	11.10	1148.87	1108.10	0	0	0	0	1	6	8	9	7	7
	9	1126.22	15.37	1148.87	1100.01	0	0	0	4	9	2	3	9	6	5
	PER CENT ACC. FREQUENCY					0	1	5	10	15	22	32	48	61	100
3 Neversink Reservoir	10	1406.99	23.19	1442.18	1363.33	0	0	5	6	1	5	5	8	3	5
	11	1408.74	27.79	1442.18	1353.50	0	3	3	5	1	2	5	7	5	7
	12	1412.83	26.88	1442.18	1344.68	0	2	3	2	3	4	4	5	3	12
	1	1415.21	27.26	1442.18	1325.37	1	1	1	3	4	2	6	2	5	13
	2	1416.10	27.69	1442.18	1323.96	1	1	2	2	2	4	5	4	3	14
	3	1424.65	22.32	1442.18	1343.66	1	0	0	1	3	3	1	7	3	19
	4	1435.67	11.37	1442.18	1387.86	0	0	0	1	0	0	2	3	5	27
	5	1437.28	8.16	1442.18	1405.82	0	0	0	0	0	1	0	3	5	29
	6	1434.69	7.70	1442.18	1408.72	0	0	0	0	0	0	1	3	9	25
	7	1428.42	9.82	1442.18	1408.74	0	0	0	0	0	0	5	10	8	15
	8	1420.77	12.99	1442.18	1392.39	0	0	0	0	1	6	7	10	7	7
	9	1413.54	18.20	1442.18	1382.18	0	0	0	4	9	2	3	9	6	5
	PER CENT ACC. FREQUENCY					0	2	5	10	15	22	31	47	60	100

TABLE V-7: Summary Tables for Storage Operations—FLEXIBLE OPERATION SCHEME
(System operations study based on 38-year inflow data at 800 to 600 mgd diversion and proposed to existing release levels. End-of-period storages. Operation duration —38 years.)

LAKE	MONTH	MEAN	STD DEV	MAX	MIN	FREQ TALLY IN PER CENT OF (SMAX-SMIN) 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
1 Pepacton Reservoir	10	1235.92	31.36	1278.92	1145.68	2	1	7	6	1	6	5	8	3	6
	11	1236.59	36.07	1278.92	1145.68	2	3	6	5	2	2	6	6	5	8
	12	1240.15	36.13	1278.92	1145.68	3	2	5	1	5	4	5	5	3	12
	1	1242.53	36.49	1278.92	1145.68	3	2	2	4	4	3	7	3	4	13
	2	1244.21	35.39	1278.92	1145.68	2	4	3	2	2	5	5	4	4	14
	3	1255.19	27.93	1278.92	1172.29	0	2	2	3	2	5	3	5	4	19
	4	1268.15	17.49	1278.92	1213.30	0	0	0	2	1	1	3	4	7	27
	5	1270.14	15.33	1278.92	1210.48	0	0	0	1	1	1	2	5	5	30
	6	1267.46	16.43	1278.92	1194.13	0	0	1	0	1	0	4	4	9	26
	7	1260.03	20.24	1278.92	1167.25	1	0	0	1	0	3	5	11	8	16
	8	1251.13	23.79	1278.92	1145.68	1	0	1	1	3	7	8	9	8	7
	9	1242.69	27.11	1278.92	1145.68	1	1	1	5	10	3	4	9	6	5
	PER CENT ACC. FREQUENCY					2	5	10	16	22	29	40	53	66	100
2 Cannonsville Reservoir	10	1115.84	24.88	1148.87	1036.10	1	2	7	6	1	6	5	8	3	6
	11	1116.31	28.55	1148.87	1036.10	2	3	6	5	2	2	6	6	5	8
	12	1118.92	28.70	1148.87	1036.10	3	2	5	1	5	4	5	5	3	12
	1	1120.60	29.44	1148.87	1036.10	3	2	2	4	4	3	7	3	5	12
	2	1122.07	28.17	1148.87	1036.10	2	4	3	2	2	5	5	4	4	14
	3	1130.89	21.40	1148.87	1065.23	0	2	2	1	4	5	3	5	4	19
	4	1140.88	13.31	1148.87	1098.63	0	0	0	2	1	1	3	4	5	29
	5	1142.25	11.58	1148.87	1096.58	0	0	0	1	1	1	2	5	5	30
	6	1140.26	12.46	1148.87	1084.32	0	0	1	0	1	0	4	4	9	26
	7	1134.58	15.77	1148.87	1060.19	1	0	0	1	0	3	5	11	8	16
	8	1127.58	19.42	1148.87	1036.10	1	0	1	1	3	7	8	9	8	7
	9	1120.98	21.76	1148.87	1036.10	1	1	1	6	9	3	4	9	6	5
	PER CENT ACC. FREQUENCY					2	5	10	16	22	29	40	53	65	100
3 Neversink Reservoir	10	1401.48	28.53	1442.18	1323.96	2	1	7	6	1	6	5	8	3	6
	11	1402.14	32.95	1442.18	1323.96	2	5	4	5	2	2	5	7	5	8
	12	1405.53	32.90	1442.18	1323.96	3	2	5	2	4	4	4	5	4	12
	1	1407.85	33.03	1442.18	1323.96	3	2	2	4	5	2	6	3	5	13
	2	1409.33	32.27	1442.18	1323.96	2	4	3	2	3	4	5	4	4	14
	3	1419.41	26.08	1442.18	1343.66	1	1	2	2	3	5	1	7	3	20
	4	1431.61	16.58	1442.18	1380.41	0	0	0	3	0	1	3	4	6	28
	5	1433.31	14.50	1442.18	1377.82	0	0	0	1	1	1	2	4	6	30
	6	1430.44	15.31	1442.18	1362.48	0	0	1	0	1	0	4	4	9	26
	7	1423.47	18.35	1442.18	1339.75	1	0	0	1	0	3	6	10	8	16
	8	1415.44	21.17	1442.18	1323.96	1	0	1	1	3	7	7	10	8	7
	9	1407.67	24.47	1442.18	1323.96	1	1	1	6	9	3	3	10	6	5
	PER CENT ACC. FREQUENCY					2	5	10	16	22	29	39	53	65	100

TABLE V-8: Summary Tables for Storage Operations—FLEXIBLE OPERATION SCHEME
(System operations study based on 45-year inflow data at 800 to 600 mgd diversion and proposed to existing release levels. End-of-period storages. Operation duration —45 years.)

TABLE V-9 - Relationship between percent storage, storages and stages for the three New York City Reservoirs

Percent Storage	Pepacton Reservoir Storage (1000-ac-ft)	Pepacton Reservoir Stage (feet)	Cannonsville Reservoir Storage (1000-ac-ft)	Cannonsville Reservoir Stage (feet)	Neversink Reservoir Storage (1000-ac-ft)	Neversink Reservoir Stage (feet)
100 (at crest level)	459.2	1280.0	302.5	1150.0	113.9	1440.0
90	416.0	1272.0	273.0	1143.0	102.2	1432.0
80	371.3	1263.0	243.5	1136.5	91.4	1424.3
70	327.5	1254.0	213.5	1129.0	80.5	1415.7
60	283.0	1244.0	184.0	1121.7	69.7	1407.0
50	240.0	1234.0	154.5	1113.7	58.8	1397.4
40	195.5	1221.5	124.6	1104.3	48.0	1387.0
30	152.0	1208.0	95.0	1094.0	37.3	1374.0
20	107.0	1192.7	65.0	1081.5	26.6	1359.0
10	63.0	1175.0	35.5	1065.3	15.7	1342.0
0 (at minimum operating level)	29.5	1152.0	8.9	1040.0	6.8	1319.0

TABLE V-10 - Comparison of Pertinent Basic Operation Schemes

Run	Diversion to New York City (mgd)	Conservation Releases	Primary Shortage Index (based on 45-yr. data)	Long-term Yield to New York City (mgd)	Chances of Reservoir filling up 1/ (percent) 38 Year Data	45-Year Data	Water Level Fluctuation (feet) (Difference between June 1 and November 1 average levels) Pepacton	Cannonsville	Neversink
Present 2/ Operation	600 3/	Existing Level	--	--	--	--	25.74	54.83	40.64
SD-1	600	Existing Level	0	600	94.7	86.7	24.18	18.57	22.98
SR-1 4/	600	Proposed Level to Existing Level	0.00081	600	94.7	86.7	25.43	19.58	24.01
SD-5	800 5/	Existing Level	0.419	793	86.8	75.6	33.49	26.42	30.89
SR-7 4/	800 to 600	Proposed Level to Existing Level	0.0532	771	76.3	66.7	34.22	26.41	31.83

Note:
1/ Based on filling to 90 percent storage level
2/ Based on analysis of data during the water years 1968 through 1972
3/ Approximately equal to the present rate of diversion
4/ Flexible operation scheme
5/ Maximum diversion permitted by the Decree

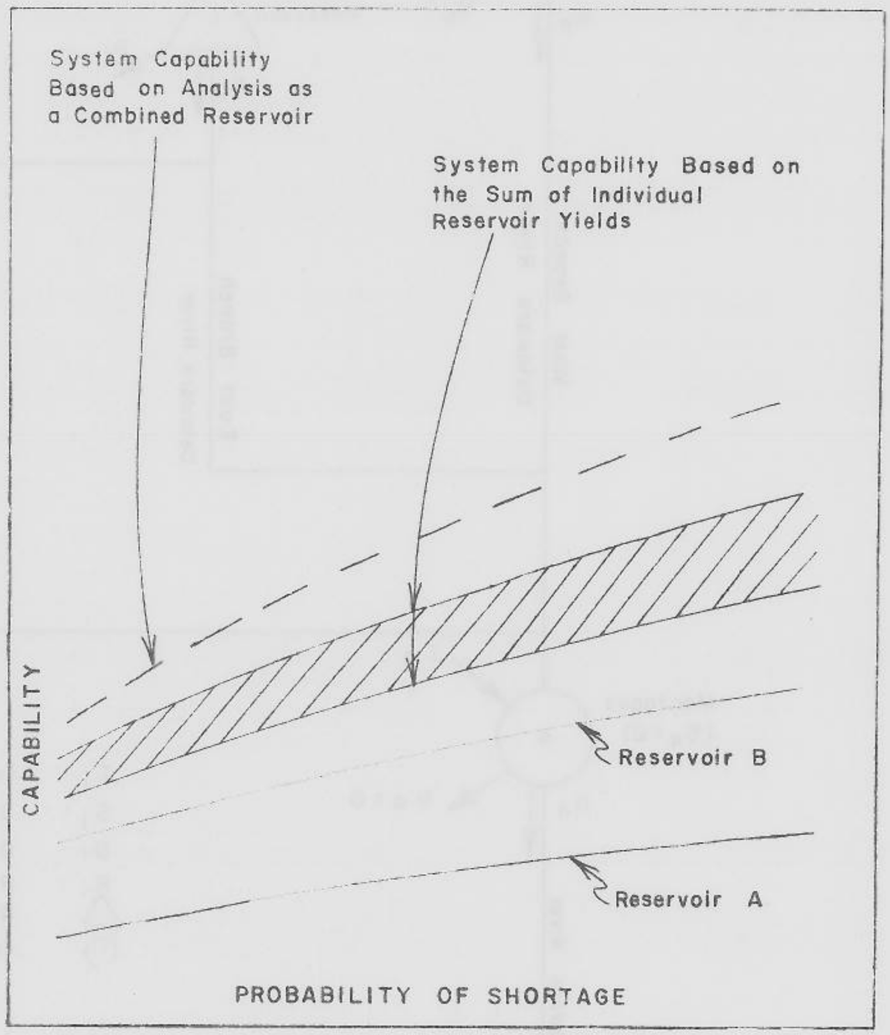

FIG. V-1

TYPICAL YIELD-PROBABILITY CURVES OF A TWO-RESERVOIR SYSTEM

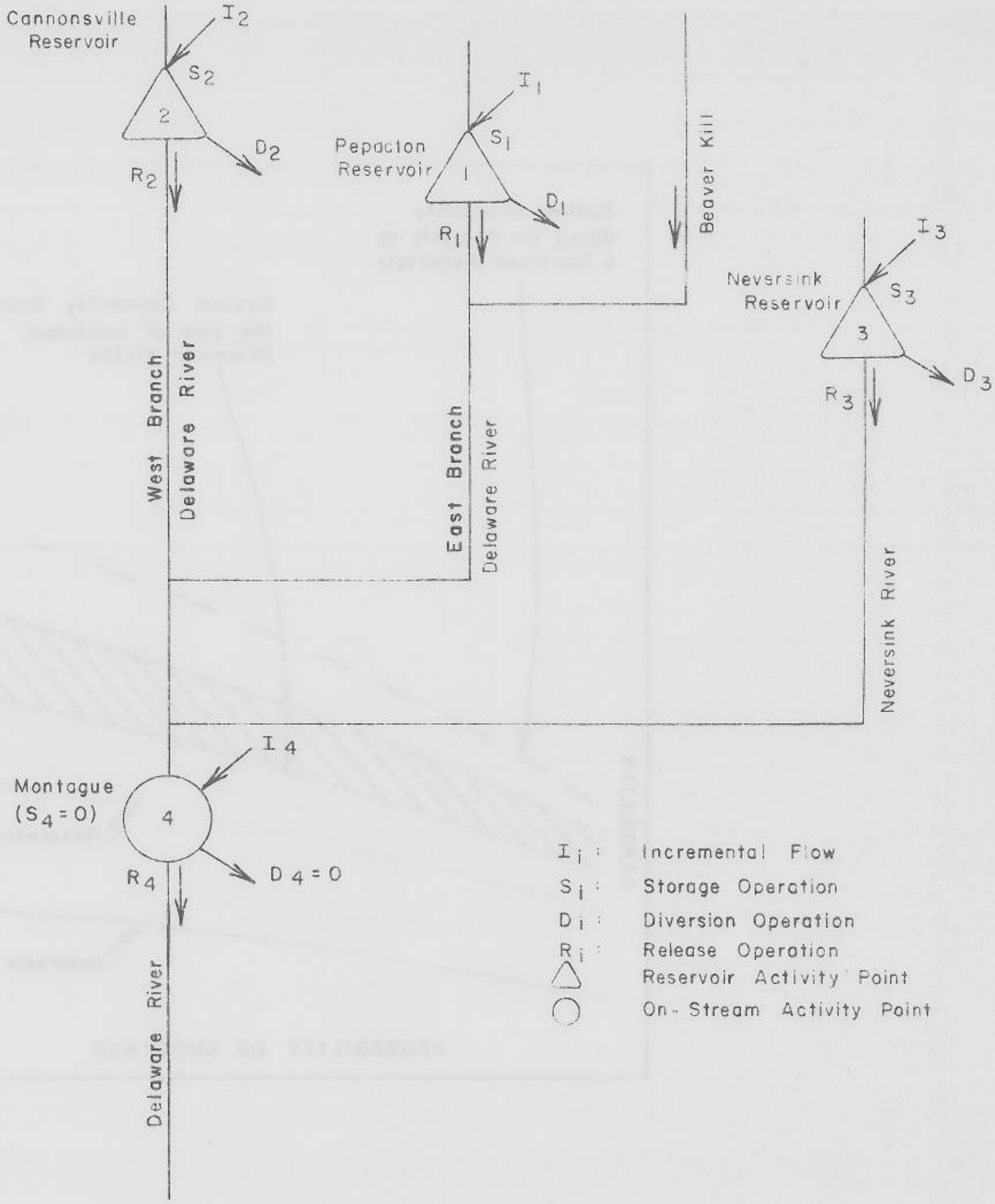

FIG. V-2

SCHEMATIC DIAGRAM FOR CONSTANT DIVERSION SCHEME

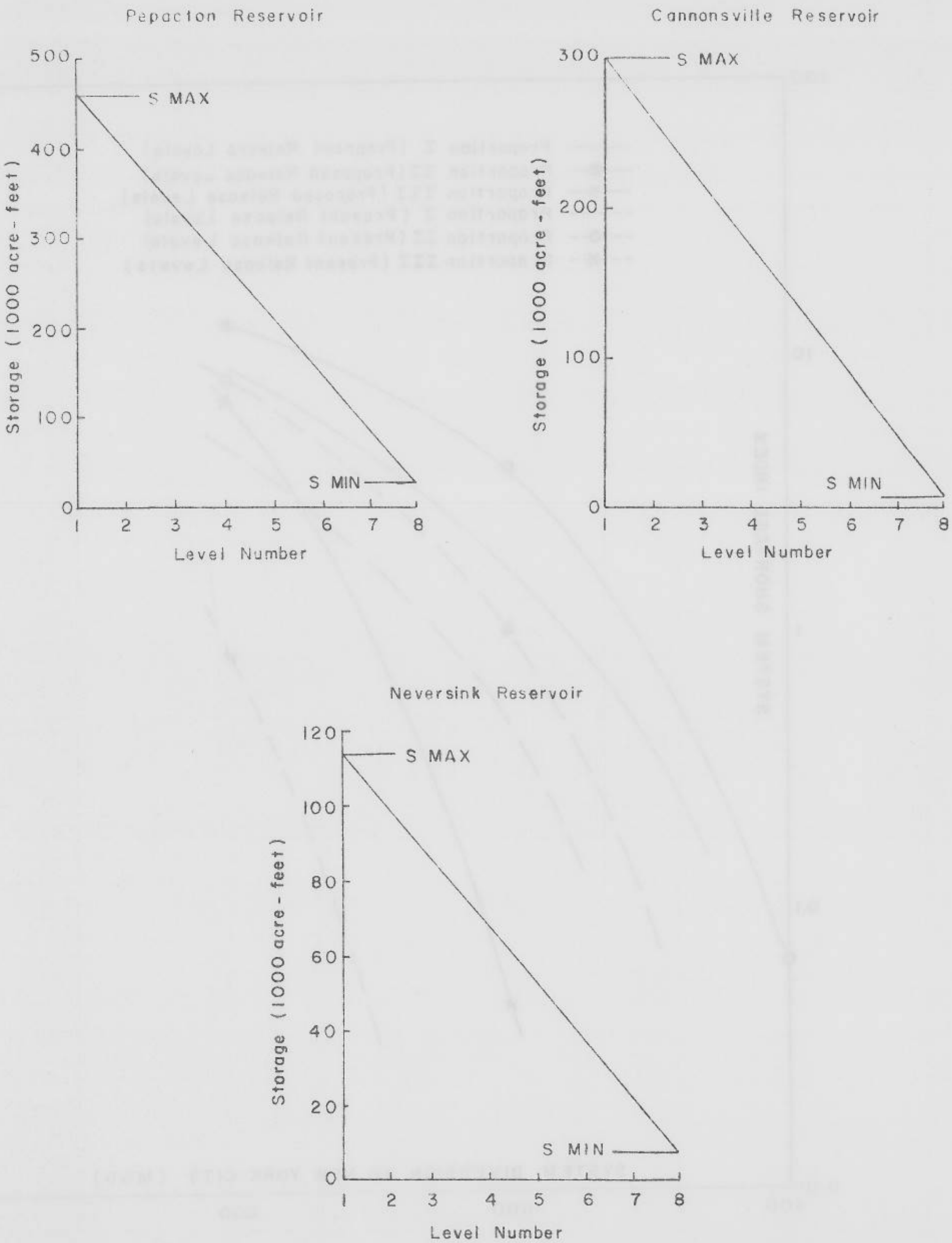

FIG. V-3

RESERVOIR LEVEL NUMBER - STORAGE CURVES

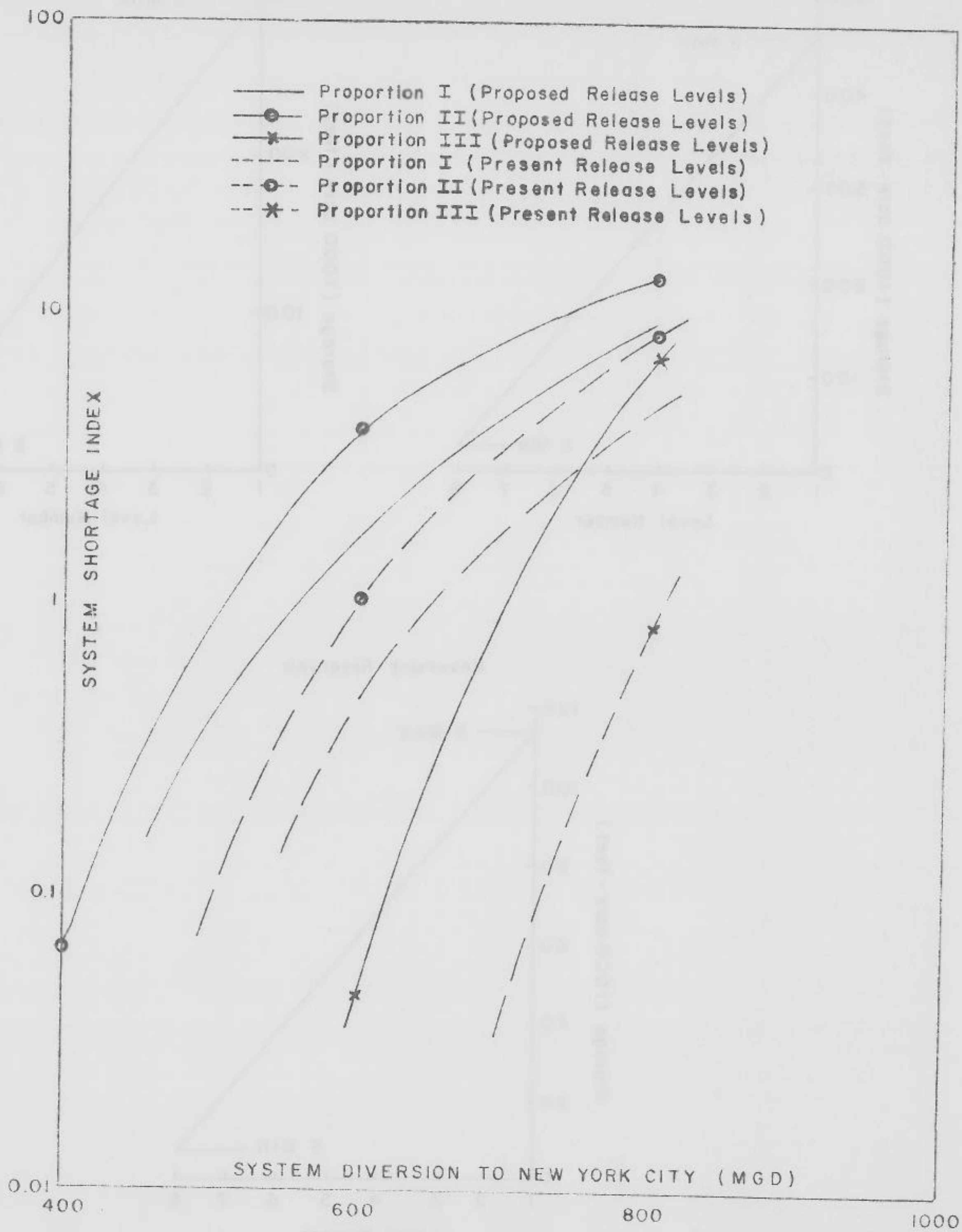

FIG. V-4

SYSTEM DIVERSION - SHORTAGE INDEX CURVES

(Constant Diversion Schemes)

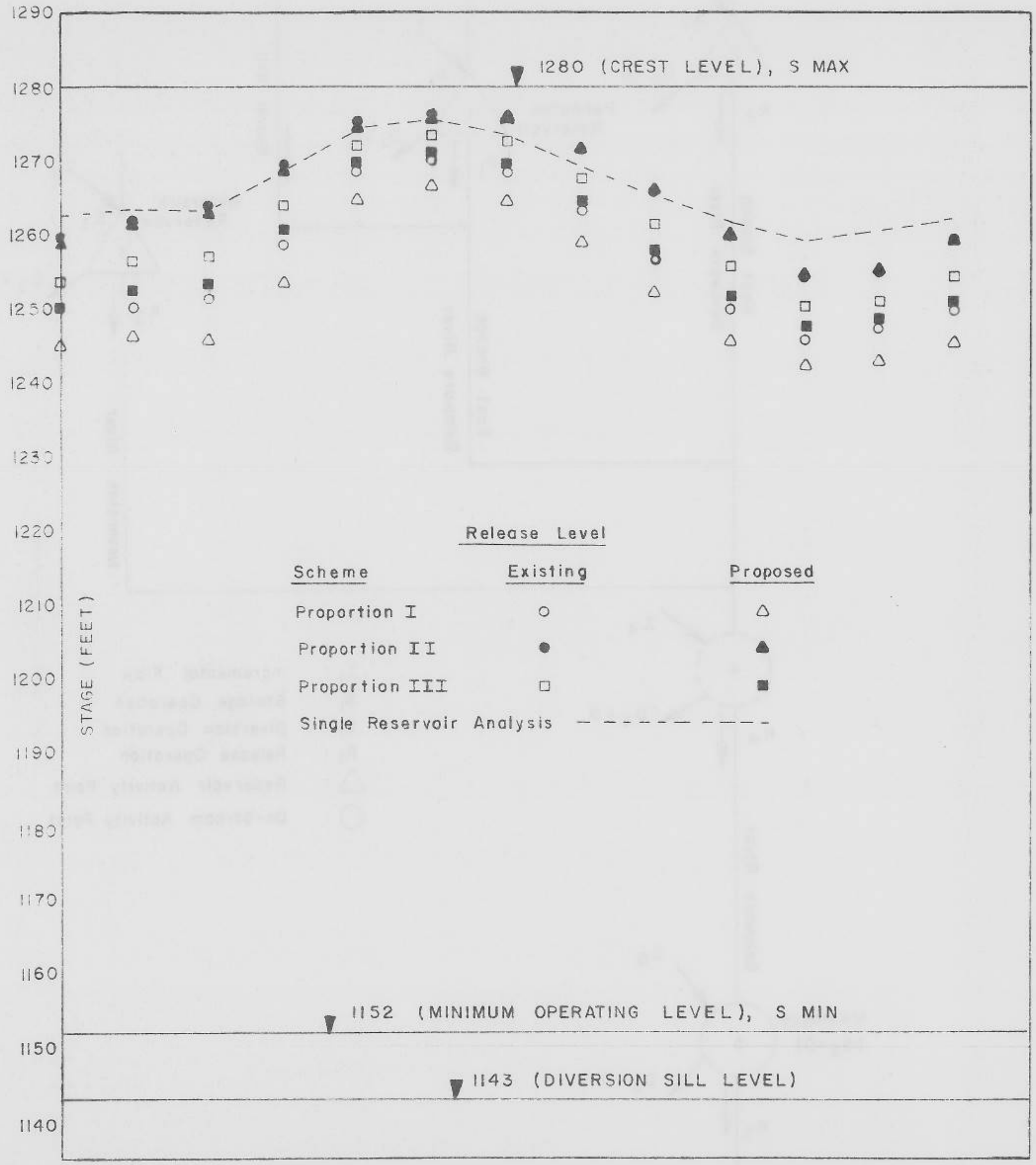

FIG. V-5

Comparison of average stages for Pepacton Reservoir at 600 mgd system diversion level (Constant Diversion Schemes)

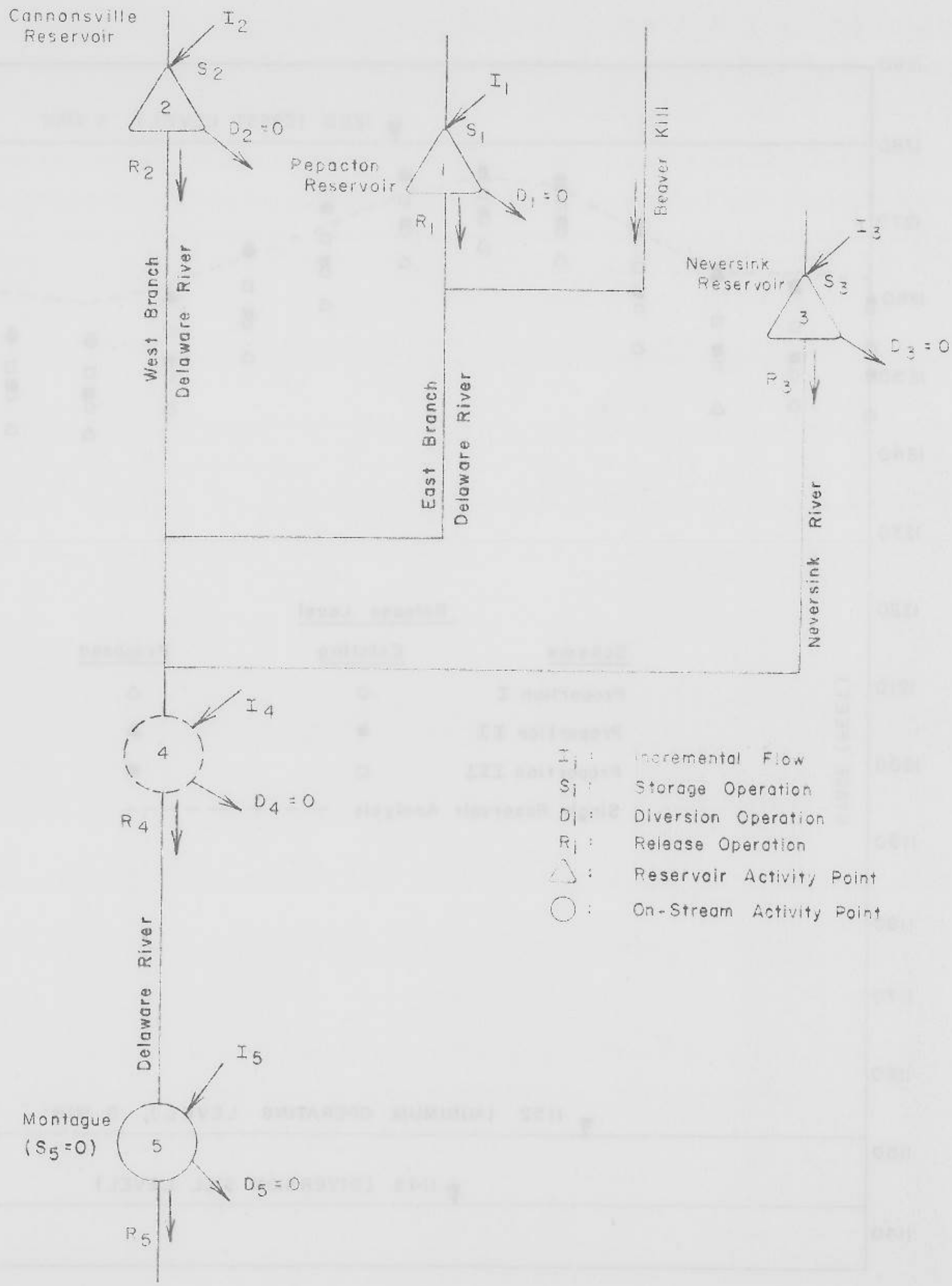

FIG. V-6

SCHEMATIC DIAGRAM FOR VARIABLE DIVERSION SCHEME

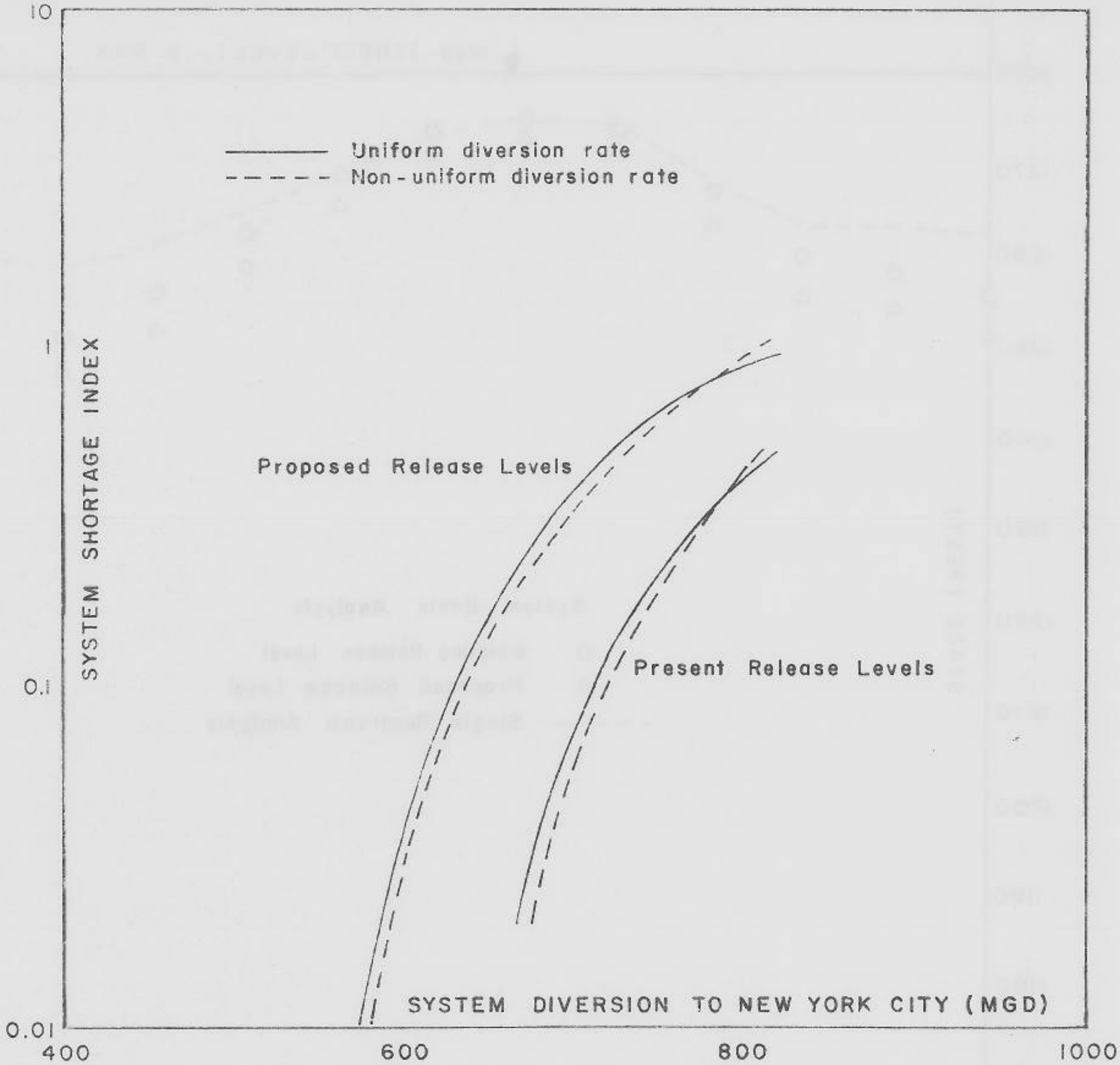

FIG. V-7

SYSTEM DIVERSION - SHORTAGE INDEX CURVES

(Variable Diversion Schemes)

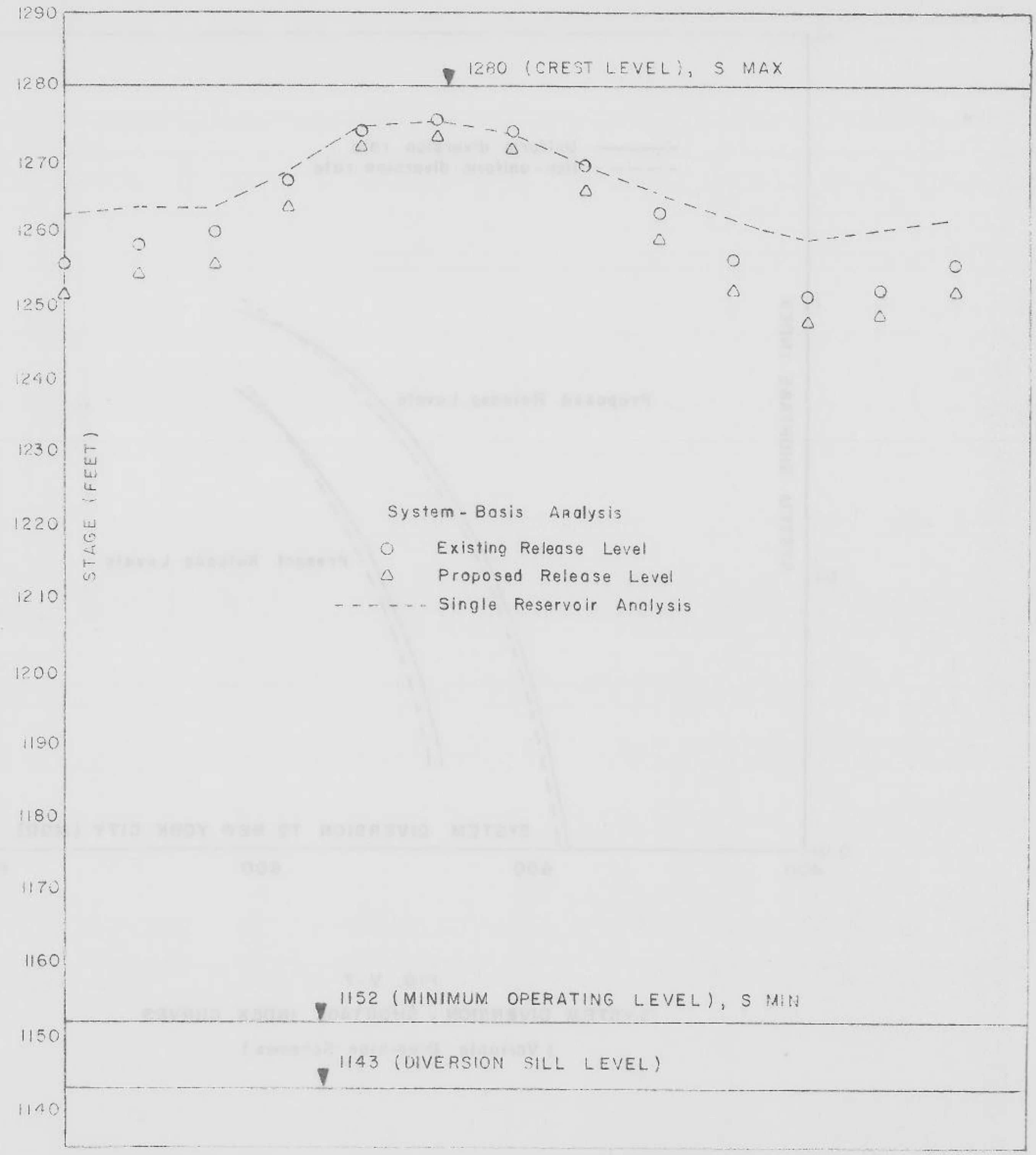

FIG V-8
Comparison of average Stages for Pepacton Reservoir
at 600 mgd system diversion level
(Variable Diversion Schemes)

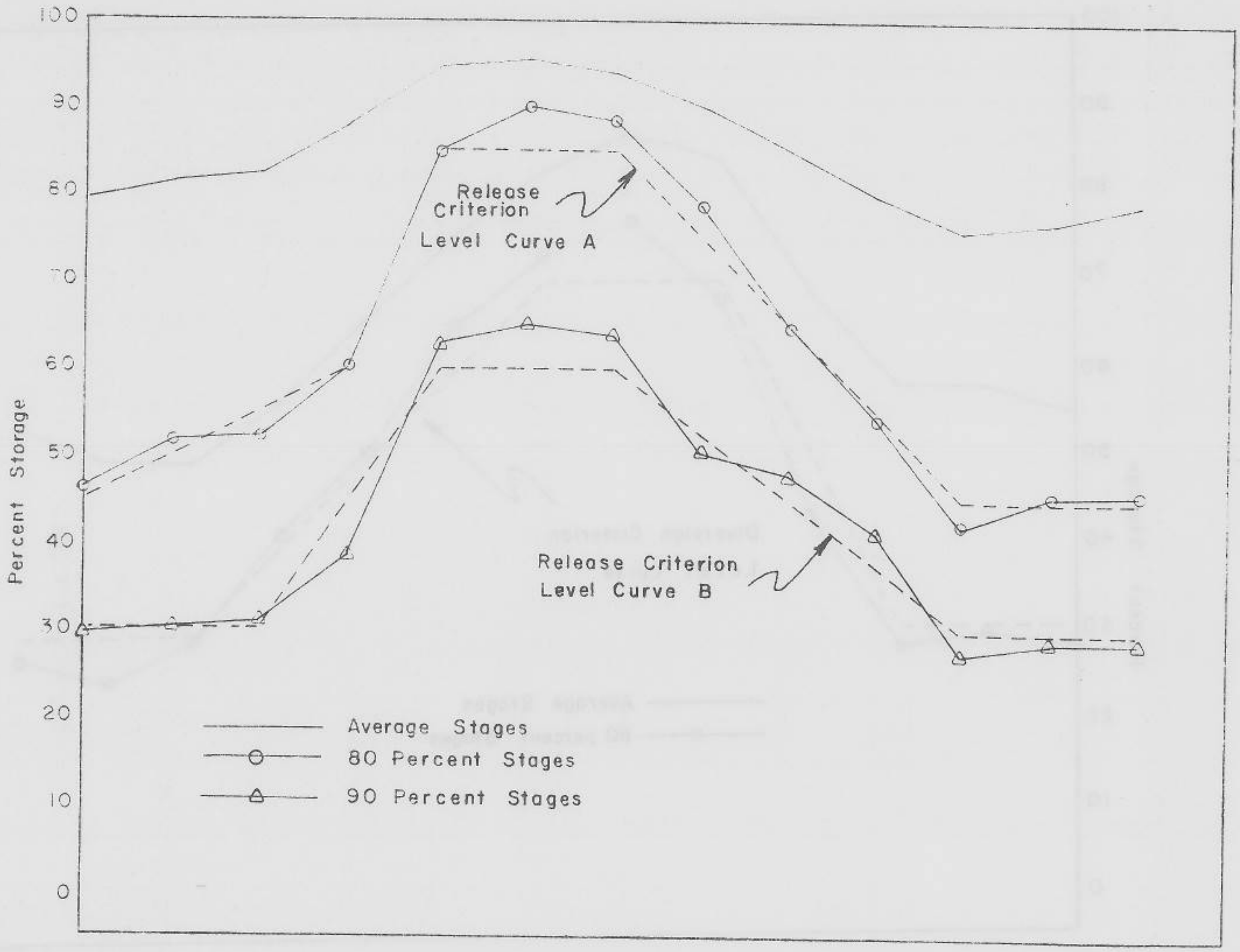

FIG. V-9

CRITERION-LEVEL CURVES FOR RELEASE OPERATION

(Analysis based on 45-year Inflow Data)

Note: End-of-month stage curves are for system diversion of 600 mgd and the proposed release level.

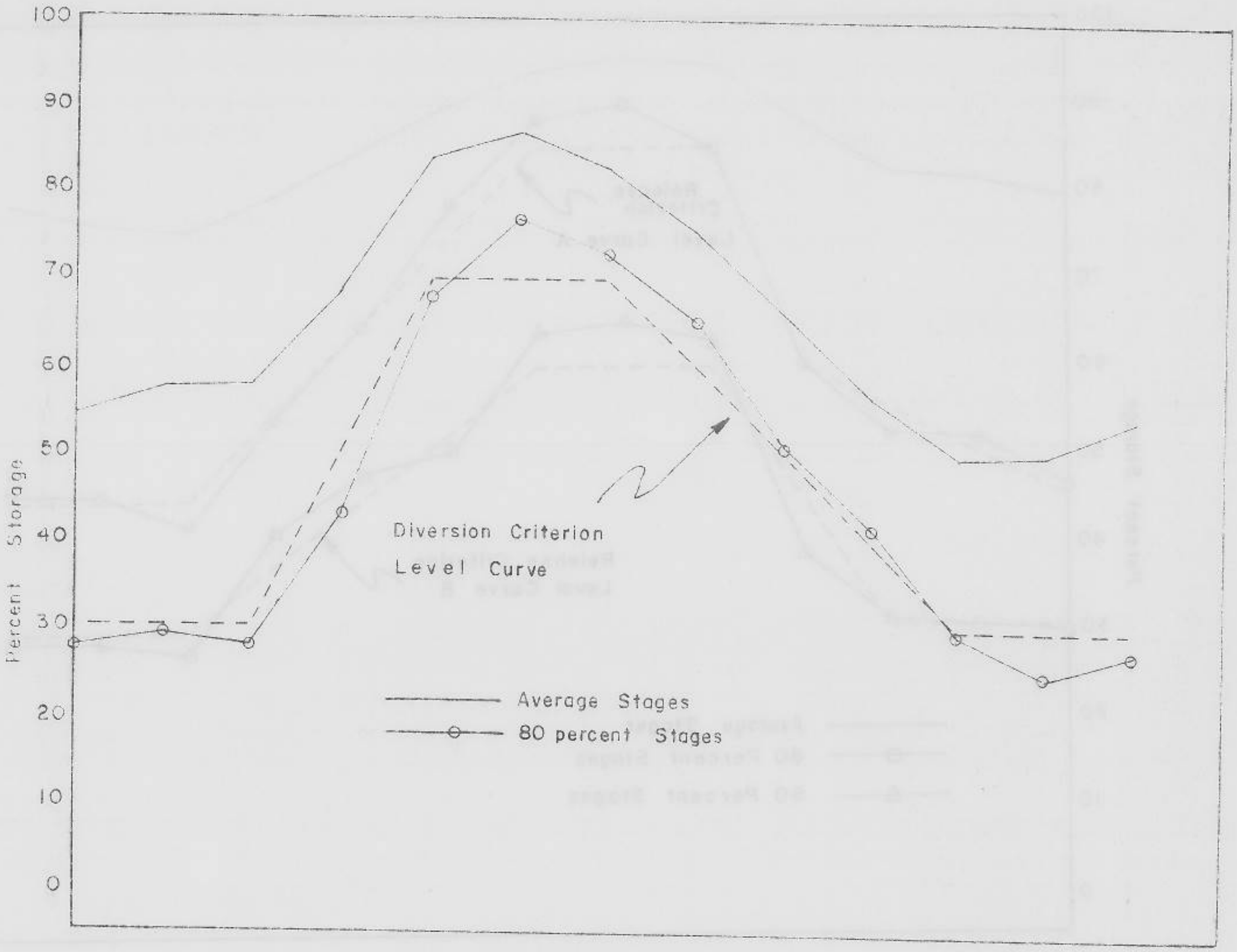

FIG. V-10

CRITERION- LEVEL CURVES FOR DIVERSION OPERATION

(Analysis based on 45-year Inflow data)

Note: End-of-month stage curves are for system diversion of 800 mgd and the existing release levels

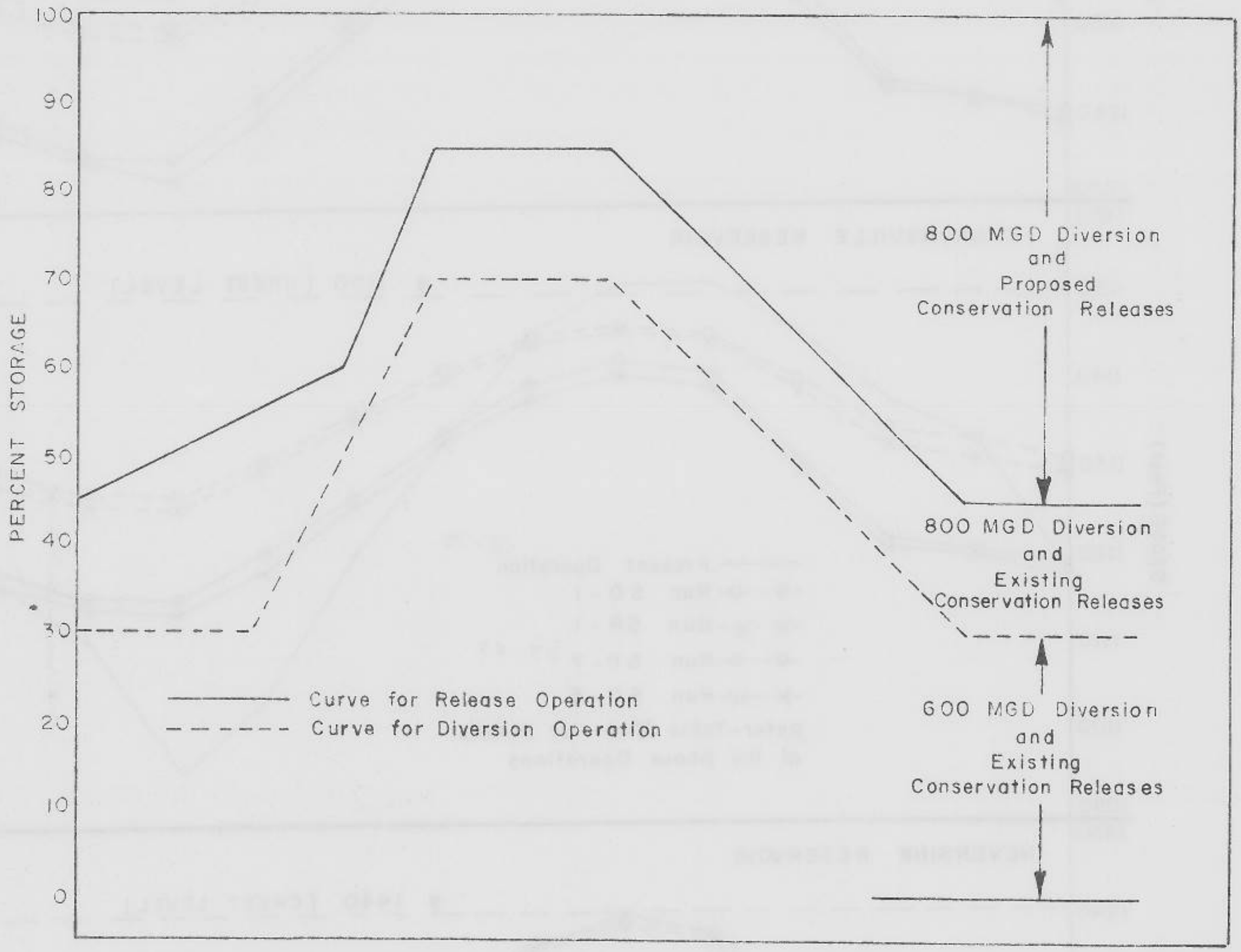

FIG. V-11

CRITERION-LEVEL CURVES

FOR DIVERSION AND RELEASE OPERATIONS

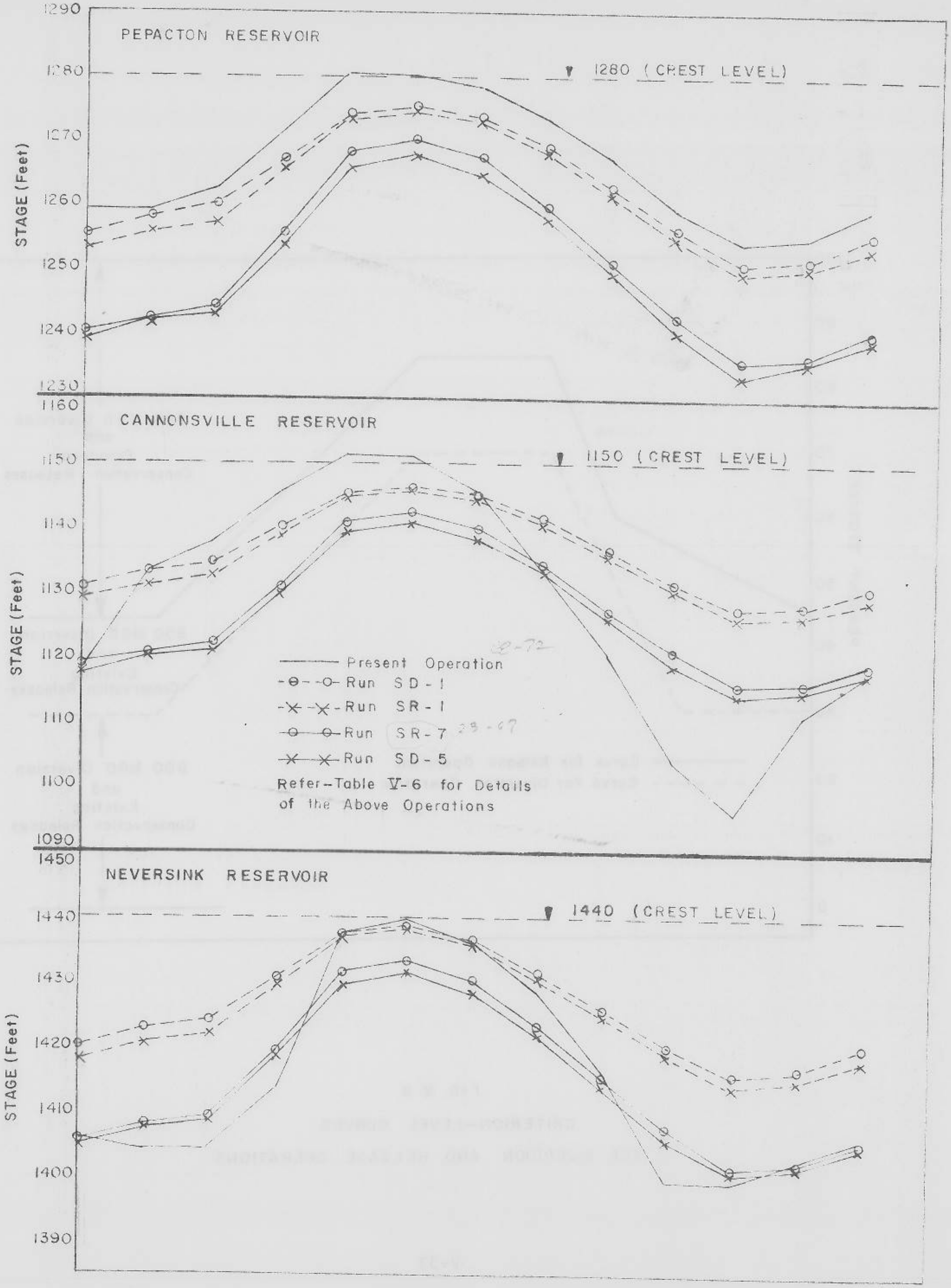

FIG. V-12
COMPARISON OF PERTINENT BASIC OPERATION SCHEMES

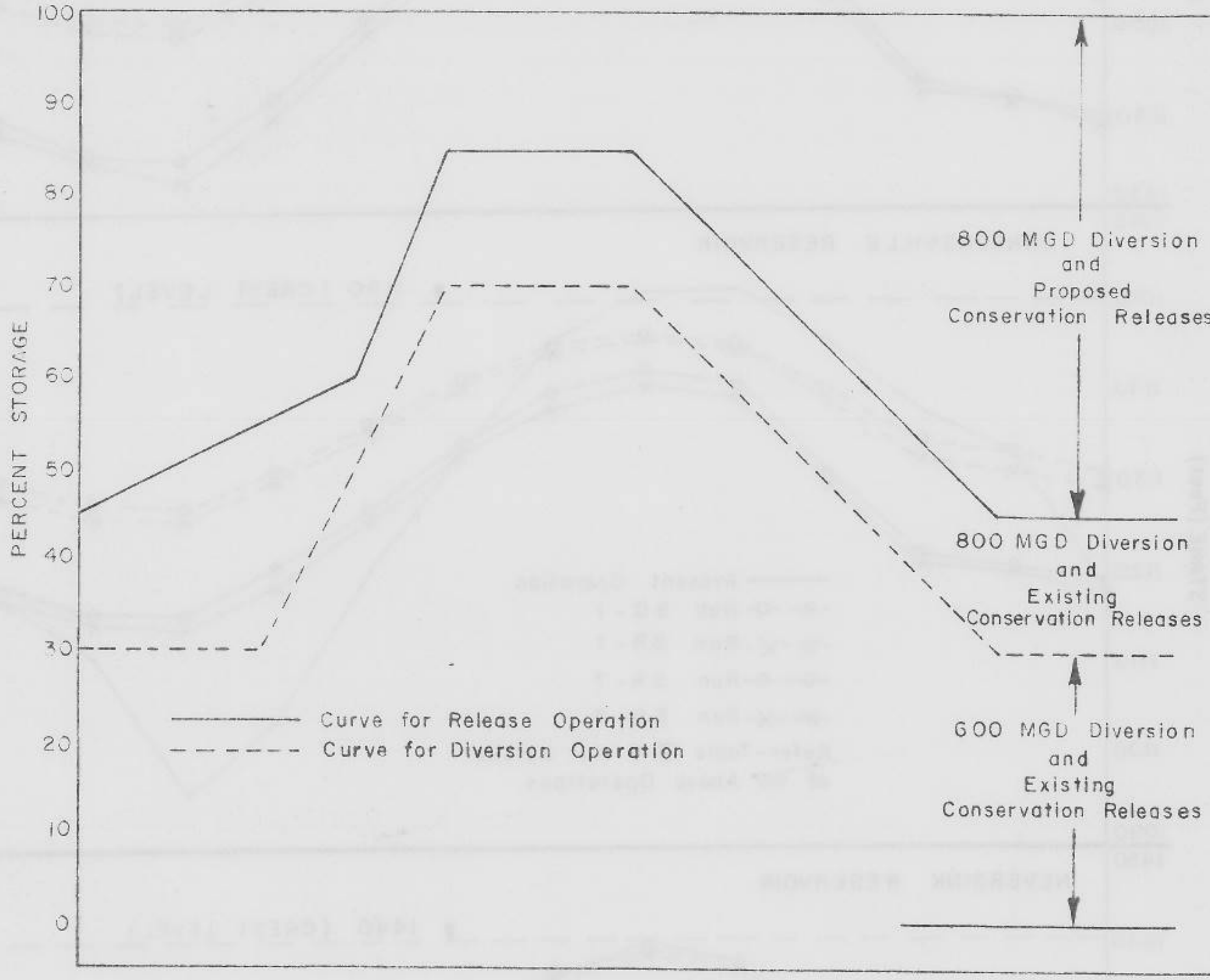

FIG. V-11

CRITERION-LEVEL CURVES

FOR DIVERSION AND RELEASE OPERATIONS

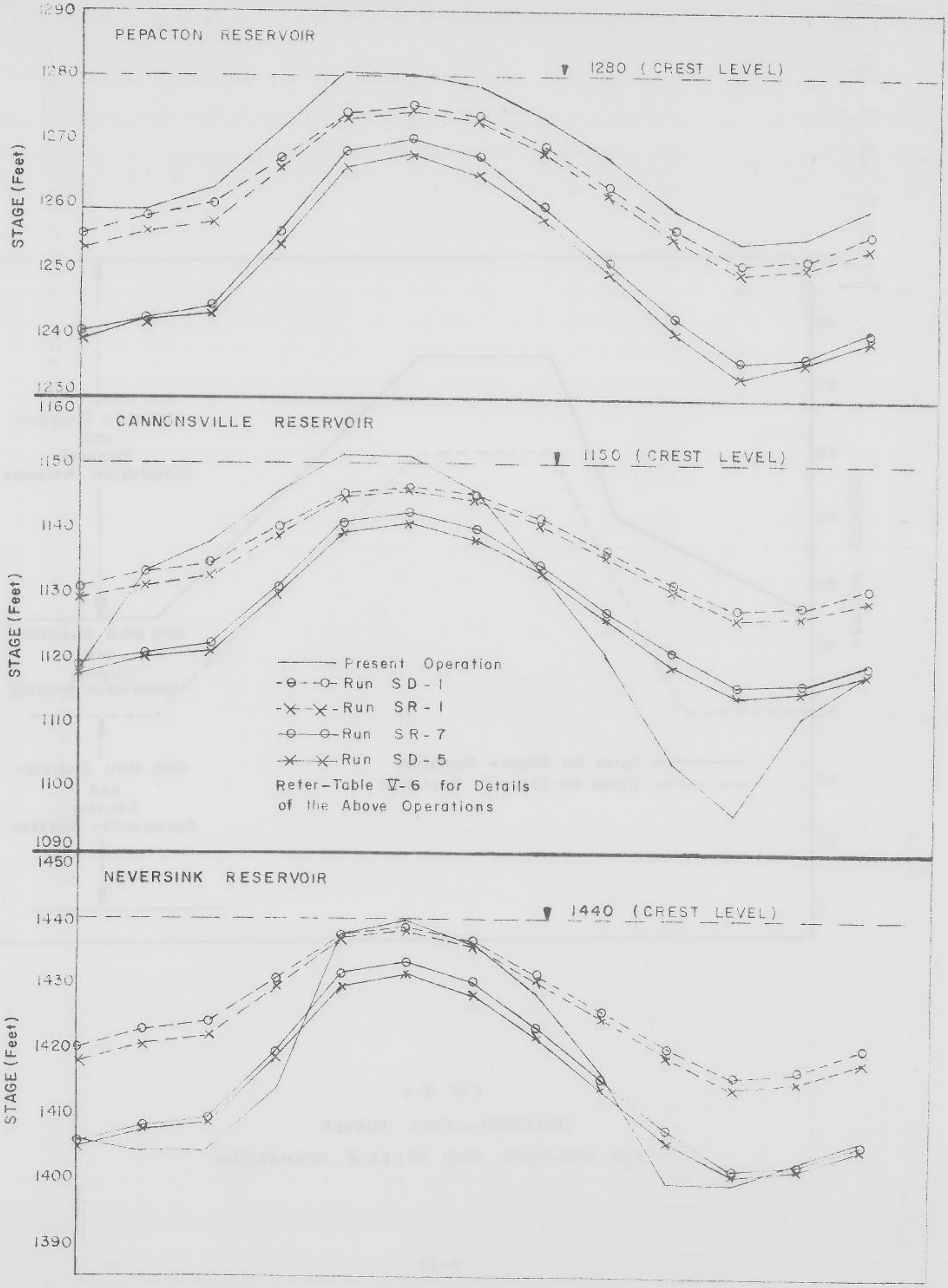

FIG. V-12

COMPARISON OF PERTINENT BASIC OPERATION SCHEMES

CHAPTER VI

ADDITIONAL SYSTEM OPERATION STUDIES

Introduction

This chapter presents the results of system operation studies made to examine the capability of the system to satisfy several additional downstream demands besides the existing diversion and release requirements which were considered in Chapter V. This Chapter considers the following aspects:

-- Meeting the excess release requirement at Montague, New Jersey during normal years

-- Reducing the flow requirement at Montague, New Jersey during extreme drought years

-- Providing flushing releases in the spring for beneficial scouring

-- Providing additional one-day flushing releases in July and August

-- Providing flood control storage in the City reservoirs below their crest levels

-- Providing adequate flows for canoeing

-- Meeting streamflow needs for fishing

-- Stream temperature analysis

Meeting the Mandatory Excess Release Requirement at Montague

The basic system operation includes meeting the minimum flow requirement of 1,750 cfs at Montague as specified by the 1954 Amended U.S. Supreme Court Decree besides meeting the primary and secondary diversion and release requirements. The Decree also prescribed that a higher level of flow should be maintained at Montague during the seasonal period (June 15 to March 15). The actual amount, which has decreased from 2,650 cfs in 1970 to 2,270 cfs now, is based on an excess release formula which considers the City's overall safe yield without pumping and their estimated consumption. Excess releases are directed by the River Master when necessary to meet the increased flow requirement during the seasonal period.

Simulation runs were made to satisfy the increased seasonal flow requirement of 2,250 cfs at Montague. The results are compared with the earlier runs satisfying only the minimum flow requirement of

1,750 cfs at Montague as follows:

A. Variable Diversion Scheme

Diversion to the City = 600 mgd (928 cfs)

Flow requirements at Montague	Shortage Index	Shortage Years
1,750 cfs	0 (0.037)	0 (3)
2,250 cfs	0.33 (0.61)	3 (5)

Note: Values in parentheses correspond to the operation at proposed conservation release levels and the others to the operation at existing conservation release levels.

B. Flexible Diversion Scheme

Diversions to the City are subdivided into 600 mgd primary diversion and 200 mgd secondary diversion. Also, conservation releases are subdivided into primary releases at the existing level and secondary releases at rates equal to the difference between the proposed and existing levels. The operations of the system are according to the criterion-level curves for release and diversion operations shown in Fig. V-11.

Flow Requirement at Montague	Primary Shortage Index	Shortage Years: Primary Diversion	Shortage Years: Primary Release
1,750 cfs	0.053	2	3
2,250 cfs (1,750 cfs primary plus 500 cfs secondary)	0.056	2	3

Meeting the increased flow requirement at Montague of 2,250 cfs has minimum effect on system operation with the flexible diversion scheme compared to system operation with the variable diversion scheme. Both schemes resulted in shortages for increased release requirements, but following the criterion level curves, reductions in releases and diversions are made to avoid extreme shortages.

Reducing the flow requirement at Montague below the minimum specified by the 1954 Amended U.S. Supreme Court Decree

The release requirement of 1,750 cfs at Montague, specified by the Decree, could not be met during the 60's drought and was waived by the Delaware River Basin Commission and the River Master. Similar flow reductions could be made in the future during extreme drought years.

A simulation run was made using the drought-criterion-level curves of the flexible operation scheme for making the primary and secondary diversion and release operations. Besides the conservation releases, the release requirement of 1,750 cfs at Montague was divided into a primary release of 1,500 cfs and a secondary release of 250 cfs. The results are compared with a previous run in which the release requirement at Montague was fixed at 1,750 cfs. No primary diversion (600 mgd) shortage occurred for this run whereas two primary diversion shortage years had occurred in the previous run. Shortages in meeting the Montague requirement remain at a minimum with one primary release shortage year recorded instead of three primary release shortage years recorded in the previous analysis. The shortage index decreased from 0.053 for the previous run to 0.005 for this run.

Simulation runs were made with the reduced flow requirement of 1,500 cfs at Montague as follows to determine the increase in safe system yield with such revision:

(i) Runs made with the present conservation releases:

NYC Diversion	Shortage Index
600 mgd	0
700 mgd	0
750 mgd	0.038
800 mgd	0.103

(ii) Runs made with the proposed conservation releases

NYC Diversion	Shortage Index
600 mgd	0
700 mgd	0.069
800 mgd	0.604

The safe system yield is found to be about 720 mgd compared to the safe yield of 600 mgd computed from the previous runs based on meeting the present minimum flow requirement of 1,750 cfs at Montague. The reduction of 250 cfs (161 mgd) in release requirement thus corresponds to an increase of only about 186 cfs (120 mgd) in the safe system yield.

Summarizing, reducing the flow requirements at Montague below the minimum specified 1,750 cfs to 1,500 cfs would improve the system performance under extreme drought conditions. During the 60's drought, primary diversion shortages are avoided and the primary release shortage is reduced.

Providing Flushing Releases in Spring

There is a need for an annual one-day flushing flow of 1,000 cfs for the purpose of beneficial scouring in the West and East Branches of the Delaware River. There is also a need for such annual one-day flushing flows of 500 cfs for the purpose of beneficial scouring in the Neversink River. Such needs would be met in most years by reservoir spills during the early spring run-off period. During the years when these needs are not satisfied by the natural runoff by May 15, providing the flushing releases from the reservoirs does not affect the basic system operation if the proposed flexible operation scheme is employed.

Providing Additional Flushing Releases in July and August

The Upper Delaware River Regional Water Resources Planning Board suggested that additional one-day flushing releases in July and August may be desirable to abate the additional pollution caused by the seasonal population. One day flushing releases in July and August at rates of 1,000 cfs in the West and East Branches of the Delaware River and 500 cfs in the Neversink River were examined meeting the 600 mgd diversion demand and the proposed conservation releases with the system operated according to the drought-criterion-level curves. The flushing release operation increases shortages at Montague with the 1,750 cfs flow requirement by about 10 percent. The above shortages are eliminated when the flow requirement at Montague is considered as 1,500 cfs primary flow and 250 cfs secondary flow, and the releases are made according to the drought-criterion-level curves. It may be concluded that the above flushing releases do not affect the basic system operation if the operations are made following the proposed flexible scheme.

However, the release of such large one-day flushing flows of cold reservoir water in July and August, would cause undesirable temperature fluctuations which would be detrimental to the fish. Also, the proposed releases are sufficient to maintain water quality standards in the streams. The additional one-day flushing releases in July and August are not considered necessary.

Providing Flood Control Storage in the City Reservoirs below their present Spillway Crest Levels

The aspect of using the City reservoirs for flood control was also considered. One approach is to provide flood control storage above their spillway crest levels by suitable structural modifications. However, in this study, the feasibility of providing flood control storage in the City reservoirs below their spillway crest levels only was examined. Simulation runs were made meeting the 600 mgd diversions demand, the 1,750 cfs flow requirement at Montague, and the conservation releases using the variable diversion scheme. The results of analyses for various flood control storages are compared below:

A. Present Conservation Release Levels:

Flood Control Storage	Shortage Index	Shortage Years	Remarks
0	0	0	
2	0.00076	1	Release shortage
4	0.00318	1	Release shortage

B. Proposed Conservation Release Levels:

Flood Control Storage	Shortage Index	Shortage Years	Remarks
0	0.038	3	No diversion but 3 release shortages
2	0.0385	3	No diversion but 3 release shortages
4	0.042	3	1 diversion shortage and 3 release shortages

All the above shortages occurred only during the 60's drought which is further evidence of the severity of the recent drought. It may be concluded that no significant increase in system shortage would result from providing the flood control operation.

However, a preliminary examination of the flooding situations shows that very little flooding occurs below the City reservoirs. Flooding in the Basin is mainly along the tributaries. Provision of flood control storage in the City reservoirs is not justified unless further detailed study reveals that significant flood damage does occur in areas which can be controlled by the City reservoirs.

Providing Adequate Flows for Canoeing

Providing adequate releases for canoeing is considered during nondrought periods when the reservoir stages are above the levels defined by the criterion-level curve for release operations shown in Figure V-11. During periods of low reservoir stages, releases of flows for canoeing are curtailed. The desirable flows for canoeing in the different streams are detailed in Chapter III. Three schemes for providing the releases for canoeing were examined based on average flow conditions for the period 1968 through 1970. Table VI-1 presents the minimum desirable streamflows for canoeing and corresponding release requirements from the City reservoirs for the three schemes examined. In this study, canoeing releases were included in the secondary release operation of the basic system operations discussed in the earlier section. The results are compared with previous runs of the basic system operations which do not consider the canoeing flows.

Scheme I examined the possibility of providing the minimum streamflows for canoeing in the Neversink River, East Branch Delaware River, West Branch Delaware River and Delaware River desired by the American Canoe Association and some of the local livery owners during the period April 1 through June 14, and on weekends only in the Delaware River during the period June 15 through August 31. Continuous releases during April and May in the range of 460 and 200 cfs to maintain flows of about 810 cfs in the West Branch Delaware River at Hale Eddy gage and 500 cfs in the Neversink River at Oakland Valley gage, respectively, for the purpose of providing canoeing are not totally acceptable because such high flows create poor fishing conditions. Also, high weekend flows followed by possible reductions to the proposed minimum conservation releases would create unstable thermal effects which are not desirable.

The results of operation studies indicate significant increases in the system operation deficiency. The primary shortage index increases by 15 percent. Frequency of shortages for the secondary releases and diversion operations increase from 27 to 35 years and 14 to 19 years, respectively, out of the 45 years studied. Average reservoir stages are also lowered by two to five feet.

Scheme II examined the possibility of maintaining an average flow of 1,000 cfs in the Delaware River at the Callicoon gage during the period April 1 through October 31. Such a flow at the Callicoon gage would assure that the canoeing requirement on the Delaware River at Port Jervis gage as specified by the American Canoe Association (1850 cfs) is met.

The results of operation studies indicate a slight increase in the system operation deficiency. There is no increase in the primary shortage index and the frequency of shortage occurrence. Average reservoir stages are lowered by less than one foot during the fall low stage months.

Scheme III examined the possibility of maintaining an average flow of 2,000 cfs during the period April 1 through May 31, and on weekends only during the period June 1 through October 31 in the Delaware River at the Callicoon gage for canoeing.

This scheme also involves high weekend flows followed by possible reductions to the proposed minimum conservation releases and consequent unstable thermal effects which are not desirable. The results of operation studies indicate a slight increase in the primary shortage index by about four percent and shortage occurrence by one year. Average reservoir stages are lowered by two to three feet during the fall low stage months.

Of the above three schemes examined based on average flow conditions for the period 1968 through 1970, which had relatively above normal rainfall, it can be concluded that the system is not capable of meeting the requirements of Schemes I and III. It can meet the requirements of Scheme II (maintaining an average flow of 1,000 cfs at the Callicoon gage for the period April 1 through October 31) without significant effect on the system operation only during nondrought years when the reservoir stages are above the levels defined by the criterion-level curve for release operations shown in Fig. V-11.

Meeting Streamflow Needs for Fishing

A minimum year-round flow of 1,000 cfs in the Delaware River at the Callicoon gage is desirable to maintain a suitable environment for fish and wildlife. Such a flow at the Callicoon gage would inject a measure of stability into the system thus encouraging establishment of a coldwater fishery from Hancock to Callicoon and a warmwater fishery from Narrowsburg to Port Jervis. A mixed warm and coldwater fishery would result between Callicoon and Narrowsburg.

The above requirement has been examined to a limited extent as Scheme II under the previous section. The analysis was based on part of the year and on average flow conditions for the period 1968 through 1970, which had relatively above normal rainfall. It is sufficient to indicate that the system is capable of maintaining an average flow of 1,000 cfs in the Delaware River at the Callicoon gage during the period April 1 through October 31 during nondrought periods. The fishery requirement in the Delaware River should be made part of the basic system operation and be built into the criterion-level curves for release operations when they are refined.

Stream Temperature Analysis

The problems associated with the present release operations of the City Reservoirs are discussed in the earlier chapters. The streamflows fluctuate widely from minimum conservation releases to high flows, when excess releases are directed to be made. Consequently the stream temperatures vary over a wide range which affects the fishery resources. The 1954 Amended U. S. Supreme Court Decree specified that a higher level of flow above the minimum basic flow of 1,750 cfs should be maintained at Montague during the seasonal period (June 15 to March 15). Sometimes the river warms up excessively (27°C and higher) before June 15. Under such conditions, release of cold water flows to meet the increased flow requirements at Montague causes undesirable temperature reversals. It was suggested by staff of the Division of Fish and Wildlife that excess releases from the reservoirs should occur no later than May 15-June 1 so as to maintain a preferred riverine temperature regime. This is presently contrary to the Supreme Court Decree. They also desire that temperatures in the East Branch Delaware River at Fishs Eddy should not be less than 13°C (May 15-June 15) and in the Delaware River at Callicoon should not exceed 24°C.

The effects of the present releases from the City Reservoirs on the temperatures in the streams below were reported by a USGS Study (11) as follows:

- releases of about 740 cfs from Pepacton in August 1966 lowered the water temperature at Fishs Eddy by as much as 11°C

-- releases of about 800 cfs from Cannonsville in June 1966 lowered the water temperature at Hale Eddy by as much as 14.5°C and

-- the above two releases lowered the water temperatures at Callicoon respectively by about 3°C and 2°C.

An analysis of temperatures in the streams below Pepacton and Cannonsville Reservoirswas conducted based on streamflow and temperature records for the period 1968 through 1971. The objectives of the study were to examine (i) the effect of reservoir releases on downstream temperatures during the summer months (ii) the possibility of using colder reservoir releases to reduce high temperatures in the streams below, and (iii) the desirable reservoir release patterns.

Since March 1967 when Cannonsville became operational, the releases from Neversink and Pepacton have been curtailed greatly while large releases have been made from Cannonsville. During the summer months of July and August, 1968-1971, the average daily water temperature in the East Branch Delaware River at Fishs Eddy varied from 20° to 29°C when the releases from Pepacton were at the minimum (about 19 cfs). Releases of more than 100 cfs (up to 500 cfs) were recorded for less than 20 percent of the time during which a reduction of about 0.7°C per 100 cfs increase in release was noted. Temperatures above 25°C did not occur when the releases were of the order of the proposed conservation release of 70 cfs from Pepacton. Temperatures below 13°C at Fishs Eddy occur rarely under the present operating policy since such low temperatures are associated only with large releases from Pepacton. During the two summer months of the period 1968 through 1971 examined, the average daily water temperatures in the West Branch Delaware River at Stilesville varied from 5°C to 20°C with the lower temperature range (5°C to 10°C) generally associated with significant releases from Cannonsville. The average stream temperatures downstream at Hale Eddy, varying from 8°C to 25°C, were seen to be directly related to the water temperatures at Stilesville and thus correlated to the Cannonsville releases. About 15 percent of the time releases from Cannonsville were below 100 cfs, and more than 55 percent of the time the releases were above 1,000 cfs. During the transitional period, when the releases vary from the minimum level to significant flow, temperature changes of more than 8°C in two days were observed. The reduction of temperature for each 100 cfs release from Cannonsville Reservoir was computed as about 0.3°C, compared to 0.7°C computed for each 100 cfs release from Pepacton Reservoir. Based on the relative level of releases being made, the Cannonsville rate of temperature reduction may be applied for larger flow releases and the Pepacton rate of temperature reduction may be applied for smaller flow releases.

The type of existing reservoir outlet structure permits only the release of cold water from the lower strata of the reservoir. When large volumes of such coldwater are released from the reservoirs into the streams below, the average water temperature and its daily variation will both be reduced because of the increased heat requirements. For the same reason, the water temperature changes are smaller for increased and continuous reservoir releases. According to the present operation policy, Cannonsville Reservoir is mostly used to meet the flow requirements at Montague. Undesirable changes in stream temperature of as much as 10°C within a short period of time, were recorded in the West Branch and Delaware River. To avoid such drastic changes in temperature, an effort should be made to release the excess flows from Cannonsville Reservoir more uniformly throughout the entire day.

The average stream temperatures at Callicoon ranged from 14°C to 26°C during the summer months of the period examined, 1968 through 1971. The average stream temperatures of about 22°C were generally associated with low combined releases of less than 400 cfs from Cannonsville and Pepacton Reservoirs. The proposed releases from both reservoirs amount to only 195 cfs. Hence, the expected average stream temperatures at Callicoon would be above 22°C. The stream temperature variation, in general, directly follows the air temperature variation. At points farther downstream the effect of reservoir releases on the water temperature is insignificant.

The results of multiple regression analysis using concurrent time records are summarized in Table VI-2. The time lag factor was found to be insignificant. The equations presented in the above Table could be used to estimate water temperatures in the streams below Cannonsville and Pepacton Reservoir.

It may be concluded that the proposed higher conservation releases would prevent the water in the streams below the City reservoirs from becoming excessively warm as compared to the present situation with low conservation releases. This would limit the wide changes in stream temperatures. The proposed conservation release of 70 cfs from Pepacton would prevent temperatures at Fishs Eddy on the East Branch Delaware River from exceeding 25°C. Temperatures below 13°C at Fishs Eddy are of rare occurrence under the present operating policy.

TABLE VI-1

Reservoir Release Requirements for Canoeing Use

Scheme	Desirable Streamflows for Canoeing	Corresponding Release Requirements at Control Points
I*	Neversink River - 500 cfs at Oakland Valley Gage #1-4370	Neversink - 200 cfs (April-May), 125 cfs (June) 50 cfs (other months)
	East Branch - 1570 cfs at Harvard Gage #1-4175	Pepacton - 70 cfs (year-round)
	West Branch - 810 cfs at Hale Eddy, Gage #1-4265	Cannonsville - 460 cfs (April-May), 293 cfs (June), 125 cfs (other months)
	Big Delaware River - 1910 cfs at Callicoon, Gage #1-4274 2520 cfs at Barryville Gage #1-4285 1850 cfs at Port Jervis Gage #1-4340	Montague - 4500 cfs (April), 5720 cfs (May) 3130 cfs (June), 2230 cfs (July) 2190 cfs (August), 1750 cfs (other months)
II*	Average flow of 1000 cfs at Callicoon Gage #1-4274, during the period April through October	Pepacton - 70 cfs (year-round) Cannonsville - 410 cfs (August), 380 cfs (September), 125 cfs (other months)
III*	Average flow of 2000 cfs at Callicoon Gage #1-4274, during the period April through May and on weekends only during the period June through October	Pepacton - 70 cfs (year-round) Cannonsville - 220 cfs (June), 374 cfs (July) 468 cfs (August) 460 cfs (September), 383 cfs (October), 125 cfs (other months)

* The schemes are detailed in the text

TABLE VI-2

Water Temperature and Streamflow Relations

Location	Estimation Equation	
Hale Eddy Gage #1-4265	$T_{4265} = 7.31 + 0.743\ T_{4250} - 2.50 \times 10^{-3}\ Q_{4250} + 0.66 \times 10^{-3}\ Q_{4265}$	(for July)
	$T_{4265} = 6.13 + 1.07\ T_{4250} - 0.47 \times 10^{-3}\ Q_{4250} - 3.0 \times 10^{-3}\ Q_{4265}$	(for August)
Fishs Eddy Gage #1-4210	$T_{4210} = 23.2 - 0.52 \times 10^{-2}\ Q_{4170} - 0.05 \times 10^{-2}\ Q_{4210}$	(for July)
	$T_{4210} = 23.7 - 1.32 \times 10^{-2}\ Q_{4170} - 0.35 \times 10^{-2}\ Q_{4210}$	(for August)
Calicoon Gage #1-4274	$T_{4274} = 5.79 + 0.412\ T_{4265} + 0.558\ T_{4210} - 0.114\ T_{4250} - 0.61 \times 10^{-3}\ Q_{4250} - 0.048 \times 10^{-3}\ Q_{4265} + 1.12 \times 10^{-3}\ Q_{4210} + 3.53 \times 10^{-3}\ Q_{4170} - 1.40 \times 10^{-3}\ Q_{4274}$	(for July)
	$T_{4274} = 12.3 + 0.306\ T_{4265} + 0.382\ T_{4210} - 0.280\ T_{4250} - 1.73 \times 10^{-3}\ Q_{4250} + 2.73 \times 10^{-3}\ Q_{4265} + 3.39 \times 10^{-3}\ Q_{4210} + 5.74 \times 10^{-3}\ Q_{4170} - 2.77 \times 10^{-3}\ Q_{4274}$	(for August)

Note: Subindices refer to U.S. Geological Survey station numbers as - #1-4170 (Downsville), 1-4210 (Fishs Eddy), $1-4250 (Stilesville), #1-4265 (Hale Eddy), $1-4274 (Callicoon).

Ranges of flows used in equation developments need to be specified, (applicable by the equation)

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GLOSSARY

As used within this report, the following words and terms shall have the meanings set forth below:

<u>basic diversion capability</u>

Diversion a reservoir or system can meet without any shortages while downstream releases are made at the specified level.

<u>BOD</u>

Biochemical oxygen demand

<u>cfs</u>

Cubic feet per second

<u>conservation</u>

Concept of management to prevent waste of natural resources

<u>conservation releases</u>

Low flows to be passed through the dams at all times to meet fish and wildlife and other environmental water needs

<u>constant diversion proportion</u>

The ratio of diversion from one reservoir to the total system diversion.

<u>constant diversion scheme</u>

Considers each reservoir diversion to the City as a constant fraction of the total diversion. By integrated system operation following the reservoir balancing rules, releases from each reservoir are varied but diversions from each reservoir are constant from one operation period to another.

<u>criterion-level curve</u>

Specifies the water levels at different periods to identify drought and non-drought period operations. When the reservoir stage is below the water level specified by the criterion-level curve, drought operations are undertaken. When the reservoir stage is above the water level specified by the curve, non-drought operations are undertaken.

<u>deviation</u>

Difference between an individual magnitude and the average for the frequency array.

diversion

The transfer of water from the City reservoirs to New York City for water supply use.

domestic water supply

Water provided for drinking, bathing, sanitary and other personal purposes.

drainage area

The area contained within a divide above a specified point on a stream.

drawdown

Difference between the end-of-September stage and spillway crest level.

drought

A period of deficient precipitation and runoff causing a reservoir to remain below a specified normal level, such as defined by the criterion-level curve.

ecology

The branch of biology dealing with the relationships between organisms and their environment.

effluent

Waste discharge, treated or untreated, into a stream.

exceedence frequency

The percentage of values that exceed a specific magnitude.

exceedence probability

Probability that an event selected at random will exceed a specific magnitude.

flexible diversion scheme

Integrated system operation following the balancing rules and criterion-level curves. Reduced diversion or release or both are considered during drought periods and increased diversion and releases are considered during non-drought periods.

flood

A temporary rise in streamflow or stage which results in inundation of the areas adjacent to the channel.

frequency curve

Graphical representation of a frequency distribution, usually with the abscissa as magnitude and the ordinate as relative frequency.

gaging station

A particular site on a stream, canal, lake or reservoir where systematic observations of water level or discharge are obtained continuously or periodically.

industrial water supply

Water used by industrial and commercial establishments.

level numbers

Numbers associated with various target levels of a reservoir.

mgd

Millions of gallons per day.

need

A condition requiring relief.

NOD

Nitrogenous oxygen demand.

objective

Result or achievement desired. More general than goals.

pollution

The introduction of substances or properties into waters of the basin which impair the uses.

reach

A term to describe the linear segments of a stream or river; e.g., stream reach or river reach.

regulation

The artificial manipulation of reservoirs.

reservoir

A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

reservoir balancing rules

Specify each reservoir's relative priority to provide water for release and diversion based on maintaining the water level in each reservoir at an equal percentage of its own total storage. The rule is expressed in terms of "level number" vs. storage relations.

reservoir capability

The maximum rate at which a reservoir will provide water under a stipulated set of conditions such as a given shortage probability, operation rule, etc.

runoff

That part of precipitation that appears in surface streams.

shortage index

Reflects the magnitude of shortage as well as the number of shortages and is defined as the sum of squares of ratios of annual shortage to annual demand within a 100-year period.

simulation model

A mathmatical model which duplicates all the important features of system operation.

single reservoir operation study

Examines the yield capability of each individual reservoir subject to constant conservation release and water supply diversion requirements.

stage

The height of water surface above an established datum plane.

standard deviation

Root mean - square deviation

system

A collection of reservoirs, river intakes, water activity locations, etc., with interconnection by rivers, aquaducts, etc.

system operation study

Examines the system yield by integrated operation of the three reservoirs as a system following the reservoir balancing rules. Because of varying inflows and the requirement to maintain relative water levels in each reservoir according to the set of operating rules, varying releases and diversions may result from each of the reservoirs to satisfy the flow requirements at Montague and the total water supply diversion.

system yield

The total sum of water supply diversions to the City from the three reservoirs in the system. The maximum system yield without shortages is the system safe yield.

UOD

Ultimate oxygen demand.

useable capacity

Capacity of a reservoir between spillway crest level and minimum operating level.

variable diversion scheme

By integrated systems operation following the reservoir balancing rules both the releases and diversions from each reservoir are varied from one operation period to another but total diversion and releases are satisfied.

water quality

The characteristics of water as determined by any given combination of chemical, physical and biological properties.

yield

The quantity of water which can be obtained from a source in a specified period of time.