WATER RESOURCES STUDY
FOR
POWER SYSTEMS

DELAWARE RIVER BASIN

MARCH 1972

TIPPETTS-ABBETT-McCARTHY-STRATTON
ENGINEERS AND ARCHITECTS
NEW YORK

WATER RESOURCES STUDY
FOR
POWER SYSTEMS

DELAWARE RIVER BASIN

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PREPARED FOR

Atlantic City Electric Company • Baltimore Gas and Electric Company • Delmarva Power & Light Company
Jersey Central Power & Light Company • Metropolitan Edison Company • New Jersey Power & Light Company
Orange and Rockland Utilities, Inc. • Pennsylvania Electric Company • Pennsylvania Power & Light Company
Philadelphia Electric Company • Public Service Electric and Gas Company

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SUMMARY AND CONCLUSIONS

Flow to the Delaware Estuary

If the drought of the 60's were to recur when non-power and power consumptive uses in the Delaware River Basin have grown to levels projected in this study for 1986:

a. Fresh water flow to the estuary would exceed the Delaware River Basin Commission (DRBC) flow goal of 3000 cubic feet second (cfs)1/ by about ten percent, and

b. DRBC salinity limits would not be exceeded.

The foregoing assumes that all DRBC Comprehensive Plan reservoirs are in operation and that the minimum discharge of 1750 cfs at Montague required by the Supreme Court Decree is maintained. Minimum diversions for New York City water supply would be about 60 percent of the amount authorized by the Supreme Court Decree.

Estimated Future Consumptive Uses.

Total consumptive use of surface water in the entire basin, including out-of-basin diversions to New Jersey, but excluding power generation requirements, are estimated to increase from 394 million gallons per day (mgd) 1/ in 1970, to 820 mgd in 1986, to 1048 mgd in 2020. Total increases in consumptive use for power generation in 1986 have been projected in this study to be 212 mgd above Trenton and 151 mgd below.

Additional Sources of Water Supply

Twenty-one possible reservoirs for additional future water supply in the Delaware River Basin were identified as promising. Operation of the proper combination of selected projects during a recurrence of the drought

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1/ Conversion factors: 1 cfs per day equals 0.646 mgd ; 1 mgd equals 1.547 cfs per day.

of the 60's could provide an additional 680 cfs at Trenton and an additional 280 cfs in the Schuylkill River. These amounts would be in addition to the yield of the DRBC reservoir system, operating with a minimum flow of 1750 at Montague.

Ground water is not considered a significant source of future water supply for power generating stations except as a possible emergency standby source at certain locations for use during short periods of extreme drought.

Section I

INTRODUCTION

A. Authorization

This study was prepared under the terms of an agreement between a group of 11 power companies located in and adjacent to the Delaware River Basin and Tippetts-Abbett-McCarthy-Stratton (TAMS), Engineers and Architects. The 11 power companies are:

Atlantic City Electric Company
Baltimore Gas and Electric Company
Delmarva Power & Light Company
Jersey Central Power & Light Company (GPU) 1/
Metropolitan Edison Company (GPU) 1/
New Jersey Power & Light Company (GPU) 1/
Orange and Rockland Utilities, Inc.
Pennsylvania Electric Company (GPU) 1/
Pennsylvania Power & Light Company
Philadelphia Electric Company
Public Service Electric and Gas Company

The study was performed under the guidance of a Steering Committee composed of representatives of each company. The Delaware River Basin Commission was represented on this Committee.

The agreement is based upon TAMS' proposal dated January 15, 1971. Authorization to proceed was given on January 28, 1971.

B. Purpose

The purpose of this study is to determine the water available for future use including that for thermal power generation plants in the Delaware River Basin. This involves an inventory of the surface and ground water resources within the study area, the assessment of present utilization of these resources, analyses and projection of non-power water needs to the year

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1/ Subsidiaries of General Public Utilities Corporation, a registered holding company under the Holding Company Act.

2020 and for thermal power to the year 1986, and exploration of additional new sources of water.

C. Scope

This study includes (1) review, analysis and revision, as necessary, of the results of previous studies relative to present and future water demands and availability within the basin and (2) identification of sites for possible development of future sources of water to meet the basin demands, including those for future proposed power generating stations.

D. Acknowledgements

The assistance of the members of the Steering Committee, the DRBC staff and the U.S. Army Corps of Engineers in providing information for the preparation of this report is gratefully acknowledged.

Section II

PHYSICAL AND CLIMATIC CHARACTERISTICS OF BASIN

A. Description of Basin and Tributaries

The Delaware River rises in the Catskill Mountains in New York State about 35 miles southwest of Albany. The river basin has a length of about 265 miles between the headwaters and the mouth at the entrance of Delaware Bay at the Atlantic Ocean. The width of the basin varies from about 40 to 80 miles. The basin is bounded on the north and west by the Susquehanna River Basin and by many small drainage basins in the State of Delaware and on the east by the lower part of the Hudson River Basin, the Passaic and Raritan River Basins and other small basins in New Jersey.

The Delaware River drains portions of the States of New York, Pennsylvania, New Jersey, Delaware and Maryland. The drainage area within each state is given in Table II-1 and a map of the basin, with sub-basins denoted, is shown on Plate II-1.

TABLE II-1

DELAWARE RIVER BASIN AREA BY STATES

State	Area (sq.miles)
New York	2,362
Pennsylvania	6,422
New Jersey	2,969
Delaware	1,004
Maryland	8
Total	12,765

The West and East Branches of the Delaware River originate as small springs and seeps on the western slopes of the Catskill Mountains in New York at altitudes of about 2,500 to 3,000 feet and flow southwesterly about 50 miles to form the main stem of the Delaware River at Hancock, New York. From this point southeastward to Port Jervis, New York, the river forms the boundary between Pennsylvania and New York. Between Hancock and Port Jervis, the principal tributaries are the Lackawaxen and Mongaup Rivers. At Port Jervis the Delaware turns abruptly to the southwest and is joined by the Neversink River. The river south of Port Jervis is the boundary between New Jersey and Pennsylvania.

At Stroudsburg, Pennsylvania, the river turns sharply to the southeast and cuts through the Blue Mountain - Kittatinny Mountain ridge at the Delaware Water Gap. Above the Gap it is joined by such tributaries as Bushkill and Brodhead Creek on the Pennsylvania side, and Flat Brook on the New Jersey side. The Lehigh River enters the Delaware from the west at Easton, Pennsylvania. The drainage from the east is collected by such streams in New Jersey as Paulins Kill, Beaver Brook and the Pequest and Musconetcong Rivers.

Below Trenton, the Delaware River is joined by the Schuylkill River from the west at Philadelphia and by the Christina River at Wilmington, Delaware. At the latter point the river turns seaward and flows to Liston Point where it enters Delaware Bay and finally reaches the ocean between Capes May and Henlopen.

The principal tributaries are indicated on Table II-2.

B. Drainage Area Subdivisions

The Delaware River Basin Commission (DRBC) has divided the basin into twelve sub-basins. These sub-basins correspond with important points on the Delaware River or isolate major tributaries. These same sub-basins are shown on Plate II-1 and have been utilized in the present studies.

TABLE II-2

DELAWARE RIVER BASIN

PRINCIPAL TRIBUTARIES AND THEIR DRAINAGE AREAS 1/

Tributary	Drainage Area (sq. mi)	Tributary	Drainage Area (sq. mi)
W. Br. Delaware R.	664.0	Crosswicks Creek	139.0
E. Br. Delaware R.	840.0	Neshaminy Creek	233.0
Beaver Kill	298.0	Rancocas Creek	342.0
Willowemoc Creek	130.0	Schuylkill River	1,909.0
Callicoon Creek	112.0	Little Schuylkill R.	137.0
Lackawaxen River	601.0	Maiden Creek	216.0
Wallenpaupack Creek	240.0	Tulpehocken Creek	218.0
Shohola Creek	84.1	French Creek	71.0
Mongaup River	208.0	Perkiomen Creek	362.0
Neversink River	346.0	Skippack Creek	55.2
Bush Kill	156.0	Wissahickon Creek	63.8
Flat Brook	65.7	Christina River	568.0
Brodhead Creek	287.0	White Clay Creek	162.0
McMichaels Creek	111.0	W. Br. Brandywine Cr.	131.0
Paulins Kill	177.0	(head of Brandywine Cr.)	
Pequest River	158.0	Brandywine Creek	329.0
Lehigh River	1,364.0	E. Br. Brandywine Cr.	123.0
Pohopoco Creek	111.0	Salem Creek	112.0
Aquashicola Creek	79.4		
Little Lehigh Creek	188.0	Delaware Bay tributaries	
Jordan Creek	81.0	Cohansey River	106.0
Musconetcong River	158.0	Maurice River	388.0
Tohickon Creek	112.0	Mispillion River	126.0
		Delaware River Basin, including the area draining into Delaware Bay 2/	12,765.0

1/ Data taken from House Document No. 522, 87th Congress.

2/ Total does not include approximately 782 square miles of water surface area of Delaware Bay.

TABLE II-3

SUB-BASINS OF THE DELAWARE RIVER BASIN

Sub-Basin No.	Description of Sub-Basin	Drainage Area (sq. mi.)
1	Delaware River drainage area above Port Jervis, N.Y. (including Neversink River drainage area).	3,422
2	Delaware River drainage area between Port Jervis, N.Y., and Riegelsville, N.J. (excluding Lehigh River drainage area).	1,542
3	Lehigh River drainage area.	1,364
4	Delaware River drainage area between Riegelsville, N.J., and Trenton, N.J. (Calhoun Street Bridge).	452
5	Delaware River drainage area in Pa. between Morrisville, Pa., (Calhoun Street Bridge) and Pa.-Del. boundary at Marcus Hook, Pa. (excluding Schuylkill River drainage area above Fairmount Dam).	678
6	Schuylkill River drainage area above Fairmount Dam.	1,893
7	Delaware River drainage area in N.J. between Trenton, N.J. (Calhoun Street Bridge) and N.J. -Del. boundary at Nortonville, N.J. (opposite Marcus Hook).	1,019
8	Delaware River drainage area in Pa. and Del. between Pa.-Del. boundary at Marcus Hook, Pa., and mouth of Christina River (including Christina River drainage area).	591
9	Delaware River drainage area in N.J. between N.J.-Del. boundary at Nortonville, N.J. (opposite Marcus Hook), and mouth of Delaware River at Hope Creek Monument (opposite-Liston Point).	257
10	Delaware River drainage area in Del. between mouth of Christina River and mouth of Delaware River at Liston Point.	166
11	Delaware Bay drainage area in N.J. between mouth of Delaware River at Hope Creek Monument (opposite Liston Point) and Cape May.	769
12	Delaware Bay drainage area in Del. between mouth of Delaware River at Liston Point and Cape Henlopen.	612
	TOTAL - DELAWARE RIVER BASIN	12,765

The twelve sub-basins are briefly described in Table II-3.

C. Climatology and Hydrology

1. Temperature. The basin climate is largely influenced by continental air masses. Summers are affected by warm air moving from the south and southeast which occasionally causes summer droughts while the winters are characterized by cool arctic air which moves south from Canada. The average basin temperature is about 51°F. Table II-4 lists the monthly temperature extremes for selected U.S. Weather Bureau Stations within the basin.

2. Precipitation. Precipitation averages about 44 inches over the basin and varies within about 10 percent of this average except in the headwaters of the Neversink River Basin where the average increases to about 60 inches. Precipitation from month to month is normally well distributed throughout the year. Monthly precipitation in the summer is slightly higher than in the winter. Showers and thunderstorms produce most of the summer rainfall. Storms of both continental and coastal origins account for much of the precipitation in the cooler months. The heaviest and most intensive rains and winds usually result from storms of tropical origin. Table II-5 summarizes the mean, maximum and minimum monthly and annual precipitation at selected stations within the basin for available periods of record. Snowfall varies from an average of about 15 inches per year in the bay area to about 70 inches per year in the mountains of the headwater area.

3. Runoff. The runoff from that part of the basin above Trenton has averaged 23.1 inches or 1.70 cubic feet per second per square mile of drainage area (based on 1914-70 runoff records, adjusted for storage and diversion). The mean monthly runoffs for the period were as follows:

TABLE II-4

MONTHLY MAXIMUM, MINIMUM, AND MEAN AMBIENT AIR TEMPERATURES
FOR SELECTED STATIONS IN THE DELAWARE RIVER BASIN IN DEGREES FAHRENHEIT

Station	Period of Record		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Port Jervis	1901-70	Max.	35.1	36.4	46.6	60.5	72.3	80.5	85.5	82.2	75.6	64.4	50.0	37.7
	1901-70	Min.	17.6	17.4	25.8	35.9	46.2	54.8	58.3	57.9	51.3	40.0	30.7	21.1
	1895-1970	Mean	25.8	26.8	35.8	48.0	59.2	67.7	72.1	69.9	63.2	52.1	40.3	29.2
Trenton	1893-1970	Max.	39.7	40.7	49.5	61.0	72.0	80.5	84.8	82.5	76.3	65.8	54.1	42.6
		Min.	25.3	24.9	32.8	41.9	52.0	61.0	66.4	64.7	58.1	47.6	38.4	28.6
		Mean	32.3	32.5	41.2	51.5	62.0	70.8	75.6	73.6	67.2	56.7	46.3	35.6
Philadelphia	1874-1970	Max.	40.0	41.1	49.8	61.4	72.5	81.1	85.3	82.9	76.9	66.0	53.7	42.8
		Min.	26.0	26.3	33.3	42.9	53.4	62.5	67.9	66.2	59.8	48.8	38.6	29.2
		Mean	33.0	33.7	41.6	52.2	63.0	71.8	76.6	74.6	68.4	57.4	46.2	36.0
Wilmington	1895-1970	Max.	40.3	41.2	51.2	62.7	73.4	81.7	85.6	83.6	77.6	66.6	54.2	42.6
		Min.	24.7	24.8	32.4	41.7	51.9	60.0	66.2	64.5	58.0	46.8	36.9	27.3
		Mean	32.5	33.0	41.8	52.2	62.7	71.3	75.9	74.1	67.8	56.7	45.6	35.0

TABLE II-5

MONTHLY MAXIMUM, MINIMUM AND MEAN PRECIPITATION IN INCHES
FOR SELECTED STATIONS IN THE DELAWARE RIVER BASIN

Station	Period of Record	Length of Record (Yrs.)		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Wilmington	1931-70	40	Max.	7.45	5.90	6.87	6.47	7.35	8.37	9.94	12.09	9.53	6.21	7.32	7.90	61.05
	1894-1970	77	Mean	3.28	3.08	3.71	3.51	3.46	3.72	4.58	4.80	3.63	2.97	3.21	3.42	43.37
	1931-70	40	Min.	0.59	1.47	0.81	1.12	0.22	0.44	0.16	1.12	0.45	0.21	0.78	0.19	24.90
Philadelphia	1931-70	40	Max.	6.44	6.12	7.43	6.58	6.93	10.06	7.99	9.84	8.78	5.24	7.45	7.23	51.37
	1874-1970	97	Mean	3.16	3.08	3.51	3.27	3.30	3.57	4.12	4.51	3.36	2.78	3.07	3.17	40.90
	1931-70	40	Min.	0.45	1.37	0.68	1.13	0.47	0.11	0.64	0.49	0.44	0.09	0.69	0.25	
Trenton	1931-70	40	Max.	6.00	5.56	7.53	5.93	8.03	9.00	10.19	14.10	10.49	6.77	7.53	6.86	50.19
	1865-1970	106	Mean	3.19	3.10	3.84	3.40	3.57	3.62	4.69	4.96	3.63	3.11	3.26	3.29	43.66
	1931-70	40	Min	0.52	1.15	1.17	0.83	0.25	0.06	0.37	0.47	0.19	0.05	0.75	0.19	28.79
Bethlehem	1931-70	40	Max.	6.22	5.54	6.36	8.20	9.68	9.98	11.97	12.02	10.80	7.85	7.09	5.90	54.95
	1931-70	40	Mean	2.80	2.58	3.55	3.40	3.55	3.26	4.43	4.30	3.45	2.77	3.40	3.32	40.77
	1931-70	40	Min.	0.65	0.66	1.25	0.85	0.77	0.17	0.22	0.69	0.21	0.06	0.69	0.25	26.62
Port Jervis	1931-70	40	Max.	5.50	4.85	7.93	9.10	8.76	8.62	11.35	18.04	8.43	9.60	7.45	6.93	56.90
	1884-1970	87	Mean	3.04	2.88	3.39	3 52	3.83	3.95	4.66	4.04	3.59	3.26	3.31	3.24	42.71
	1931-70	40	Min.	0.61	0.59	1.19	1.02	0.87	0.59	0.97	0.73	0.40	T	0.71	0.36	29.97

T = Trace

Month	Average Runoff above Trenton (inches)	(cfs/sq.mi.)
Jan.	2.04	1.77
Feb.	1.92	1.84
Mar.	3.74	3.24
Apr.	3.84	3.44
May	2.39	2.07
June	1.40	1.25
July	1.16	1.01
Aug.	1.02	0.88
Sept.	0.88	0.79
Oct.	0.95	0.82
Nov.	1.68	1.51
Dec.	2.11	1.83

Runoff is a minimum during the summer and early autumn under the combined effect of high evapo-transpiration and depleted ground-water storage. It increases slightly in the winter and is a maximum during the spring when the winter's accumulation of snow melts and enters the streams.

The areal distribution of the average annual runoff in the basin varies much more than the distribution of the annual precipitation. The area of high precipitation in the Catskill Mountains in the headwaters of the East Branch of the Delaware and Neversink Rivers produces average annual runoff depths up to 40 inches. The headwaters of the Lackawaxen, Lehigh and Schuylkill River Basins, in the divide between the Delaware and Susquehanna River Basins, have centers of high runoff with average annual depths of 27 to 29 inches. In the flatter terrain in the lower basin south of Easton, Pa., the average runoff is less than 20 inches, with a minimum of 14 inches in the bay area.

D. Droughts

1. Drought History. Prolonged droughts in the Delaware River

Basin, continuing for two or more years, have occurred on the average once in 10 years. The major droughts have been those in the years 1907-08, 1930-32, 1943-44, 1953-54, and 1961-66. Single years of low runoff, preceded and followed by years of adequate water supply, have occurred between the major drought periods, as in 1936, 1939, 1941 and 1957. The great droughts of record have not been equally severe over the entire drainage basin, and the times of beginning and ending have varied from one sub-basin to another.

In the humid northeastern States a drought may be classified generally as a period when the average runoff for one or more years falls below 65 percent of the long-term average. The runoff in single years may approach 50 percent or less of the average runoff, as in 1965.

2. Drought of the 1930's. In the period 1930-36 about two-thirds of the Eastern United States experienced an almost continuous period of drought. The disastrous experience in the Plains States (the "Dust Bowl") called nationwide attention to the drought. Although the Northeastern States suffered from severe water shortages, records in those States in the subsequent 35-40 years have revealed that the 1930 conditions were more a minimum in terms of the years of records then available than they were a one to two percent chance event. The allocations of water under the Supreme Court decree of 1954 were based on the assumption that the 1930's drought was a safe basis for determining dependable supplies. The average recurrence interval of the drought of the 1930's in the upper tributaries of the Delaware River Basin for 18-month and 30-month periods has been estimated by the USGS to be about 12 and 15 years, respectively. In the Beaver Kill Basin, for durations up to a year, the recurrence interval is only 5 years. Further south, in the Lackawaxen Basin, the indicated recurrence interval is 17 years, while in the Lehigh Basin the interval increases to about 30 years. On tributaries of the lower Delaware Basin, particularly in the Schuylkill Basin, the annual flow in 1931 appears to have been equal to that in 1966,

but 10 to 15 percent more than in 1965. Some minimums of record for short durations were recorded in 1930 and 1932 in the Schuylkill Basin. On the basis of annual flows the recurrence interval for the earlier drought on the tributaries is about 25 years, but on the main river the recurrence interval of the minimum year 1931-32 (see Plate II-3) appears to be between only 5 and 15 years. Some monthly flows in the main lower Delaware River, particularly in October 1930, appear to be equivalent to the low monthly flows in 1965, but the average annual flow at Trenton in the water year 1930-31 was 70 percent greater than in 1964-65 and 29 percent greater than in 1965-66.

3. Drought of the 1960's. The drought of the 1960's was outstanding for its widespread areal distribution in the Northeastern States and for its persistence in time. Deficient runoff began in the Delaware River Basin in August 1961, but the water-year ending September 1961 was near normal because of high runoff in the spring. Record low annual runoff began with the water-year ending September 1962 in a wide band of area extending from southern Maine across southeastern New York (including the upper Delaware River Basin) and on into northeastern Ohio. The drought continued into the water-years 1962-63 with cumulative effects producing new record short-duration minimums in the lower Delaware River in October 1963. Deficient precipitation and runoff continued in the water-years 1963-64 and 1964-65 with a continuous drop to new record lows in ground water levels and runoff. The lowest annual runoff occurred in the water-year 1964-65. There was some increase in average runoff in 1966 but the drought did not end finally until the calender year 1967. Pertinent low stream-flow data at selected gaging stations on the main Delaware River and its tributaries are given in Table II-6. The data show that the average natural flow for the water-year 1965 was only 40-50 percent of long-term average. On the main river below Montague, N.J., and in the Schuylkill River Basin the two year average for 1965-66 was still only about 50 percent of the average. In some

TABLE II-6

LOW-FLOW CHARACTERISTICS AT SELECTED DELAWARE RIVER BASIN GAGING STATIONS

U.S.G.S. Gaging Station	I-4720 Schuylkill River at Pottstown, Pa.	I-4635 Delaware River at Trenton, N.J.	I-4575 Delaware River at Riegelsville, N.J.	I-4385 Delaware River at Montague, N.J.	I-4530 Lehigh River at Bethlehem, Pa.	I-4510 Lehigh River at Walnutport, Pa.	I-4205 Beaver Kill at Cooks Fall, N.Y.
Drainage area (sq mi)	1147	6780	6328	3480	1279	889	241
Period of continuous record	1927-70	1913-70	1906-70	1939-70	1909-70	1946-70	1913-68
Minimum discharge (cfs) 1/ Date of occurrence	87 Aug. 13,'30	1180 Oct. 31,'63	1150 2/ Oct. 30, '63	382 Aug. 24,'54	125 June 28,'65	57 July 27,'65	16 Nov. 22,'64
Minimum daily discharge (cfs) 1/ Date of occurrence	175 Sept. 19,'32	1240 July 10,'65	1370 Oct. 29,'63 July 3-4,'65	412 Aug. 23,'54	255 Sept. 27,'64	134 Sept. 18,'64	23 Sept., 25,'64
Minimum 7-day discharge (cfs) 1/ Date of occurrence	211 Sept. 17-23,'32	1371 July 4-10,'65	1439 June 29 - July 5,'65	565 July 1-7, '65	267 July 23-29,'65	144 Sept. 16-22,'64	26 Oct. 21-27,'64
Minimum monthly discharge (cfs) 1/ Date of occurrence	256 Sept. '32	1548 July, '65	1530 Oct., '31	715 Aug, '54	334 Sept., '64	179 Sept. '64	31 Oct., '64
Mean 1964 3/ discharge (cfs) 1/	1543	8175 (9042) 5/	8003 (8724) 5/	4139 (4860) 5/	1841	1355	398
Mean 1965 3/ discharge (cfs) 1/	843 4/	4708 (5447) 5/	4625 (5222) 5/	2309 (2906) 5/	1165	859	277
Mean 1966 3/ discharge (cfs) 1/	980	6277 (7419) 5/	6227 (7217) 5/	3185 (4175) 5/	1576	1196	410
1964-65 2-year average discharge (cfs) 1/	1193	6442 (7244) 5/	6314 (6973) 5/	3224 (3883) 5/	1503	1107	338
1965-66 2-year average discharge (cfs) 1/	912	5492 (6433) 5/	5426 (6220) 5/	2747 (3540) 5/	1370	1028	344
Long-term average discharge (cfs) 1/ 6/	1791	11,360 (11,500) 5/	10,380	5715	2225	1716	543
Years of record (yrs)	44	58	63	31	63	24	54

1/ All discharges are based on USGS observed data, unadjusted for storage or diversion, except as noted by parentheses.
2/ Minimum of 870 cfs, Sept. 20, 1908, does not include flow of Musconetcong River.
3/ Water year, Oct. to Sept.
4/ Mean 1930, 921 cfs.
5/ Recorded flow adjusted for storage changes and diversions.
6/ Based on period of record.

tributary basins the average runoffs for a continuous period of five years were as low as 55 percent of the long-term average.

4. Frequency of the Drought of the 1960's. No broad general statement can be made regarding the frequency (recurrence interval) of flows in the drought of the 1960's. As mentioned above two facts stand out in appraising both the severity and the frequency, namely, the widespread distribution and the long duration. The short duration minimums, up to a period of a month or more, have occurred at least once in the last 70 years in parts of the basin in the 1930's or possibly in other isolated dry years. This is indicated in Tables II-6 and II-7 which shows the recurrence intervals for 30, 60, 90-days durations for two representative tributaries, and for the water-year 1964-65 for other selected tributaries. The locations of the tributary areas are shown on Plate II-2.

For longer durations of a year or more and for the main Delaware River, recurrence intervals for flows in the 1960's increase, except possibly in the Schuylkill Basin. In the Beaver Kill Basin in the headwaters in New York State the low water-year (1965) appears to have a 200-year recurrence interval. The U.S. Geological Survey has estimated a recurrence interval of 400 years for the drainage areas of the New York City reservoirs. Because of the large probable recurrence intervals of low flows on the main Delaware River and the short length of records relative to these intervals, estimates of return periods of the 1965 average flow vary widely. The 29-year flow record at Montague is not long enough for estimating a recurrence interval that may be five or more times the length of record. Low-flow frequency curves for discharges in terms of mean flow for main river stations are shown on Plate II-3 and the estimated recurrence intervals for the 1965 water-year at selected points are shown on Plate II-4. It is quite certain that the runoff in the driest year has a return period of at least 100 years and may increase to several hundred years in the lower reaches of the main river. The mean generalized frequency curve for the main stations shown on Plate II-3

TABLE II-7

RETURN PERIOD IN YEARS FOR FLOWS OF SELECTED DELAWARE RIVER TRIBUTARIES IN DROUGHT OF THE 1960's

Stream and Location	Sub-basin	USGS Gage No.	Drainage Area (sq.mi.)	Minimum Discharge (cfs)	Duration of Minimum Discharge (days)	Date	Approx. Return Period (years)
Beaver Kill at Cooks Falls, N.Y.	1	I-4205	241	31.3	30	Oct.'64	40
				31.6	60	Sept.-Oct.'64	50
				35.2	90	Sept.-Nov.'64	100
				277	365	1964-65	200
Wallenpaupack Crk. at Wilsonville, Pa.	1	I-4320	228	113	365	1964-65	120
Paulins Kill at Blairstown, N.J.	2		126	67.5	365	1964-65	80
Lehigh River at Bethlehem, Pa.	3	I-4520	1279	334	30	Sept.'64	50
				370	60	Aug.-Sept.'64	50
				394	90	Aug.-Oct.'64	60
				1165	365	1964-65	60
Perkiomen Crk. at Graterford, Pa.	6	I-4730	279	164	365	1964-65	40

indicates a recurrence interval of 330 years for the flow in the 1964-65 water year. The probable return period of the two-year average flow of 1965-66 cannot be estimated reliably but such flows probably approach the "minimum probable event" on the main river.

E. Ground Water

1. Ground Water Provinces. Ground-water recharge in the Delaware River Basin is almost entirely from precipitation and occurs mainly during the non-growing season.

The portion of ground water which lies above the level of streams can discharge into them by gravity. This discharge is a significant part of the streamflow in the Basin at all times (probably about 40 percent in an average year and about 60 percent in years of drought). During the growing season, or when precipitation is less than potential evapo-transpiration, much of the stream flow is derived from ground water. The contribution of ground water and its rate of discharge are such that in the complete absence of precipitation major streams like the Delaware probably would not run dry for many months.

In general ground water does not move as freely from one aquifer to another as it does within the aquifers. The hydrologic importance of this low rate of movement lies in the fact that it prevents the rapid discharge of waters in the ground-water reservoir and results in long-sustained ground-water discharge.

The ground-water aquifers in the Delaware Basin have been previously classified into five major categories[1] whose extent and location are shown on Plate II-5. The full capability of these aquifers is not known with any degree of precision, although it is known that those underlying the coastal plains of New Jersey and Delaware have a relatively large

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1/ Reference No. 123

potential.

The five major aquifers within the Basin are:

(1) Coastal Plain. The coastal plain part of the Basin is situated east and south of Trenton in the New Jersey portion of the Basin and in the coastal area of the State of Delaware. Well yields of 500 gallons per minute (gpm) are not uncommon and occasionally 2000 gpm or more is obtained from a single well. The lower yield aquifers are generally not extensively developed because of the widespread availability of aquifers that yield larger quantities to wells.

The major coastal-plain aquifers are not only highly productive, but they extend over wide areas. They can be tapped in many places beyond their areas of outcrop. In many places two or more aquifers can be tapped at different depths at the same place. The United States Geological Survey estimated[2/] (1964) that the withdrawal of ground water in the 1956-57 period was about 210 mgd. The Survey also estimated that this represented less than 7 percent of the natural recharge of water from precipitation, and that the potential ground-water supply in the Coastal Plain was several times that rate of ground-water withdrawal. On the basis of the USGS studies it has been assumed that a yield of about 600 mgd can be developed from the aquifers of the Coastal Plain.

(2) Crystalline Rocks. The crystalline rocks of various types cover extensive areas, mainly in southeastern Pennsylvania west of Trenton. They extend to great depths and yield water almost exclusively from cracks in otherwise dense rock masses or from weathered zones. Local recharge and water-table conditions generally prevail and low yields per well are the general rule.

2/ Reference No. 119

(3) Carbonate Rocks. Ground water is stored in and transmitted through solution channels, cracks and fissures in the carbonate rocks. Although this type of rock extends to great depths, yields are primarily from the top few hundred feet of their mass. The predominate mass of these rocks occur in the Lehigh and Schuylkill River Basins.

As the recharge in these aquifers occurs by percolation through the soil and by direct drainage into sink holes, they are not as dependent upon the condition of the soil as the other aquifers. During the growing season they often receive recharge from brief storms that do not eliminate the soil moisture deficiency so that recharge through the soil can occur. This ordinarily results in a more uniform rate of recharge to, and discharge from carbonate rocks than from other types of aquifers but only if the growing-season storms occur. Otherwise the discharge of carbonate aquifers may decline to very low levels. This was observed in the drought of the 1960's in the Northeast during a period when summer storms did not occur.

Water tends to move rapidly through the enlarged water bearing openings for considerable distances. In the absence of the filtering action of granular materials or thin cracks, contaminants may also move rapidly for considerable distances. The total storage in such aquifers may be significantly greater than in non-carbonate consolidated rocks. Wells that encounter major water-bearing cavities may yield very large quantities (1,000 gpm or more). On the other hand a well may encounter only small openings or none and have a very low yield.

(4) Sandstones and Shales. The sandstones and shales comprise the majority of the Basin area above Trenton and are generally reliable sources of small (up to 10 gpm) quantities of water which

are stored and carried primarily in cracks in the rocks. Based on well yields, the sandstones and shales fall into four main categories: the Triassic shales and sandstones, the Martinsburg shales, the Catskill and related formations, and a miscellaneous group of formations of relatively small individual areal extent. Reported yields of wells tapping the Triassic beds range from a few gallons per minute to as much as 500 gpm. Those from the Martinsburg generally do not exceed 75 gpm and those from the Catskill range from a few to more than 300 gpm with the majority in the lower ranges. The yields of wells tapping the remaining shales and sandstones vary widely from one formation to another and within formations, but are generally less than those of the Catskill.

(5) Glacial Outwash and Alluvium. The glacial outwash and alluvium are capable of yielding very large quantities of water to wells on a sustained basis in some places, particularly adjacent to streams or other bodies of surface water. Yields of 1000 gpm or more have been reported. The recharge that supports these yields is partly from precipitation on their outcrop, partly from adjacent rocks and, quite often, largely induced from adjacent bodies of surface water. Some areas of thick glacial outwash, because of their well-sorted granular nature, store significant quantities of water from precipitation and support the yield of wells without recharge from surface-water bodies. Unfortunately the overall extent of this type of aquifer within the basin is relatively small.

2. Potential for Emergency Use of Storage in Ground-Water Reservoirs. In the May 1970 report entitled "A Program for the Investigation and Management of Ground Water in the Delaware River Basin" prepared by Henry C. Barksdale, Consulting Ground-Water Hydrologist, for the

DRBC, it was recommended that a study be undertaken to "investigate potential for ground-water management to supplement low flows". This project, labelled S-2, was estimated to require a 5-year period of study at a cost of $500,000. In a 10-year program of projects assigned Priority A, Barksdale recommended this project for years 5-10, inclusive.

Using a limited amount of information at hand for this report, it has been possible to make some tentative estimates of the potential capacity and cost of works to provide an emergency ground-water source during periods of extremely low streamflow for one or more thermal-electric plants. An "emergency" system of ground-water pumping is suggested which would operate perhaps one year in 10, drawing water from accumulated ground-water storage and allowing a long time for such withdrawals to be replaced naturally.

The potential has been studied for 50 square miles of glacial deposits occurring in mile-wide valleys northeast of Port Jervis and northeast and southwest of Stroudsburg. The following design assumptions are taken from the USGS Professional Paper 381, "Water Resources of the Delaware River Basin", dated 1964, page 92:

Aquifer thickness	100 ft
Water yield	15% of aquifer volume
Withdrawal	20% of water yield

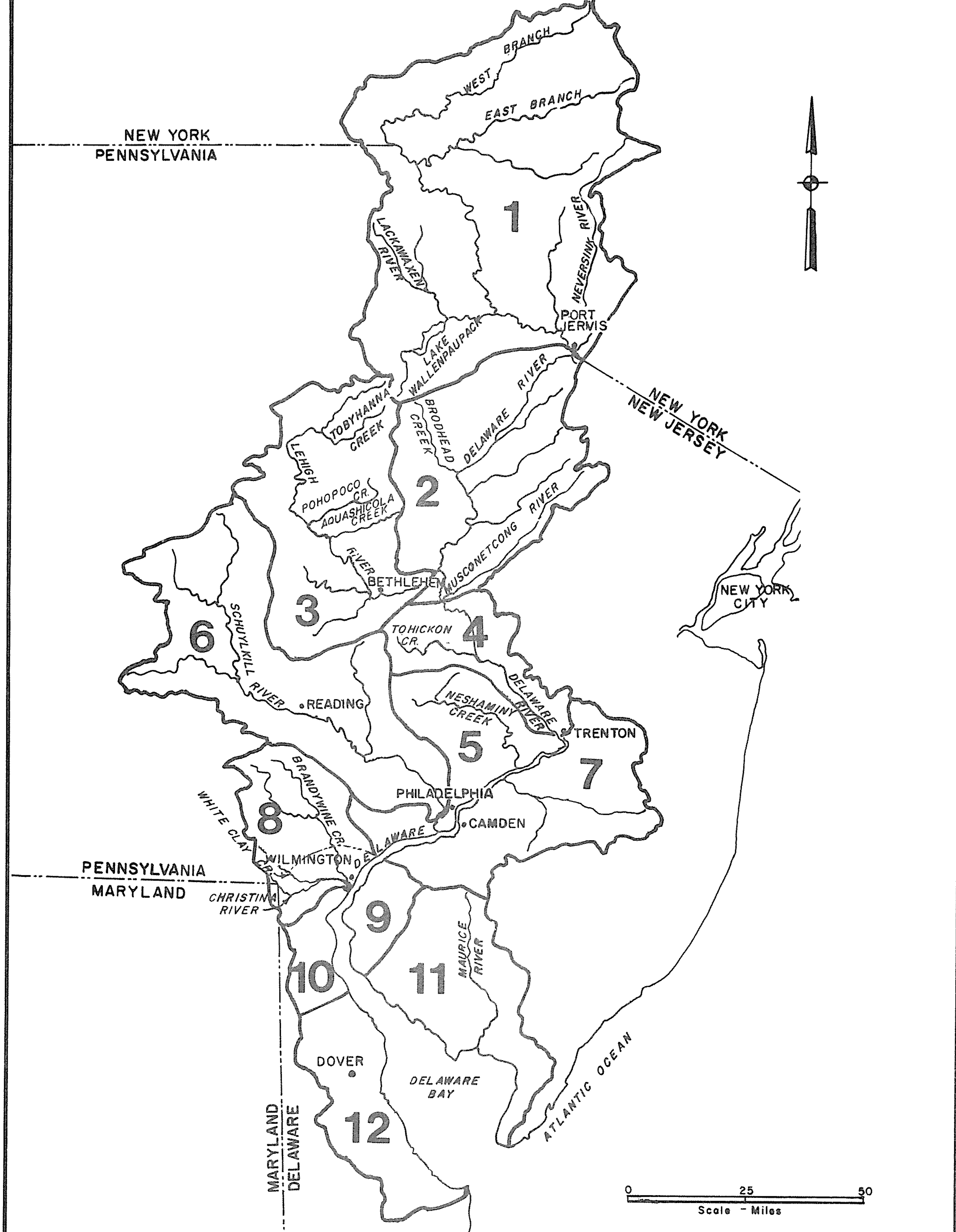
For 50 square miles, the volume of water withdrawn would be 4150 million cubic feet. If a 6-month low streamflow period is assumed, the withdrawal of this volume would be at the rate of 268 cfs. This water could be pumped into the Delaware River, and used either above or below the Tocks Island project under a management scheme coordinated with the operation of Tocks Island Reservoir. If as much as 268 cfs were withdrawn, over 10,000 MW of thermal power plant could be served.

The following preliminary design and cost estimate has been prepared for a net withdrawal rate of 25 cfs to serve a 1000 MW plant.

Fifty wells would be installed at 500 ft. spacing on lines 2000 ft from the stream. Wells would be connected to a common header and a gravity conduit would be provided for each four wells to the stream. Each 12-inch well would have a pumping capacity of 1000 gpm. Header diameter would be 12 inches and stream conduit diameter would be 15 inches. The total capacity of 50 wells would be over 100 cfs. Each well would be pumped for 30 days and would be idle for 30 days to permit recovery of drawdown. Thus 50 percent of the wells would be pumped at one time and also, each well during pumping would derive an average of 50 percent of its flow from the stream due to induced infiltration. The estimates of induced infiltration are based on unpublished work done by Paul R. Seaber of the USGS in studies for the Susquehanna River Basin near Binghamton.

Cost of pumping installations have been estimated using data in the paper by E.F. Hollyday and P.R. Seaber entitled "Estimating Cost of Ground Water Withdrawal for River Basin Planning", Journal of National Well Water Association, Vol. 6, No.4, 1968, and in an unpublished paper dated 23 August 1966 of the Harrisburg office of the USGS. Cost of pumping installations have been updated to 1971 and cost of piping arrangements have also been added.

Initial costs for a net flow augmentation of 25 cfs including 25 percent for contingencies, engineering, and administration would be about $2,300,000. Annual costs including capital charges, operation and maintenance, and power would be about $300,000, or $0.30 per Kw per year. Even if such costs were found by further investigation to be much higher than indicated above, they could be seriously considered.



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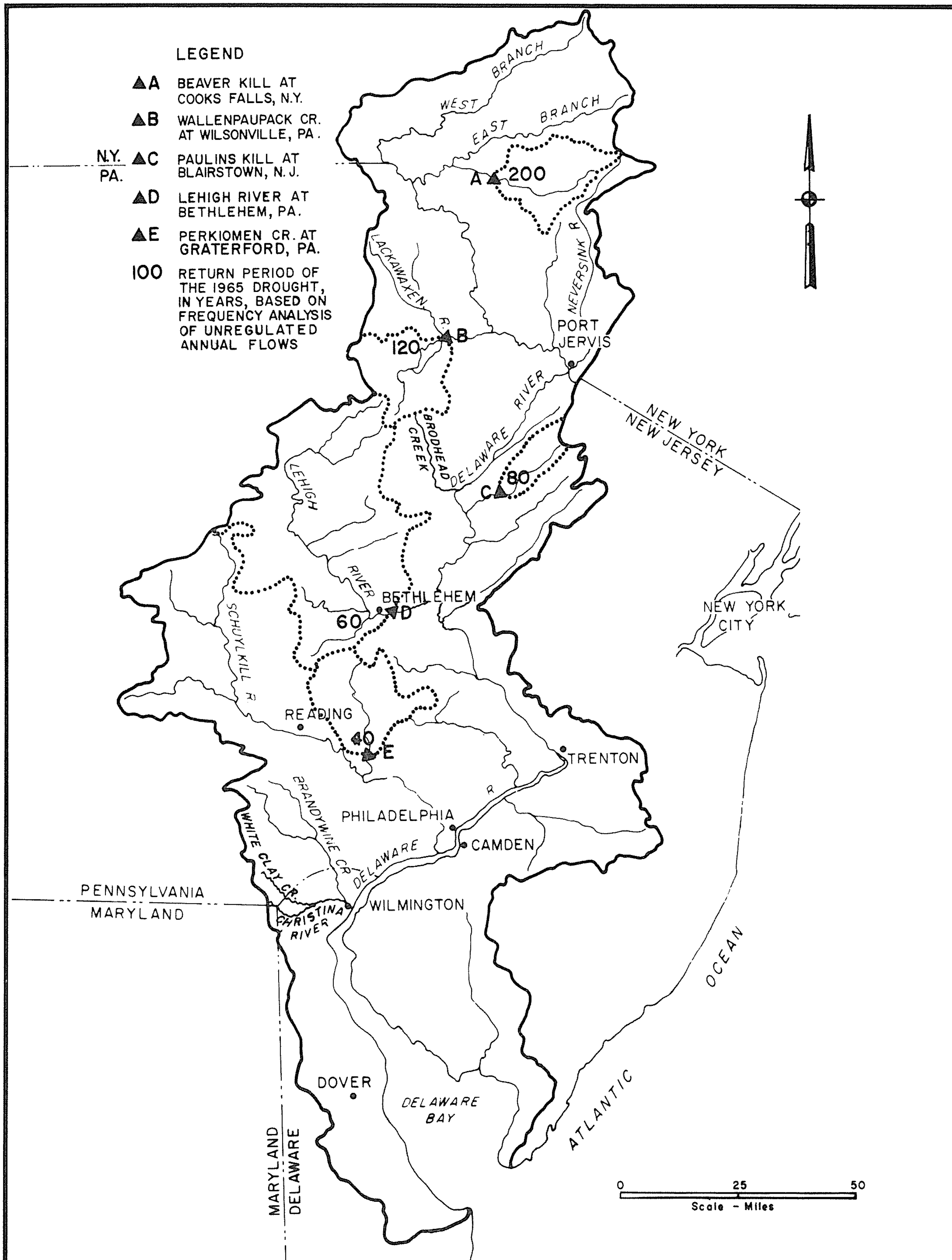
WATER RESOURCES STUDY
DELAWARE RIVER BASIN
SUB-BASINS

PLATE II-1



WATER RESOURCES STUDY

DELAWARE RIVER BASIN

FREQUENCY OF 1965 DROUGHT FOR SELECTED TRIBUTARIES

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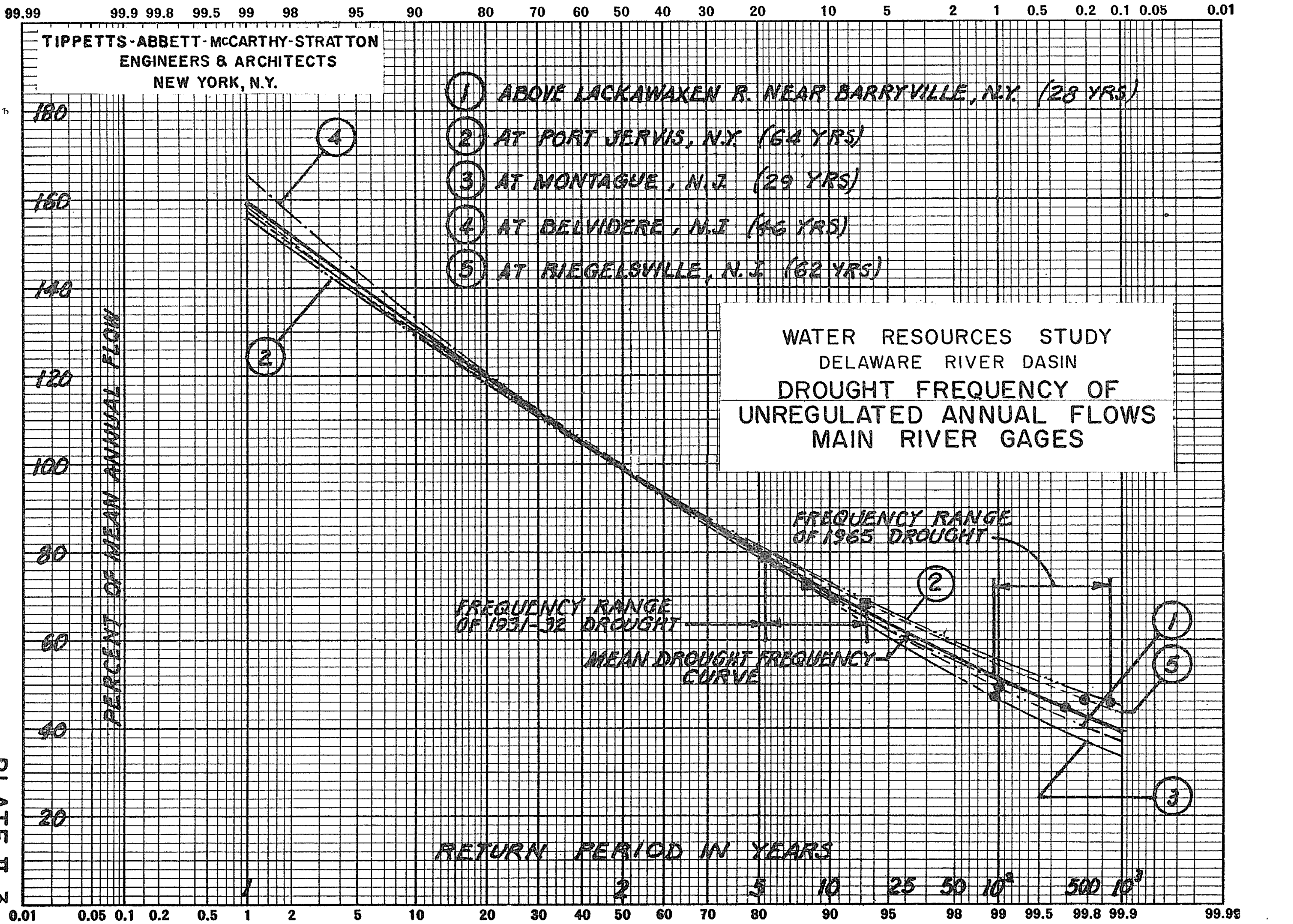
PLATE II-2


TIPPETTS-ABBETT-McCARTHY-STRATTON
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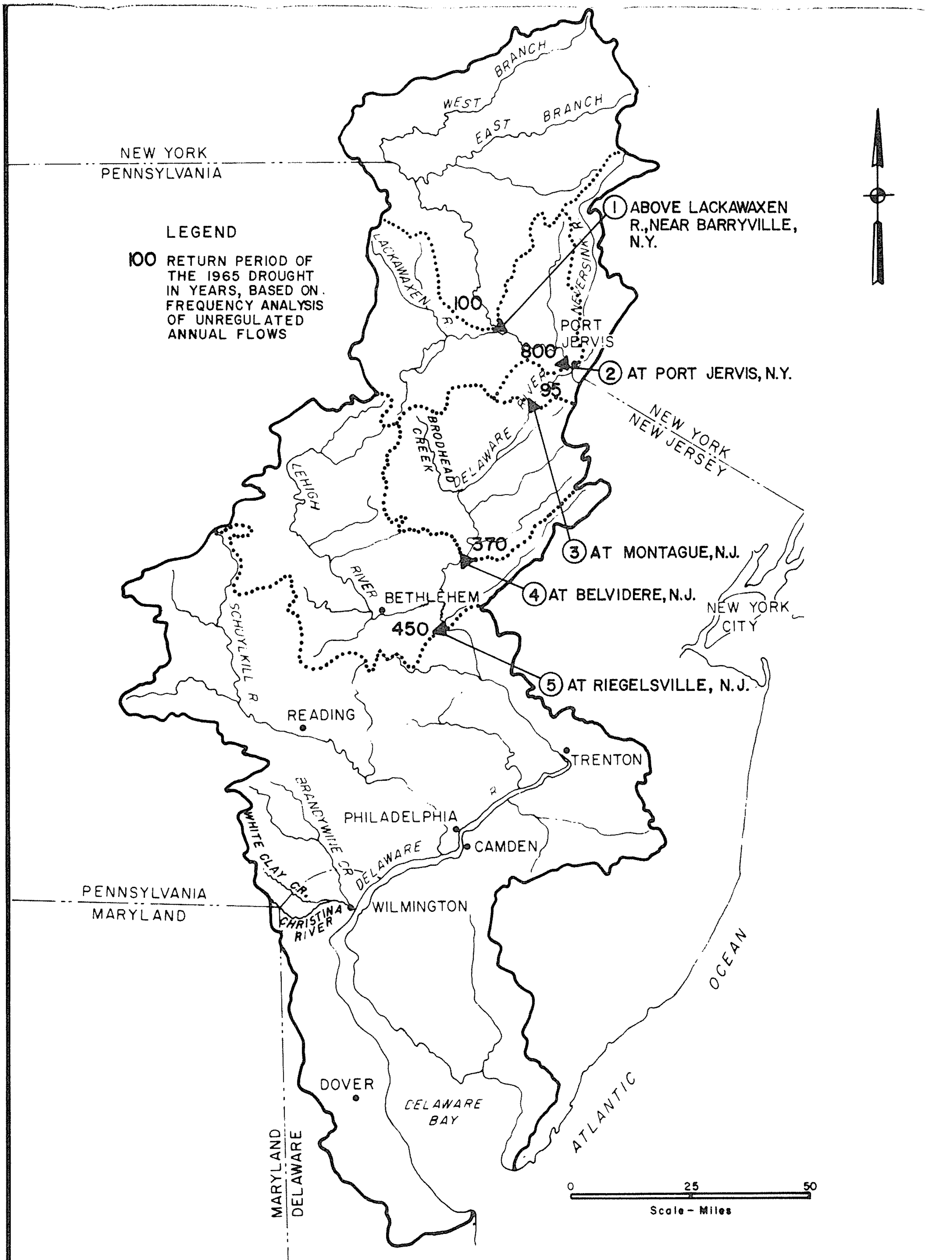
NEW YORK, N.Y.
1 ABOVE LACKAWAXEN R. NEAR BARRYVILLE, N.Y. (28 YRS)
2 AT PORT JERVIS, N.Y. (64 YRS)
3 AT MONTAGUE, N.J. (29 YRS)
4 AT BELVIDERE, N.J (46 YRS)
5 AT RIEGELSVILLE, N.J. (62 YRS)
WATER RESOURCES STUDY
DELAWARE RIVER DASIN
DROUGHT FREQUENCY OF
UNREGULATED ANNUAL FLOWS
MAIN RIVER GAGES
PERCENT OF MEAN ANNUAL FLOW
FREQUENCY RANGE OF 1965 DROUGHT
FREQUENCY RANGE OF 1931-32 DROUGHT
MEAN DROUGHT FREQUENCY CURVE
RETURN PERIOD IN YEARS
1
2
5
10
25
50
10²
500
10³
180
160
140
120
100
80
60
40
20

PLATE II-3



WATER RESOURCES STUDY
DELAWARE RIVER BASIN
FREQUENCY OF 1965 DROUGHT FOR SELECTED ON-CHANNEL STATIONS

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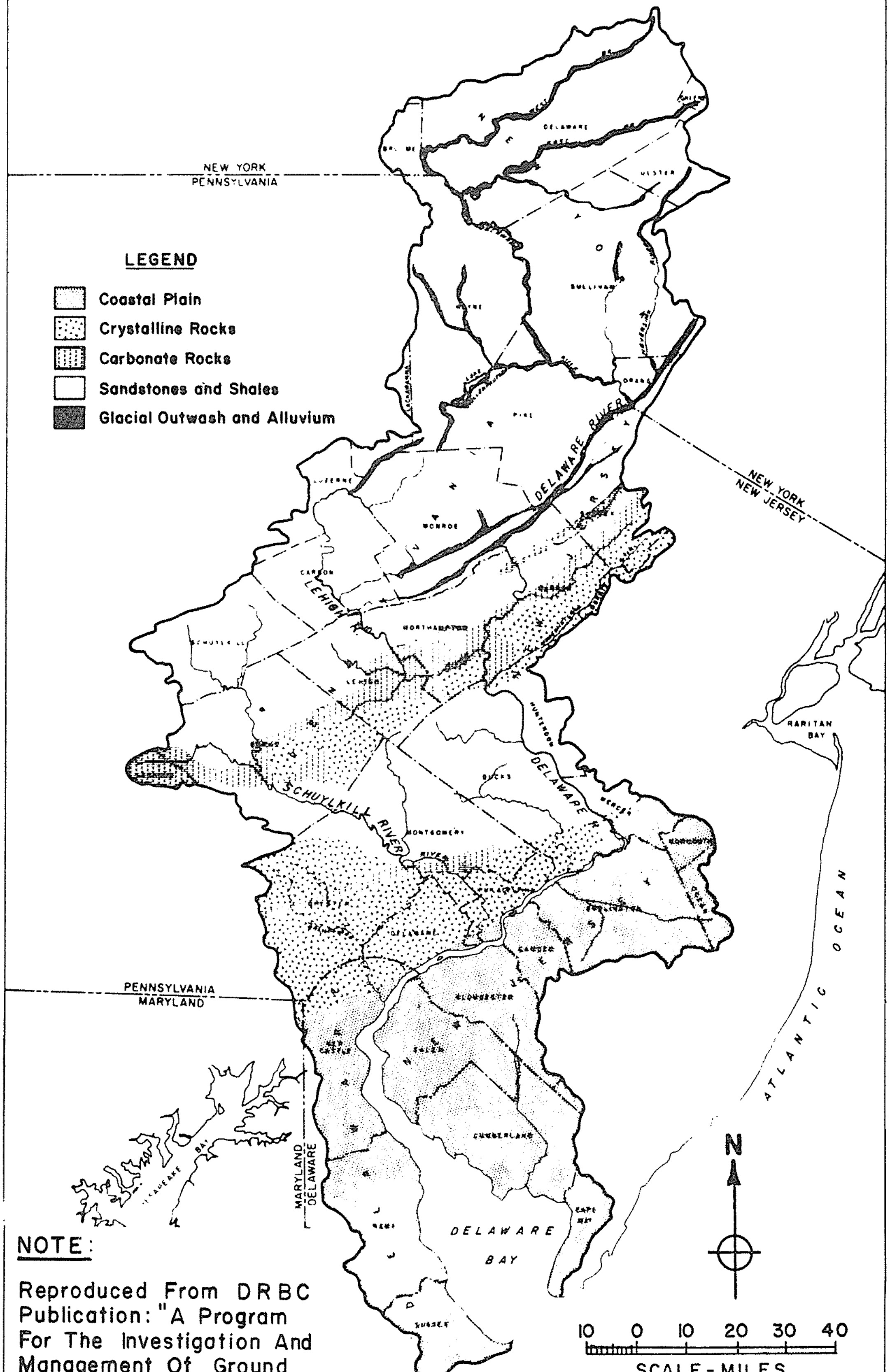
PLATE II-4



NOTE:

Reproduced From DRBC Publication: "A Program For The Investigation And Management Of Ground Water In The Delaware River Basin", May 1970.

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WATER RESOURCES STUDY
DELAWARE RIVER BASIN
GROUND-WATER SUBREGIONS
PLATE II-5

Section III

SALINITY - FLOW RELATIONSHIPS FOR DELAWARE RIVER ESTUARY

A. General

The Delaware River enters a tidal estuary below Trenton. The fresh-water and salt-water mixture in any downstream reach is affected by the tides which are semidiurnal. Among the factors determining the salinity are the magnitude of fresh-water inflows, movement of water under tidal influences, pollution due to discharged wastes, wind, and temperature. By far the most significant factor is the fresh-water inflow, and most of the studies which have been published on the subject of inflow-salinity relationships are keyed to the fresh-water discharge values at Trenton.

Salinity is defined in these studies in terms of the chloride concentration in milligrams per liter (mg/l) which is the same as parts per million (ppm). Salinity distribution in an estuary is shown by imaginary lines representing specified concentrations known as isochlors. During 1964 and 1965, the 250 mg/l isochlor in the Delaware River extended to the vinicity of Philadelphia, five to ten miles upstream from the mouth of the Schuylkill River. Subsequent to the declaration of a water supply emergency in July 1965, the DRBC controlled the operation of the remaining water storage, partly to provide adequate fresh-water flow to the Delaware River at Trenton.

B. Water Quality Standards for Chlorides

Stream quality objectives of the DRBC are defined in their publication dated March 1968 entitled "Basin Regulations - Water Quality". The objectives for chloride concentrations are as follows:

Zone 2 - Delaware River from R.M. 133.4 (Trenton) to R.M. 108.4 (below mouth of Pennypack Creek) - 50 mg/l.max. 15-day mean.

Zone 3 - Delaware River from R.M. 108.4 to R.M. 95.0 (below Walt Whitman Bridge) - 200 mg/l. max. (instantaneous)

Zone 4 - Delaware River from R.M. 95.0 to R.M. 78.8 (Pa. - Del. boundary line) - 250 mg/l max. (instantaneous) at R.M. 92.47 (mouth of Schuylkill River).

The objectives in the regulations are limited to the reaches listed above extending from the gage at Trenton to the mouth of the Schuylkill River and include the tidal portions of the tributaries.

The draft of the revised DRBC Comprehensive Plan (July 1970) states that the chloride objective of 250 mg/l at the mouth of the Schuylkill River (R.M. 92.47) "will require a minimum fresh water inflow at Trenton, New Jersey, of about 3000 cfs ..." (Sec. 1.5, Para.b.1).

The water uses to be protected are specified in the water quality regulations. They include agricultural, industrial and public water supplies after reasonable treatment for Zones 2 and 3 and industrial water supply after reasonable treatment for Zone 4. A satisfactory source for municipal water supply would provide adequate water for the other purposes. The U.S. Public Health Service recommendation for chlorides in drinking water is 250 mg/l and, since treatment does not affect chlorides, the raw water should also be limited to this maximum concentration. It is noted, however, that higher chlorides may generally be tolerated without unfavorable physiological effects, and the 250 mg/l standard should be considered essentially as an <u>index</u> of excessive salinity intrusion and/or pollution and not as an inviolable provision. The 200 mg/l and 50 mg/l maximum chloride objectives by the DRBC are even lower than the Federal standard of 250 mg/l.

C. Salinity - Flow Studies

The studies described here were made using historical streamflow and salinity data published by the U.S. Geological Survey. (The USGS uses the ppm designation for chloride concentration and this unit is used in the balance of this Section). Stress has been placed on the data for the drought period of the 60's.

Curves of daily mean chloride concentration for locations on the Delaware River from Trenton downstream to the Delaware Memorial Bridge (R.M. 68.70) are shown for the drought period on Plate III-1. Each curve is identified by the date on which the salinity value is stated and the 30-day average flow at Trenton preceding this date. Salinity values were estimated from tables of chlorides versus specific conductance furnished by the DRBC. Daily mean specific conductance values were used for these estimates. Taking the 30-day average flow during the low-flow season tends to smooth out variations due to the unsteady nature of the salinity intrusion phenomenon.

The highest instantaneous chloride concentration during a tidal cycle would occur at high-water slack. However, daily mean values used herein are more significant from a water supply standpoint.

The curves in Plate III-1 are quite steep for low flows. For the isochlors reaching farthest upstream (on November 20, 1964) there was approximately a 10-fold decrease in average salinity between R.M. 70 and R.M. 102 and another 10-fold decrease between R.M. 102 and R.M. 115. The general shape of the curves is characteristic of those observed for well-mixed estuaries such as the Delaware. There are some inconsistencies between the curves which may be attributed to a lack of precision in the flow and salinity measurements, instability of the salt water movements when subjected to a varying historical flow, and normal statistical variations expected for water quality data.

Plate III-1 also shows by a heavy line the water quality objectives of the DRBC for chlorides, as discussed above. It appears that, during the drought of the 60's, two periods of flows failed to meet the DRBC chloride objectives, namely the fall periods in 1964 and 1965 when the average flows at Trenton were below 3000 cfs. Table III-1 shows chloride concentration data for June 1 to December 2, 1964, and August 15 to December 31, 1965.

TABLE III-1

CHLORIDE CONCENTRATIONS IN DELAWARE RIVER NEAR PHILADELPHIA IN DROUGHT OF 60'S

Date	Preceding 30-day Average Flow at Trenton (cfs)	Daily Mean Chloride Concentration at Philadelphia (ppm) Mouth of Schuylkill River	Torresdale
1964			
June 1	10,237	17	less than 10
Aug. 3	3,062	54	17
Sept. 1	2,457	120	21
Oct. 5	2,192	250	22
Nov. 20	1,837	600	36
Dec. 2	1,916	370	27
1965			
Aug. 15	1,725	230	28
Aug. 31	1,820	260	33
Sept. 15	1,846	360	35
Oct. 1	2,092	390	40
Oct. 8	2,453	340	24
Oct. 11	2,768	265	27
Oct. 21	3,424	220	20
Oct. 31	3,528	220	20
Nov. 15	2,565	260 1/	25
Nov. 30	2,656	230	25
Dec. 15	3,716	185	13
Dec. 31	5,016	57	less than 10

1/ Estimated

Considerations of the hydraulics for a well-mixed estuary, and observations elsewhere, show that salinity positions are related primarily to fresh water inflow. This is demonstrated clearly by the data for 1964 which show the chloride concentration at Philadelphia increasing with each succeeding reduction of inflow. The data for 1965 do not demonstrate the theory as conclusively. After a very long period of low inflows (under about 2100 cfs) the salinity intrusion was so severe by October 1, 1965, that two months of higher flows were required before acceptable chloride levels were reached at the mouth of the Schuylkill River. These studies and earlier studies of the 50's by the USGS[1/] show that salinity distribution curves may be affected not only by the magnitude of current inflows but also by the magnitude and duration of prior inflows. With the available data on variable inflows and salinities for the Delaware River, the firm relationships that would apply to steady state conditions cannot be formulated by simply graphical comparisons.

The inflow-salinity phenomena in the Delaware estuary are complex and further studies and additional data are needed before precise predictions can be made of the relationships between these parameters, especially for inflows less than 3000 cfs and chloride concentrations less than 500 ppm.

D. Effect of Chesapeake and Delaware Canal

This canal enters the Delaware River estuary approximately nine miles south of the Delaware Memorial Bridge. The Corps of Engineers has estimated that the net-tidal drift of low-salinity water from the head of Chesapeake Bay to the Delaware River is about 4000 cfs.[2/] This is some 2400 cfs greater than the drift experienced prior to the completion of a dredging project in 1968.

This increased drift through the canal, if available during 1964 and 1965, would have modified the salinity distribution curves shown on Plate III-1.

1/ Reference No. 117
2/ Reference No. 148

An estimate of the effect of the canal improvement on conditions at Philadelphia, 30 miles or more upstream, has not been made.

E. Effect of Consumptive Uses in the Estuary on Salinity

The draft of the revised DRBC Comprehensive Plan of July 1970 (Sec. 3,6, Para. C) states that:

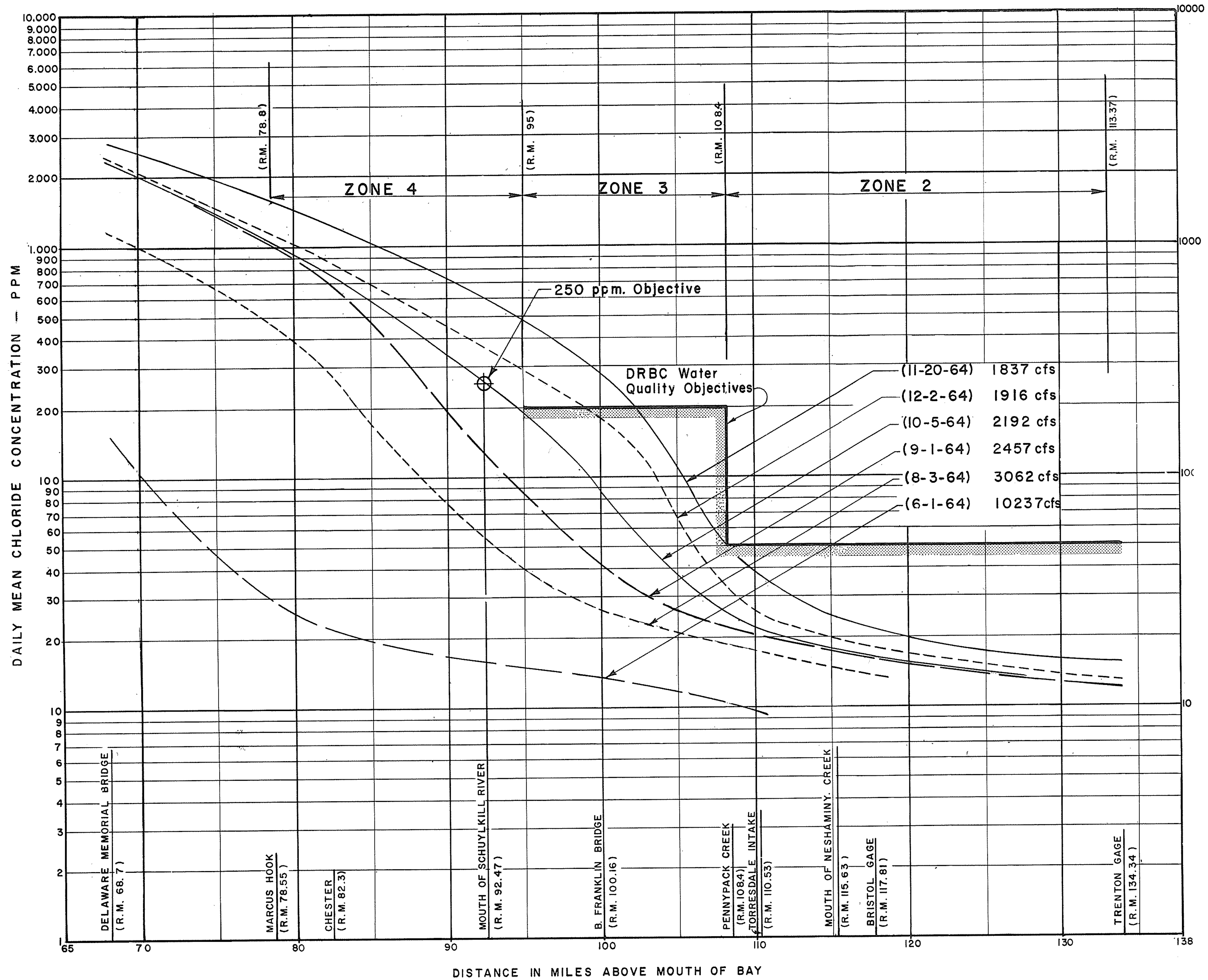
> "some streamflow regulation will be necessary, not only to augment the natual fresh-water inflow to the estuary, but also to make up for the consumptive losses of water. It is important to emphasize that, in this connection, evaporation of brackish water from the tidal Delaware River and Bay, no less than evaporation of fresh water, unless compensated by regulation of fresh-water inflow, will result in greater concentration of sea salts in the estuary and upstream advance of the salt front".

In the above quotation it is assumed that "evaporation of brackish water" means withdrawals for consumptive use. The phrase "salt front" requires further definition as there is no well defined interface between salt and fresh water in this estuary.

The above statement appears to be theoretically correct but requires qualification with regard to relative magnitudes in the salinity-withdrawal relation. Theoretically any brackish water withdrawal, however small, would increase the average salinity at that location in the estuary. Curves similar to those in Plate III-1 would also be displaced upward at points upstream and downstream of the withdrawal point,which means that salinity concentrations would increase upstream and downstream. It can be shown that the percentage change in average salinity at a point of withdrawal would be of approximately equivalent to the percentage change in the fresh water component of the fresh water - salt water mixture.

In 1986, and with a repetition of drought conditions of the 60's, the minimum fresh-water flows in the estuary (assuming construction of the reservoirs in the draft of the 1970 revised DRBC Comprehensive Plan) would be 3450 cfs at Trenton and 4120 cfs below the mouth of the Schuylkill River at Philadelphia (see Section VIII) after reductions for diversions and consumptive uses projected in this study. By 1986 the projected additional consumptive uses in the reach between Trenton and the above mentioned point in Philadelphia would be 284 cfs (Sub-basins 5, 6, and 7) or eight percent of the average net flow of about 3600 cfs as augmented by reservoirs. It is, therefore, concluded from Plate III-1 and the data in Table III-1 that the sustained residual fresh water flows of the order indicated above would result in a safe margin between probable salinities and water quality objectives for chlorides even after some upstream displacement of the isochlors.

Below Philadelphia the incremental increase in projected consumptive uses would be 106 cfs (Sub-basins 8, 9, 10, 11, and 12) or about two percent of the fresh water flow and should result in a negligible effect on salinity conditions in the Philadelphia area.



SALINITY DISTRIBUTION CURVES
1964

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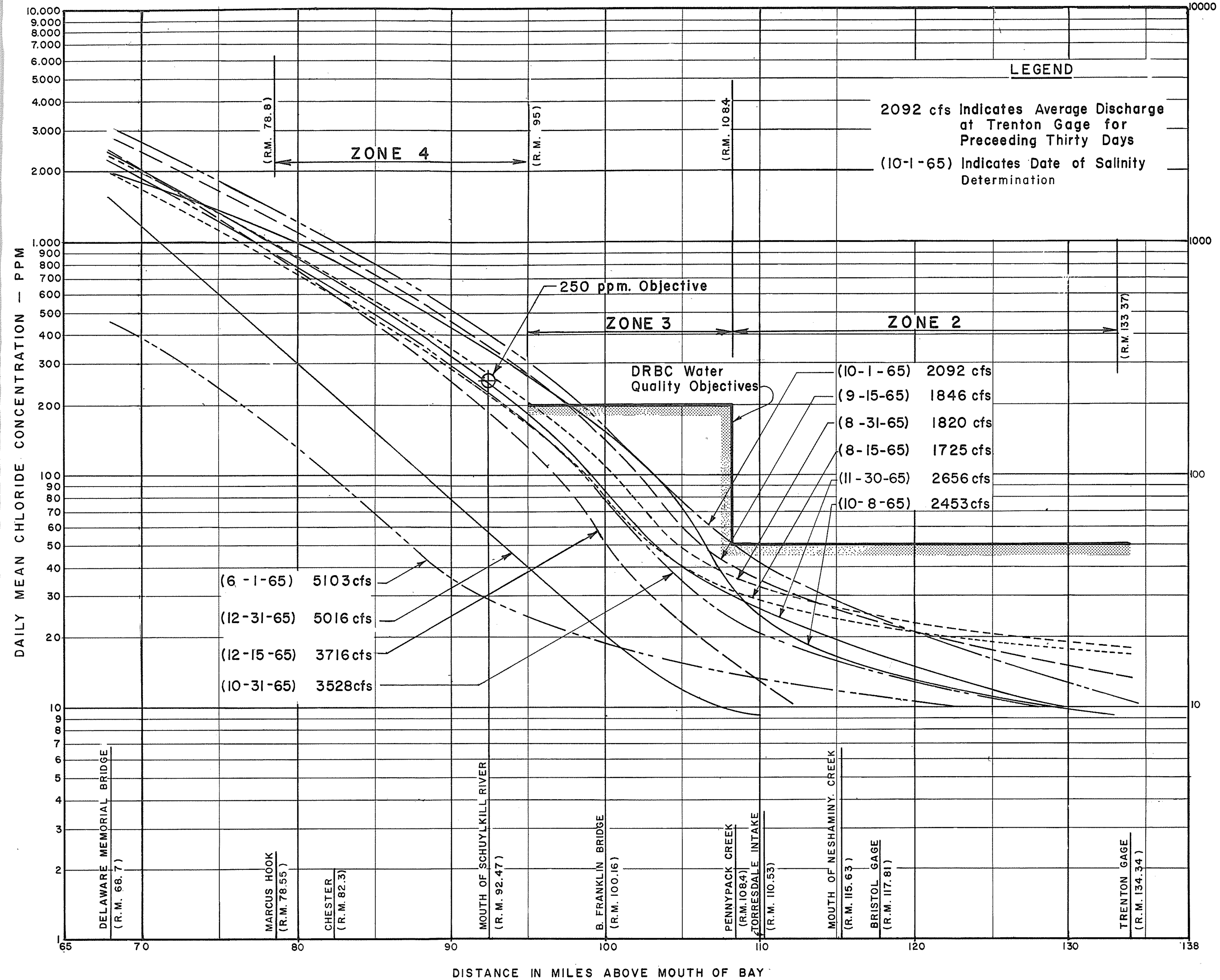

SALINITY DISTRIBUTION CURVES
1965

WATER RESOURCES STUDY
DELAWARE RIVER BASIN
SALINITY DISTRIBUTION CURVES
DELAWARE RIVER ESTUARY

PLATE III-1

Section IV

OUT-OF-BASIN DIVERSIONS

A. Elements of 1931 and 1954 Supreme Court Decrees

1. Historical and Legal Background. The following statement, extracted from a report of the Delaware River Basin Commission, summarizes the chronological steps in the interstate allocation of waters of the Delaware River.

> Use of the Delaware River and its tributaries as a source of municipal and domestic water supply can be traced to the late 1700's with the building of municipal waterworks at Bethlehem and Philadelphia. In the 1920's New York City contemplated going to the headwaters of the Delaware River for an additional water supply. Negotiations between the States of New York and New Jersey and the Commonwealth of Pennsylvania at that time failed to provide any acceptable solution to their mutual water supply problems. A resolution to this phase of the Basin's water resources development came through a decree of the United States Supreme Court in 1931 which granted the City of New York the right to a diversion of 440 million gallons per day (mgd) and required that New York City release from its Delaware Basin reservoirs a limited quantity of water to maintain minimum flows. Following World War II, work was resumed on the New York City system of reservoirs in the Delaware headwaters. Neversink Reservoir was placed in operation in 1953 and Pepacton Reservoir in 1955. In 1954, the Supreme Court amended the original decree of 1931 (Amended Decree of the U.S. Supreme Court dated June 7, 1954 - New Jersey v. New York, 347 U.S. 995)[1/] and authorized an additional diversion by New York City to a total of 800 mgd. The diversions are subject to specific conditions and obligations regarding compensating releases and sewage treatment. The decree limited the diversion to 490 mgd until completion and partial filling of Cannonsville Reservoir on the West Branch of Delaware River, and 800 mgd thereafter. New York City was required, upon completion and placing in operation of the Neversink and Pepacton reservoirs to release water from one or more of its storage reservoirs to maintain a minimum basic rate of flow at the Montague gaging station of 1525 cfs until the Cannonsville Project was completed and partially filled and 1750 cfs thereafter. In addition, certain excess release requirements were also specified. The decree also granted the State of New Jersey the right to divert 100 mgd from the Basin without compensating releases. Cannonsville Reservoir became officially in operation on March 31, 1967.

1/ Reference No. 128

On October 27, 1961 the Delaware River Basin Compact became law creating the Delaware River Basin Commission, an agency and instrumentality of the principals; the United States of America; the State of Delaware, the State of New Jersey; the State of New York, and the Commonwealth of Pennsylvania.

2. Administration of the Decree. The Delaware River Basin Commision has certain powers to carry out the terms and intent of the decree, and may temporarily modify such terms in case of an emergency.

Regulation of releases from the New York City reservoirs and the maintenance of records at control points is under the direction of the Director and Chief Hydraulic Engineer of the US Geological Survey, but actual day-by-day operation is under a Deputy River Master appointed by the Survey.

B. Assumptions Made for New York City Diversions

As mentioned in Section II-D above, the drought of the 1930's was used at the time of the amended decree in 1954 as the design drought for determining the safe yield of the New York City reservoirs and the flow that should be maintained at Montague. Studies made by the US Geological Survey, and confirmed by additional studies made for this report reveal that, under a repetition of the 1962-66 drought, it will not be possible to maintain both the authorized diversions to New York City of 800 mgd and the required flow on the Delaware River at Montague of 1750 cfs. The later studies are, of course, based on the assumption that storage in Cannonsville Reservoir was available throughout the drought period.

C. Existing Diversions to New Jersey

A second major out-of-basin diversion consists of the diversions to the Raritan River Basin from Sub-basin No. 4 by means of the Delaware-Raritan Canal. As noted in Section IV-A-1 above, the State of New Jersey was granted the right to divert an average of 100 mgd from the basin without compensating releases by the Supreme Court decree. The decree further stipulated that the maximum daily diversion rate should not exceed 120 mgd.

Actually New Jersey has been taking an average of only about 50 mgd in recent years.

D. Other Existing Diversions and Imports

1. Miscellaneous Diversions - Above Philadelphia there are several other authorized minor out-of-basin diversions which are listed in Table IV-1.

Table IV-1

PRESENT AUTHORIZED OUT-OF-BASIN DIVERSIONS

(Above Philadelphia)

Beneficiary	From Sub-basin No.	Rate (MGD)
Otisville, State Training School, Otisville, New York	1	0.5
Village of Woodbridge, New York	1	0.4
Pennsylvania Gas and Water Co.	3	3.0
Hazelton Joint Sewer Authority	3	3.0
Flemington, New Jersey	4	0.5
	Total	7.4

Authorized out of basin diversions below Philadelphia total 3.6 mgd.

2. Imports. The Chester Water Authority is authorized to import up to 60 mgd from the Susquehanna River. About half can be obtained from the Authority's Octoraro Creek Reservoir and the remainder can be taken when needed from the Conowingo Reservoir on the main Susquehanna River. Any other imports to the basin are minor.

E. Proposed Additional Diversions to New Jersey

1. Proposed Diversion to Northern and Central Areas. The State of New Jersey has advised DRBC that it will request authorization for an additional 300 mgd diversion from the Delaware River to meet its future water needs. In addition informal conversations with the Water Resources

Division of the State of New Jersey reveals that the State desires to divert, via "flood skimming", an additional quantity of water. The volume of this added water would only be limited by the maximum amount authorized by DRBC or by economic considerations. This additional water from the Delaware Basin is contemplated to be transmitted to the north and central areas of the New Jersey Metropolitan Region 2/.

2. Conditions Imposed on Future Diversions. Relative to future diversions from the Delaware River, the Amended Supreme Court decree states:

> "B. Conditions and Obligations Imposed in Connection with Diversions by New Jersey.- The diversions by New Jersey from the Delaware River shall be made under the supervision of the River Master and shall be subject to the following conditions and obligations:
>
> "1. Until the State of New Jersey builds and utilizes one or more reservoirs to store waters of the Delaware River or its tributaries for the purpose of diverting the same to another watershed, the State may divert not to exceed 100 m.g.d. as a monthly average with the diversion on any day not to exceed 120 million gallons,
>
> "2. If and when the State of New Jersey has built and is utilizing one or more reservoirs to store water of the Delaware River or its tributaries for the purpose of diversion to another watershed, it may withdraw water from the Delaware River or its tributaries into such impounding reservoirs without limitation except during the months of July, August, September and October of any year, when not more than 100 m.g.d. as a monthly average and not more than 120 million gallons in any day shall be withdrawn.
>
> "3. Regardless of whether the State of New Jersey builds and utilizes storage reservoirs for diversion, its total diversion for use outside of the Delaware River watershed without compensating releases shall not exceed an average of 100 m.g.d. during any calendar year".

3. Assumptions Made in Estimating Requirements.

The water demand projections, available water supply sources and proposed water resources development formulated by the State of New

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2/ Reference No. 136

Jersey have been reviewed. The water demand projections used by the State are based upon projections for industrial, agricultural, and municipal demand. Review indicates that the industrial and agricultural projections are quite reasonable but the projections for municipal use appear to be quite high. The State's projections for the latter demands are based upon both increases in population and per capita demand. The population projection appears reasonable but the increase in per capita demand from 125 gpcd[3/] in 1964 to 256 gpcd in 2020 appears to be too high. Per capita demand in the Delaware Basin as a whole is estimated to vary from from 108 gpcd (Sub-basin 8) to 177 gpcd in 2020 (Sub-basin 11) with an overall basin average of 145 gpcd[4/].

A more realistic future per capita demand in 2020 for the State of New Jersey would be from 165 to 170 gpcd. Using this latter figure the region will be deficient approximately 180 mgd in 2020 even with the proposed Delaware River diversion. It appears that the State of New Jersey can present strong evidence for their needs for this water.

The State of New Jersey has proposed[5/] the additional diversion upon completion of the Tocks Island Reservoir and other storage facilities in the DRBC Comprehensive Plan and intends to contribute a share of the water supply costs of these projects. The State anticipates that the major point of diversion of Delaware River water will be in the vicinity of Frenchtown, New Jersey, although consideration is also being given to the diversion of a portion of the total amount directly from the Tocks Island Reservoir.

F. Other Proposed Diversions and Imports

The city of Newark has proposed a plan to divert 50 mgd directly from the Tocks Island Reservoir but this diversion would be included in the 300 mgd already requested by the State.

3/ Gallons per capita per day (gpcd).
4/ Reference No. 125
5/ Reference No. 136

In addition to the existing and planned out-of-basin diversions, there is a planned intra-basin diversion which affects the flow at Trenton. A proposed water supply development program for the Neshaminy Creek Basin in Buck and Montgomery counties, Pa., provides for a 90-day peak diversion rate of 71 mgd by 1986 and 200 mgd by 2020 from the Delaware River into the Neshaminy Basin by means of pumping facilities to be located at Point Pleasant, Pa. About 90 percent of this diversion would be non-consumptive and would appear in Neshaminy Creek as return flow and enter the Delaware River between Trenton and Philadelphia[6/]. This diversion was not deducted from the flow of the Delaware River at Trenton in the water balance studies in Section VIII.

6/ Reference No. 127

Section V

RESERVOIR PROJECTS IN DRBC COMPREHENSIVE PLAN

A. Location and Description of Projects

The Delaware River Basin Commission's long-term Comprehensive Plan for the development of the water resources of the Basin was adopted March 28, 1962. Included within this plan is a selected group of 12 reservoir projects. The locations are shown on Plate V-1 and pertinent data are given in Table V-1.

The principal source for selecting projects for inclusion in the Plan was the Comprehensive Survey of the Water Resources of the Delaware River Basin (HD 522, 87th Cong. 2 Sess.) completed by the U.S.Army Corps of Engineers in 1961. That report recommended eight major multi-purpose reservoirs including Prompton (modification), Tocks Island, Francis E. Walter (modification), Beltzville, Aquashicola, Trexler, Blue Marsh and Maiden Creek. These projects were authorized by Congress in October 1962 and were included in the Comprehensive Plan. In addition, several other reservoir projects recommended in the Corps' report for non-Federal development were included in the Plan, namely Hackettstown, Nockamixon, Evansburg, and Newark.

Tocks Island, the only reservoir proposed for the main stem of the Delaware River, is by far the largest of the Plan projects. Land is currently being acquired by the Corps of Engineers. A report on the project's environmental impact is currently under review by appropriate Federal agencies.

Two other Corps of Engineers projects -Prompton and Francis E. Walter- are already in existence as flood control reservoirs. The Plan envisages modification of both to incorporate a water supply function. Prompton is in the Lackawaxen River tributary basin and is the only Plan project

TABLE V-1

RESERVOIR PROJECTS IN DRBC COMPREHENSIVE PLAN

Name of Project	Sub-basin No.	River	Location	Drainage Area (sq mi)	Usable Storage (acre-ft)	Min. Monthly Unreg. Flow 1961-66 (cfs)	Dependable Gross Yield[1/] (cfs)	Remarks
Prompton Dam	1	Lackawaxen	4 miles west of Honesdale, Pa.	60	28,000	5.2	68[2/]	Existing flood control projec will be modified
Tocks Island Dam	2	Delaware	7 miles N.E. of Stroudsburg, Pa.	3827	425,600	563	2850	
Hackettstown Dam[3/]	2	Musconetcong River	3 miles north of Hackettstown, N.J.	70	22,000	0	46	Initial construction to be for recreation
F.E. Walter Dam	3	Lehigh	4 miles north of White Haven, Pa.	290	69,500	46	235	Existing flood control project will be modified
Beltzville Dam	3	Pohopoco Creek	4 miles east of Lehighton, Pa.	96	39,830[4/]	16	81	
Aquashicola	3	Aquashicola Creek	3 miles east of Palmerton, Pa.	66	24,000	12	60	
Trexler Dam	3	Jordan Creek	8 miles NW of Allentown, Pa.	52	40,000	1	45	
Nockamixon[3/]	4	Tohickon Creek	About 1 mile SW of Otisville, Pa.	75	30,000	1	4	Initial construction to be for recreation
Maiden Creek Dam	6	Maiden Creek	12 miles north of Reading, Pa.	161	74,000	7	50[5/]	
Blue Marsh Dam	6	Tulpehocken Creek	6 miles NW of Reading, Pa.	175	19,900[6/]	32	155	
Evansburg Dam[3/]	6	Skippack Creek	2 miles SW of Collegeville, Pa.	54	23,500	7/	8/	Initial construction to be for recreation
Newark Dam[3/]	8	White Clay Creek	1.5 miles north of Newark, Del.	67	30,000	7/	8/	

1/ Dependable gross yield is the sustained constant draft which utilizes all the active long-term storage during a repetition of the severest drought of record. Values except as noted were estimated from results of the computer study (see Section VIII).

2/ Reference 126, p. 49.

3/ Non Federal project.

4/ Includes 27,880 AF of water-supply storage and 11,950 AF of water-quality storage.

5/ Yield based on mass curve of inflow for the drought period July 1964 through June 1967.

6/ Includes 8,000 AF of water-supply storage, 6620 AF of water-quality storage and 5280 AF of temporary usable storage available April through August.

7/ Not available.

8/ From draft of revised DRBC Comprehensive Plan, July 1970.

upstream from Tocks Island Reservoir. Francis E. Walter is in the upper Lehigh River tributary basin. No work on modification of either has been started.

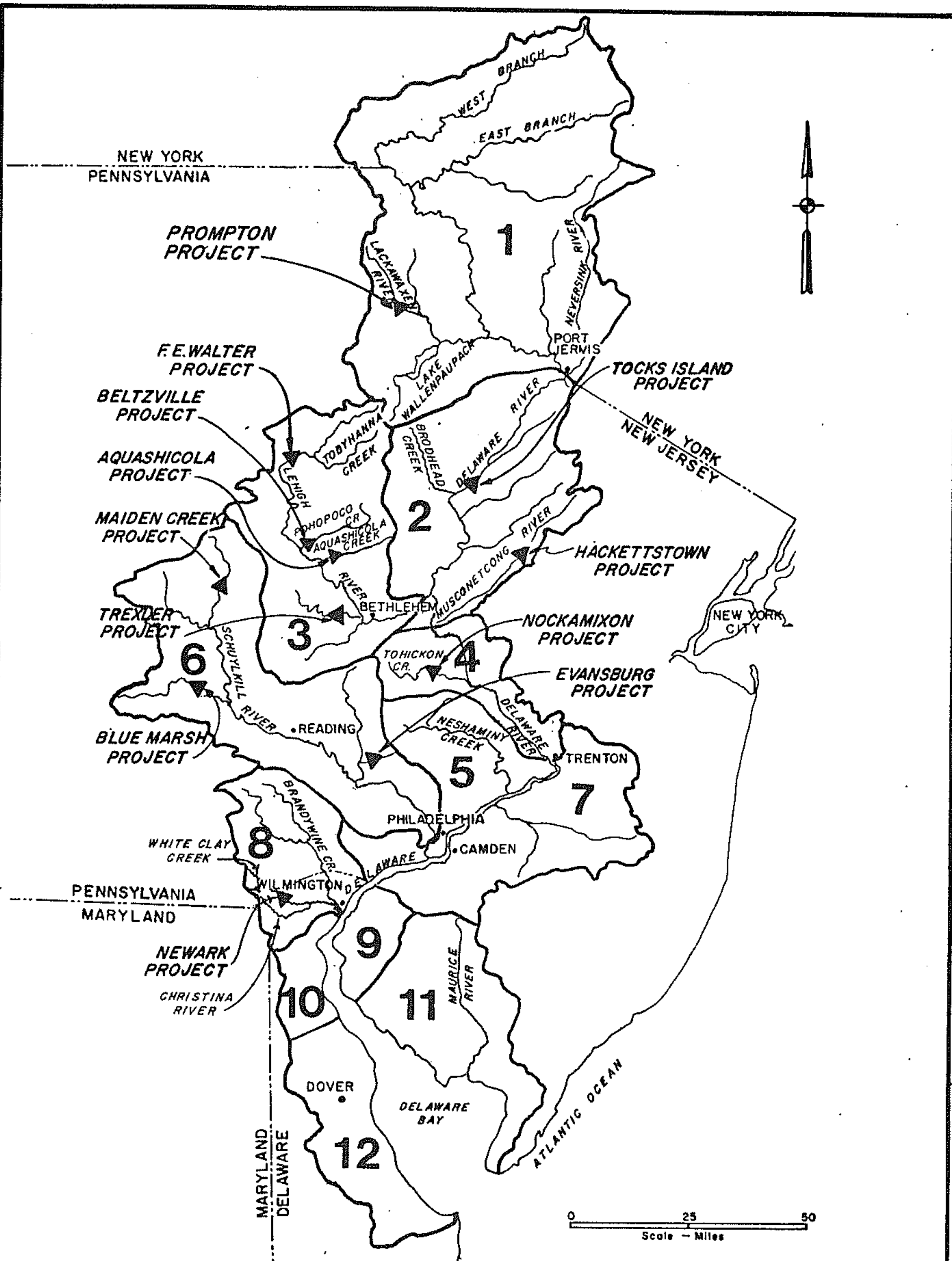
Three other Corps of Engineers projects -Beltzville, Trexler, and Aquashicola- are located on tributaries of the Lehigh River. Beltzville has recently been completed and preconstruction design is underway for Trexler. No post-authorization work for Aquashicola is scheduled yet.

The remaining two Corps of Engineers projects, Blue Marsh and Maiden Creek, are on tributaries to the Schuylkill River which enters the Delaware River near Philadelphia. Land acquisition is expected to be initiated for Blue Marsh, but no post-authorization work is underway for Maiden Creek.

The other four projects in the Plan are reserved for development by the States in which they are located. New Jersey is reported to be acquiring land for the Hackettstown project, which will have both recreation and water supply storage. Pennsylvania is constructing Nockamixon, initially as a recreation reservoir, and is acquiring land for Evansburg. Newark Reservoir is planned as a water supply project by the State of Delaware. The Pennsylvania reservoirs are pllaned for conversion for water supply when needed.

B. <u>Storage-Yield Data for Reservoir Projects</u>.

The large number of reservoirs in the Comprehensive Plan, their wide dispersion throughout the drainage area, the large uncontrolled drainage areas downstream from these reservoirs, and the need for operating rules for each reservoir made it essential that their effectiveness be studied through use of systems analysis. A computer program for this purpose was developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Center in Davis, Calif., and was modified by the Philadelphia District of the Corps and the DRBC. The program permits a study of the effect of the Plan reservoirs in the drought period June 1961 to May 1967 and use was made of it for this report. The results are summarized in Section VIII. The regulated flows obtainable from each of the Plan reservoirs under the proposed plan of operation are tabulated in Table V-1 in this section.



TIPPETTS-ABBETT-McCARTHY-STRATTON
ENGINEERS & ARCHITECTS
NEW YORK, N.Y.

WATER RESOURCES STUDY
DELAWARE RIVER BASIN
LOCATION OF DRBC RESERVOIRS

PLATE V-1

Section VI

WATER USES IN BASIN FOR NON-POWER PURPOSES

A. Classifications of Use

The DRBC has classified water withdrawals into the following seven major categories[1/]:

(1) Rural-domestic demands

(2) Community water systems

(3) Industrial (not including power)

(4) Irrigation

(5) Livestock

(6) Diversions

(7) Power

The same categories have been utilized in the present studies and are outlined below, except for categories (6) and (7) which are discussed in Sections IV and VII, respectively.

Water use projections in this section are limited to those demands which will be supplied from surface water sources. A comparison of ground-water yields, available surface supplies, and estimated requirements for the various sub-basins indicate the following:

1. Ground water in Sub-basins 1, 2, 4, and 5 is minor and was not considered.
2. Ground-water yield in Sub-basins 3, 6, 7, and 8 is small in comparison to total needs and available surface supplies. It was assumed that future demands in these sub-basins would be supplied from surface sources.
3. In Sub-basins 9 through 12, the ground-water yield is large in comparison to both needs and surface supplies. Hence,

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1/ Reference No. 125

it was assumed that demands in these sub-basins, except for some industrial cooling using brackish water, would be supplied from ground water.

B. Rural-Domestic Demands

These demands are for the basin population served by private wells and other individual household water supply systems. They are expected to remain almost constant during the projection period. As urban centers grow outward, there is a trend in outlying areas towards abandonment of private supplies in favor of municipal supplies. Therefore, increases in private demands were considered negligible in the study.

C. Community Water Systems.

1. General. The Basin domestic demands not satisfied by private wells and other individual household water supply systems are met by publicly and privately owned community and institutional systems. These municipal systems in many cases supply industrial demands and lawn and garden irrigation in addition to purely domestic or household demands. The different per capita demands in various parts of the Basin are partially due to these non-household demands and partially due to other factors such as extent of metering, general level of economic development, and water rates.

2. Withdrawals. Withdrawal rates by community water systems vary considerably throughout the year from their annual average rates, hence the use of average rates for relatively short periods of time does not reflect the true critical withdrawal rates. For this report it was decided to base the analysis on the most critical 30-day period. From data available for the Philadelphia Water System, essentially confirmed by experience in other systems, it was concluded that the maximum monthly withdrawal rate should be 20 percent greater than the annual average rate[2/].

2/ Reference No. 138

3. Consumptive Use. Ten percent[3/] of the water withdrawn from surface sources for municipal systems was assumed to be consumed and hence not returned to surface flow. The consumptive use would be higher if restrictions on water use, particularly lawn sprinkling, were not in effect as in the past.

D. Industrial

1. Withdrawals. Self-supplied industrial demands are currently met from both ground and surface water sources. For the Pennsylvania portion of the basin a study[4/] by the Pennsylvania Department of Forests and Waters was used to estimate the withdrawals from surface water sources during the drought of the 1960's. For the New Jersey portion of the basin, the DRBC estimates were used. Future requirements for the basin were taken from the draft of the revised DRBC Comprehensive Plan. Since industrial demands are relatively constant, the annual average rate was used for the 30-day critical periods.

2. Consumptive Use. Ten percent[3/] of the water withdrawn from surface water for industry was assumed to be used consumptively, except in Sub-basin 10, where only one percent of the brackish water withdrawn for industrial cooling was assumed to be consumed.

E. Irrigation

1. Withdrawals. The State of Pennsylvania made a study of the irrigation water utilized within that state during the years 1966-68[4/], which indicated that the volume of irrigation water used during the drought year 1966 was about five times greater than that used in 1967, a year in which near normal rainfall occurred, and nearly three times greater than in 1968. In 1968 the greatest use occurred during the months of July and August with about 80 percent of the irrigators applying water. It is believed that during

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3/ Reference No. 145
4/ Reference No. 137

a drought such as occurred in 1964-65 this percentage would approach 100 and the greatest demand would occur during this same two-month period.

The total volume of irrigation water obtained from ground water and surface-water sources has been evaluated. For estimates of future increases in total irrigation demand, the withdrawals from ground water have been assumed to be unchanged, and all increases were assumed to be met from surface water sources.

For the present studies the peak rates as set forth in the Pennsylvania Report has been used for the 30-day withdrawal rates for the Pennsylvania portion of the Basin and the rates set forth in the draft of the revised DRBC Comprehensive Plan for the remainder of the Basin.

2. Consumptive Use. The studies for this report assumed that all irrigation water was used consumptively.

F. Livestock

Withdrawal rates for livestock were taken directly from the draft of the revised DRBC Comprehensive Plan with the assumption that all of these needs are supplied from surface water sources and used consumptively. Since the livestock demands are relatively small and are expected to remain essentially constant within the projection period, neither the source nor the percent consumed affects the study in any significant manner.

G. Summary of Withdrawals and Consumptive Uses

The estimated surface water withdrawals and consumptive uses for Sub-basins 1 through 12 are summarized in Tables VI-1 and VI-2. The increase in consumptive uses between those occurring during the drought of the 1960's and those estimated for the years 1986 and 2020 are summarized in Table VI-3.

TABLE VI-1

DELAWARE RIVER BASIN

ESTIMATED MAXIMUM 30-DAY WITHDRAWALS FROM SURFACE WATER SOURCES (MGD)

Sub-basin No. 1/	Municipal				Industrial 2/				Agricultural				Total			
	1965	1970	1986	2020	1965	1970	1986	2020	1965	1970	1986	2020	1965	1970	1986	2020
1 3/	10.8	10.8	11.7	14	6	7	7	8	6.3	6.9	7	7	23.1	24.7	25.7	29.0
2	20	24	37	89	46	51	68.2	127	1.1	1.4	1.7	2.7	67.1	76.4	106.9	218.7
3 4/	45	59	78.4	125	260	300	333.6	421	2.2	2.7	3.7	5.6	310.2	364.7	421.7	557.6
4 3/	8	10	13.2	21	6	7	8.6	15	1.8	2.2	2.7	4.3	15.8	19.2	24.5	40.3
5	197	240	348	577	900	985	1158	1660	0.8	1.7	2.3	2.8	1097.8	1226.7	1508.3	2239.8
6	282	315	363.6	450	200	212	246.4	345	8.8	8.7	12.9	16.6	490.8	535.7	622.9	811.6
7	120	148	214.6	396	230	275	386.4	810	18	18	18	19	368.0	441.0	619.0	1225.0
8	53	59	80.4	140	100	117	166.2	349	2.5	2.5	5.3	6.3	155.5	178.5	251.9	495.3
9 5/	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 5/	-	-	-	-	380	491	800	2244 6/	-	-	-	-	380.0	491.0	800.0	2244.0

1/ See Plate II-1 and Table II-3 for location and description.
2/ Same as DRBC estimate.
3/ Total does not include out of basin diversions.
4/ Total includes 3 mgd out of basin diversion through 1970 and 6 mgd in 1980 and thereafter.
5/ Future fresh water requirements for Sub-basins 9, 10, 11 and 12 are assumed to be supplied from ground water.
6/ Brackish water for industrial cooling. Negligible amounts would also be needed in Sub-basins 8 and 9.

TABLE VI-2

DELAWARE RIVER BASIN

ESTIMATED 30-DAY CONSUMPTIVE USE TO BE MET FROM SURFACE WATER SOURCES (MGD)

Sub-basin	Municipal [1]				Industrial [1]				Agricultural [2]				Total			
No.	1965	1970	1986	2020	1965	1970	1986	2020	1965	1970	1986	2020	1965	1970	1986	2020
1 [3]	1.1	1.1	1.2	1.4	0.6	0.7	0.7	0.8	6.3	6.9	7.0	7.0	8.0	8.7	8.9	9.2
2	2.0	2.4	3.7	8.9	4.6	5.1	6.8	12.7	1.1	1.4	1.7	2.7	7.7	8.9	12.2	24.3
3 [4]	4.5	5.9	7.8	12.5	26.0	30.0	33.4	42.1	2.2	2.7	3.7	5.6	35.7	41.6	50.9	66.2
4 [3]	0.8	1.0	1.3	2.1	0.6	0.7	0.9	1.5	1.8	2.2	2.7	4.3	3.2	3.9	4.9	7.9
5	19.7	24.0	34.8	57.7	90.0	98.5	115.8	166.0	0.8	1.7	2.3	2.8	110.5	124.2	152.9	226.6
6	28.2	31.5	36.4	45.0	20.0	21.2	24.6	34.5	8.8	8.7	12.9	16.6	57.0	61.4	73.9	96.1
7	12.0	14.8	21.5	39.6	23.0	27.5	38.6	81.0	18.0	18.0	18.0	19.0	53.0	60.3	78.1	139.6
8	5.3	5.9	8.0	14.0	10.0	11.7	16.6	34.9	2.5	2.5	5.3	6.3	17.8	20.1	29.9	55.2
9 [5]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 [5]	-	-	-	-	3.8	4.9	8.0	22.4 [6]	-	-	-	-	3.8	4.9	8.0	22.4

1/ Consumptive use estimated as 10% of withdrawals except for the brackish water for Sub-basin 10 which is about 1%.
2/ Consumptive use estimated as 100% of withdrawals

3/ Total does not include out-of-basin diversions
4/ Total includes 3 mgd out of basin diversions through 1970 and 6 mgd in 1980 and thereafter

5/ Future fresh water requirements for Sub-basins 9, 10, 11 and 12 are assumed to be supplied from ground water
6/ Brackish water for industrial cooling. Negligible amounts would also be needed in Sub-basins 8 and 9.

TABLE VI-3

DELAWARE RIVER BASIN

ESTIMATED INCREASE IN 30-DAY CONSUMPTIVE USE FROM BASE YEAR 1965 TO BE MET FROM SURFACE WATER SOURCES 1/

(MGD)

Sub-basin No.	Year 1986	Year 2020
1	0.9	1.2
2	4.5	16.6
3	15.2	30.5
4	1.7	4.7
Total to Trenton	22.3	53.0
5	42.4	116.0
6	16.9	39.1
7	25.1	86.6
8	12.1	37.4
9 2/	0	0
10 2/	4.2 3/	18.6 3/
Total	123.0	350.7

1/ Does not include consumptive uses for power or out-of-basin diversions except as noted in Tables VI-1 and VI-2.

2/ Future fresh water requirements for Sub-basins 9, 10, 11, and 12 are assumed to be supplied from ground water.

3/ Brackish water requirement for industrial cooling. Negligible amount would also be needed in Sub-basins 8 and 9.

Section VII

WATER FOR THERMAL POWER GENERATION

A. Existing Plants

An inventory of existing water related electric generating stations using the water resources of the Delaware River Basin, with data on plant ownership, location, capacity and type of unit and method of cooling is given in Table VII-1. The locations of the plants are shown on Plate VII-1. Identifying numbers of existing plants are prefixed with the letter "E" in Table VII-1 and on Plate VII-1. Data for the listing of plants are based on the latest survey as summarized in the Master Siting Study.[1/]

Abbreviations and meaning of symbols and terms used in tables are explained in Table VII-3.

B. Proposed Plants

A list of all proposed water related electric generating stations using the water resources of the Delaware River Basin, together with additions, retirements and reductions in the capacity of existing plants, as planned for the period 1972-86 are listed by years in Table VII-2. The locations of these plants are also shown on Plate VII-1. Other pertinent data such as plant ownership, capacity, and estimated water consumptive use are given in Table VII-2. The letter "P" has been prefixed to the identifying number for new plants in both the Table VII-2 and on Plate VII-1. Numbers identifying plant retirements and reductions in capacity of existing plants correspond to those on Table VII-1. All information on proposed plants has been taken from the Master Siting Study[1/].

1/ Reference No. 143

C. Proposed Future Consumptive Use

Estimates of the future consumptive use of water for thermal power plant cooling for the period 1972-86 by years are shown in Table VII-4 for each of the Delaware River sub-basins. Plate VII-2 is a graphical presentation of the estimates showing cumulative totals for the basin above and below Trenton. These estimates are based on the forecast of consumptive use presented in Table VII-2. They reflect average requirements considering life time plant capacity factors and annual mean river water temperature and wind speed. The maximum monthly requirements would be approximately 20 percent greater than the average.

Requirements for plants existing during the 60's are reflected in the minimum stream flow records of that period. Water related plant capacity increases within the basin between 1965 and 1972 have been small and consumptive water uses are considered to have remained constant.

In preparing the estimates, all increases in water needs because of new capacity and reductions due to retirement or derating of existing generating units were considered. An exception are the requirements for Plant P-13 in Sub-basin 8 which were not included as it is proposed to import the consumptive and non-consumptive water needs from the Susquehanna River.

The total estimates given in Table VII-4 were based on supplying the plants under average river flow conditions. However, there are several proposals noted below and in the footnotes to Table VII-2 for particular plants which would modify the demands within the basin during the low-flow periods, but are not reflected in the estimates.

These proposals are:

1. Supply the requirements for Plant P-6 in Sub-basin 2 and Plant P-18 in Sub-basin 4 by a reallocation of existing storage in the Lackawaxen Basin (Sub-basin 1).

2. Supply the requirements of Plant P-22 in Sub-basin 6 from storage to be provided on a Schuylkill River tributary.

3. Supply the requirements of Plant P-9 in Sub-basin 6 by an intra-basin diversion from the Delaware River in Sub-basin 4.

TABLE VII-1
DELAWARE RIVER BASIN
EXISTING WATER RELATED ELECTRIC GENERATING STATIONS
YEAR 1971

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Type of Cooling
E-1	Philadelphia Electric Co.	Richmond #9,10, 11 & 12	5	F[1]	447	OTF[1]
E-2	Philadelphia Electric Co.	Delaware #2,4,5, 6,7 & 8	5	F	346	OTF
E-3	Philadelphia Electric Co.	Southwark #1,2	5	F	369	OTF
E-4	Philadelphia Electric Co.	Eddystone #1,2	5	F	662	OTF
E-5	Philadelphia Electric Co.	Chester #1,2,3,4 5 & 6	5	F	263	OTF
E-6	Philadelphia Electric Co.	Cromby #1,2	6	F	357	OTF
E-7	Philadelphia Electric Co.	Barbadoes #1,3 & 4	6	F	155	OTF
E-8	Philadelphia Electric Co.	Schuylkill #1,3,5,8 & 9	5	F	306	OTF
E-9	Atlantic City Electric Co.	Greenwich #1,2	7	F	12.5	None

1/ Abbreviations and meaning of symbols are explained in Table VII-3

TABLE VII-1 (Cont'd)
DELAWARE RIVER BASIN
EXISTING WATER RELATED ELECTRIC GENERATING STATIONS
YEAR 1971

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Type of Cooling
E-10	Atlantic City Electric Co.	Deepwater #1,3,4,5, 6 & 7	9	F	325	OTS
E-11	City of Vineland, N.J.	Vineland #4,5,6	11	F	11.9	SP
		#7,8,9 & 10	11	F	59.6	CT
E-12	General Public Utilities	Portland #1 & 2	2	F	410	OTF
E-13	General Public Utilities	Gilbert #1,2 & 3	4	F	128	OTF
E-14	General Public Utilities	Eyler #5,6 & 7	6	F	54	OTF
E-15	General Public Utilities	Titus #1,2 & 3	6	F	240	OTF
E-16	Delmarva Power & Light Co.	Delaware City #1,2 & 3	10	F	120.5	OTS
E-17	Delmarva Power & Light Co.	Edge Moor #1,2,3 & 4	8	F	391	OTS
E-18	City of Dover - Delaware	Dover #1 & 2	12	F	34	CT

TABLE VII-1 (Cont'd)
DELAWARE RIVER BASIN
EXISTING WATER RELATED ELECTRIC GENERATING STATIONS
YEAR 1971

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Type of Cooling
E-19	Pennsylvania Power & Light Co.	Martins Creek #1 & 2	2	F	302	OTF
E-20	Public Service Electric and Gas Co.	Mercer #1 & 2 #3	7 7	F CT	600 140	OTF OTF
E-21	Public Service Electric and Gas Co.	Burlington #1,2,3,4, 5,6 & 7	7	F	480	OTF
E-22	General Public Utilities and Public Service Electric and Gas Co.1/	Yards Creek #1,2 & 3	2	PSH	330	None
E-23	Orange and Rockland Utilities, Inc.	Swinging Bridge #1 & 2	1	H	11.75	None
E-24	Orange and Rockland Utilities, Inc.	Mongaup #1, 2,3 & 4	1	H	4	None
E-25	Orange and Rockland Utilities, Inc.	Rio #1 & 2	1	H	10	None
E-26	Orange and Rockland Utilities, Inc.	Grahamsville #1	1	H	18	None
E-27	Pennsylvania Power & Light Co.	Wallenpaupack #1 & 2	1	H	44	None

1/ Joint Ownership - General Public Utilities - 50%, Public Service Electric and Gas Co. - 50%

TABLE VII-2
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1972

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
E-1	Philadelphia Electric Co.	Richmond #10 & 11	5	F	(17)D 1/ 2/	30	OTF 2/	(0.4)	(0.2)
E-2	Philadelphia Electric Co.	Delaware #6	5	F	(16)R	30	OTF	(0.6)	(0.2)

1/ Derating occurred on 12/31/71

2/ Abbreviations and meaning of symbols are explained in Table VII-3

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1973

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-1	Delmarva Power & Light Co.	Edge Moor #5	8	F	400 1/	50	OTS	4.2	3.2
P-2	General Public Utilities	Gilbert Phase I 2/	4	CT	190	6 3/	OTF	Negl.	0
E-5	Philadelphia Electric Co.	Chester #1,2,3 & 4	5	F	(39)D	30	OTF	(1.6)	(0.5)
P-3	Public Service Electric and Gas Co.	Burlington Module #105	7	CC	40	8	OTF	0.5	0.1

1/ Capacity shared equally with the Philadelphia Electric Co. until 1975.

2/ Initial combustion turbine phase.

3/ Capacity factor 40% after 1974.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1974

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-2	General Public Utilities	Gilbert Phase 2	4	CC	130	40	CT	4.0	2.0
P-4	Philadelphia Electric Co.	Eddystone #3	5	F	400	45	OTF	4.6	2.3
E-7	Philadelphia Electric Co.	Barbadoes #1	6	F	(21)R	15	OTF	(1.0)	(0.3)
E-5	Philadelphia Electric Co.	Chester #1,2,3 & 4	5	F	(80)R	30	OTF	(8.0)	(2.9)
E-2	Philadelphia Electric Co.	Delaware #2,4, & 5	5	F	(78)R	30	OTF	(6.4)	(1.8)
E-1	Philadelphia Electric Co.	Richmond #10 & 11	5	F	(94)R	30	OTF	(2.7)	(1.2)
E-8	Philadelphia Electric Co.	Schuylkill #5 & 8	5	F	(43)R	40	OTF	(1.2)	(0.3)
P-5	City of Dover - Delaware 1/	Dover #3	12	F	110	50	CT	None	None

1/ Existing capacity of 34-MW (See E-18) and additional capacity of 110-MW are to be incorporated into the PJM System, through the Delmarva Power & Light Co., in 1974. Cooling tower makeup is from the municipal well water system.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1975

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-6	Pennsylvania Power & Light Co.	Martins Creek #3	2	F	800	50	CT	14.7	13.7 1/
P-4	Philadelphia Electric Co.	Eddystone #4	5	F	400	45	OTF	4.6	2.3
P-7	Public Service Electric and Gas Co. 2/	Salem #1, 2	9	N	2205	78	OTS	38.2	28.0
E-21	Public Service Electric and Gas Co.	Burlington #1,2,3 & 4	7	F	(45)R	4	OTF	(0.2)	Negligible

1/ It is proposed to supply the demand during low-flow periods by reallocation of existing storage.

2/ Joint Ownership - Public Service Electric and Gas Co. (42.59%); Philadelphia Electric Co. (42.59%); Atlantic City Electric Co. (7.41%); Delmarva Power & Light Co. (7.41%).

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1976

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-8	General Public Utilities and Public Service Electric and Gas Co. 1/	Kittatinny Phase 2	2	PSH	500	20	None	0	0
P-9	Philadelphia Electric Co.	Limerick #1	6	N	1055	80	CT	33.0	27.0 2/

1/ Joint Ownership - General Public Utilities (35%); Public Service Electric and Gas. Co. (65%).

2/ It is proposed to supply the demand during low-flow periods by intra-basin diversion from the Delaware River in Sub-basin 4.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1977

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-6	Pennsylvania Power & Light Co.	Martins Creek #4	2	F	800	50	CT	14.7	13.7 1/
P-9	Philadelphia Electric Co.	Limerick #2	6	N	1055	80	CT	33.0	27.0 2/
E-14	General Public Utilities	Eyler #5,6,7	6	F	(54)R	25	OTF	1.0 (1.0)	(0.8)

1/ It is proposed to supply the demand during low-flow periods by reallocation of existing storage.

2/ It is proposed to supply the demand during low-flow periods by intra-basin diversion from the Delaware River in Sub-basin 4.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1978

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
E-10	Atlantic City Electric Co.	Deepwater #3 & 4	9	F	(106)R	32	OTS	(0.6)	(0.5)
P-10	Atlantic City Electric Co.	Deepwater #10	9	F	300	50	OTS	2.2	1.4
E-1	Philadelphia Electric Co.	Richmond #12	5	F	(160) R	40	OTF	(5.6)	(2.0)
P-11	Public Service Electric and Gas Co.	Newbold Island #1	7	N	1100	78	CT	31.5	27.1

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1979

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
P-12	Delmarva Power & Light Co.	Red Lion #1	10	N	800	75	OTS	14.0	11.9
P-13	Philadelphia Electric Co.	Mid County #1	8	N	1160	80	CT	30.0 1/	27.0 1/
P-11	Public Service Electric and Gas Co.	Newbold Island #2	7	N	1100	78	CT	31.5	27.1
P-8	General Public Utilities and Public Service Electric and Gas Co. 2/	Kittatinny Phase 3	2	H & PSH	800	22.5	None	0	0

1/ It is proposed to import water from Susquehann River including 10 cfs of non-consumptive supplies which will be released to the Delaware Basin.

2/ Joint Ownership - General Public Utilities (35%); Public Service Electric and Gas Co. (65%).

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1980

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
P-14	General Public Utilities	Thuerk #1	4	CC	316	35	CT	4.0	2.0
P-15	Orange and Rockland Utilities, Inc.	Lumberland #1	1	PSH	150	30	None	0	0

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1981

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-10	Atlantic City Electric Co.	Deepwater #11	9	F	400	50	OTS	2.9	1.8
P-16	General Public Utilities	Portland #5	2	N	1200	80	CT	32.0	28.0
P-15	Orange and Rockland Utilities, Inc.	Lumberland #2	1	PSH	150	30	None	0	0
P-6	Pennsylvania Power & Light Co.	Martins Creek #5	2	F	800	50	CT	14.7	13.7 [1]
P-13	Philadelphia Electric Co.	Mid County #2	8	N	1160	80	CT	30.0	27.0 [2]
E-5	Philadelphia Electric Co.	Chester #5 & 6	5	F	(144)R	60	OTF	(2.7)	(1.9)
E-21	Public Service Electric and Gas Co.	Burlington #5	7	F	(118)R	30	OTF	(0.8)	(0.2)

1/ It is proposed to supply the demand during low-flow periods by reallocation of existing storage.

2/ It is proposed to import water from Susquehanna River including 10 cfs of non-consumptive supplies which will be released to the Delaware Basin.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1982

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
P-12	Delmarva Power & Light Co.	Red Lion #2	10	N	800	75	OTS	14.0	11.9
P-17	Orange and Rockland Utilities, Ins.	Delaware #1	1	F	600	70	CT	11.3	10.2

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1983

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-16	General Public Utilities	Portland #6	2	N	1200	80	CT	32.0	28.0
P-18	Pennsylvania Power & Light Co.	Lower Lehigh #1	4	N	1120	70	CT	31.0	25.0 1/
P-19	Philadelphia Electric Co.	Upper Delaware River #1	4	N	1500	80	CT	43.0	40.0
E-8	Philadelphia Electric Co.	Schuylkill #9	5	F	(33)R	50	OTF	(1.2)	(0.3)
E-21	Public Service Electric and Gas Co.	Burlington #6	7	F	(120)R	40	OTF	(1.3)	(0.5)
P-20	Public Service Electric and Gas Co.	Frenchtown #1	4	N	1500	78	CT	43.0	36.6

1/ It is proposed to supply the demand during low-flow periods by reallocation of existing storage.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1984

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
P-21	Atlantic City Electric Co.	Bayside #1	11	F	400	50	OTS	2.9	1.8
P-20	Public Service Electric and Gas Co.	Frenchtown #2	4	N	1500	78	CT	43.0	36.6

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1985

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity Mw	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Water Consumptive Usage - CFS Avg.
P-22	General Public Utilities	Berne	6	N	1200	80	CT	32.0	28.0 1/
P-23	General Public Utilities	No.Jersey #1	2	CC	316	40	CT	4.0	2.0
P-17	Orange and Rockland Utilities, Inc.	Delaware #2	1	F	600	70	CT	11.3	10.2
P-18	Pennsylvania Power & Light Co.	Lower Lehigh #2	4	N	1120	70	CT	31.0	25.0 2/
P-19	Philadelphia Electric Co.	Upper Delaware River #2	4	N	1500	80	CT	43.0	40.0
E-4	Philadelphia Electric Co.	Eddystone #1	5	F	(328)R	75	OTF	(3.0)	(2.2)
P-24	Public Service Electric and Gas Co.	Mercer #4	7	F	400	10	OTF	2.2	1.6

1/ It is proposed to provide conservation storage to supply the demand during low-flow periods.

2/ It is proposed to supply the demand during low-flow periods by reallocation of existing storage.

TABLE VII-2 (Cont'd)
DELAWARE RIVER BASIN
PLANNED AND PROPOSED WATER RELATED ELECTRIC GENERATION ADDITIONS AND RETIREMENTS
YEAR 1986

Plant Ref. No.	Company	Location & Unit No.	DRBC Sub Basin No.	Type of Unit	Capacity MW	Lifetime Capacity Factor %	Type of Cooling	Water Consumptive Usage - CFS Max.	Avg.
P-21	Atlantic City Electric Co.	Bayside #2	11	F	500	50	OTS	3.7	2.3
P-25	Public Service Electric and Gas Co.	Delaware Bay #1	11	N	1500	78	OTS	26.0	19.1
P-26	Philadelphia Electric Co.	Croydon #1 & 2	5	F	1500	50	CT	36.0	28.0
E-4	Philadelphia Electric Co.	Eddystone #2	5	F	(334)R	75	OTF	(3.1)	(2.3)

TABLE VII-3

DEFINITION OF TERMS AND ABBREVIATIONS
FOR
TABLE VII-1
EXISTING WATER RELATED ELECTRIC GENERATING STATIONS
AND
TABLE VII-2
PROPOSED AND PLANNED WATER RELATED
ELECTRIC GENERATION ADDITIONS AND RETIREMENTS

TYPE OF UNIT

CC - Combined Cycle, (Gas Turbine and Steam Turbine)
F - Fossil Fueled Steam Cycle
H - Hydroelectric
N - Nuclear Fueled Steam Cycle
PSH - Pumped Storage Hydroelectric

CAPACITY - MW

Megawatts of summer net capacity.

(-)D denotes "Derating" of unit or plant capacity.

(-)R denotes reduction in capacity due to "Retirement" of plant equipment.

All capacity additions and retirements scheduled on the basis of being available for service for summer peak load (June 1).

TYPE OF COOLING

OTF - Once Through Fresh Water
OTS - Once Through Salt or Brackish Water
CT - Cooling Tower, Closed Loop
SP - Spray Pond

LIFETIME CAPACITY FACTOR

Ratio of the total kilowatt hours generated to the maximum possible kilowatt hours that may be generated for the remaining life of the station or unit, calculated on an average annual basis.

WATER CONSUMPTIVE USAGE - CFS

Cubic Feet Per Second

"Average" based on the lifetime capacity factor.

"Maximum" based on the month in which the capacity factor and other pertinent variables result in the highest consumptive use.

The following references were used as guidelines in the estimation of consumptive water usage for "once through" cooled electric generating units: Edison Electric Institute Reports numbered: 69-901, entitled "Surface Heat Exchange at Power Plant Cooling Lakes" by D. K. Brady, W. L. Graves, Jr. and Dr. J. C. Geyer, dated November 1969; 65-902, entitled "Heat Exchange in the Environment" by Dr. J. C. Geyer, and Dr. J. E. Edinger, dated June 1, 1965.

Estimates of consumptive water usage for cooling towers were based on data supplied by cooling tower manufacturers.

(-) denotes reduction in consumptive water usage due to derating or retirement of electric generating units.

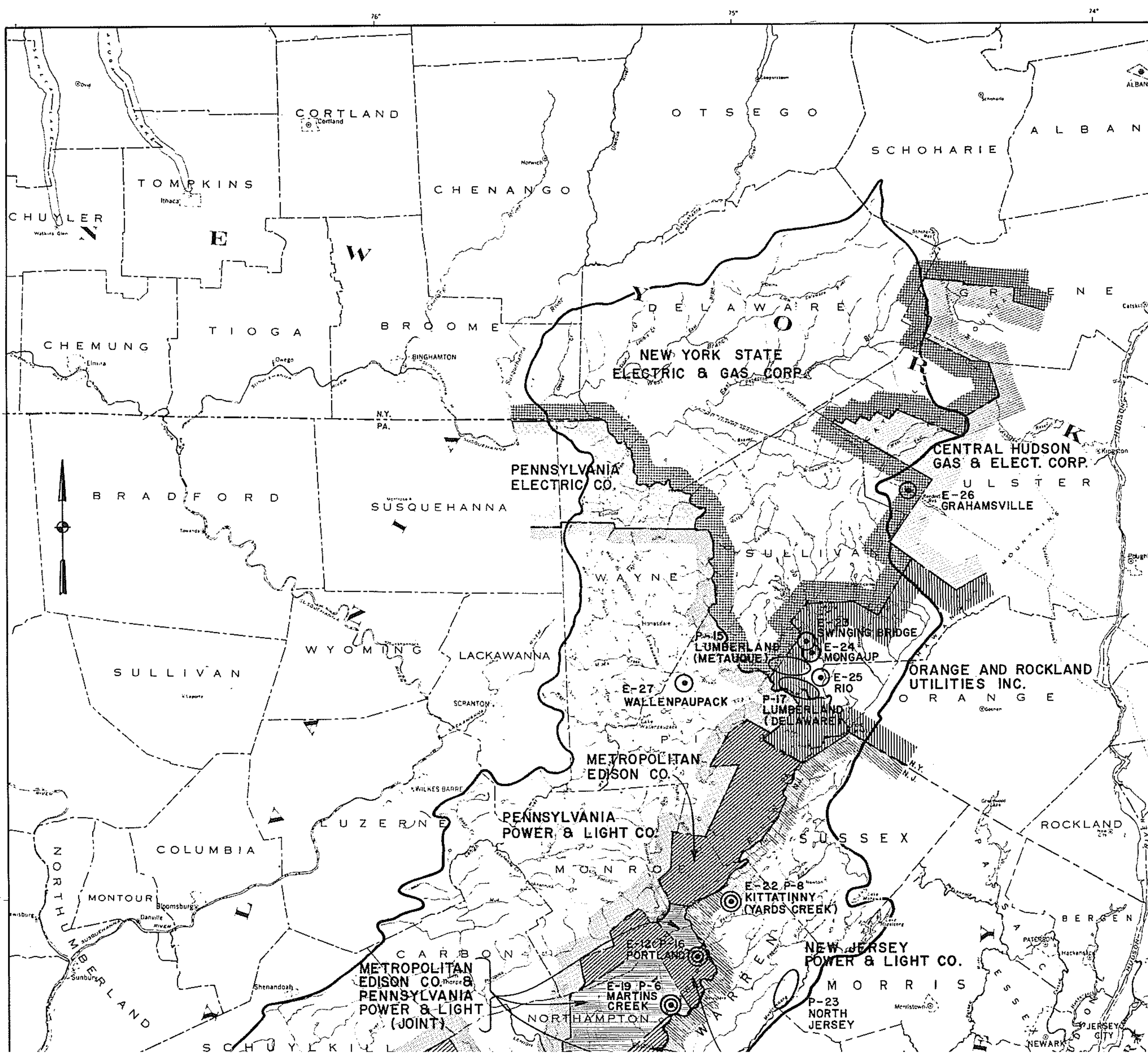
TABLE VII-4

DELAWARE RIVER BASIN

AVERAGE FUTURE CONSUMPTIVE WATER USE FOR THERMAL POWER PLANT COOLING - CFS

Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total
Sub-basin																
1											10.2			10.2		20.4
2				13.7		13.7				41.7		28.0		2.0		99.1
3																0
4			2.0						2.0			101.6	36.6	65.0		202.7
Sub-Total, Above Trenton			2.0	13.7		13.7			2.0	41.7	10.2	129.6	36.6	77.2		326.7
Accumulative Sub-total			2.0	15.7	15.7	29.4	29.4	29.4	31.4	73.1	83.3	212.9	249.5	326.7	326.7	
5	(0.4)[1/]	(0.5)	(3.9)	2.3			(2.0)			(1.9)		(0.3)		(2.2)	25.7	16.8
6			(0.3)		27.0	26.2								28.0		80.9
7		0.1					27.1	27.1		(0.2)		(0.5)		1.6		55.2
8		3.2														3.2
9				28.0			0.9			1.8						30.7
10								11.9			11.9					23.8
11													1.8		21.4	23.2
12																0
Sub-total, Below Trenton	(0.4)	2.8	(4.2)	30.3	27.0	26.2	26.0	39.0		(0.3)	11.9	(0.8)	1.8	27.4	47.1	233.8
Accumulative Sub-total	(0.4)	2.4	(1.8)	28.5	55.5	81.7	107.7	146.7	146.7	146.4	158.3	157.5	159.3	186.7	233.8	

1/ Numbers in parenthesis denote a reduction in consumptive use because of retirements or derating of existing capacity.



76°
75°
74°
CORTLAND
OTSEGO
SCHOHARIE
ALBANY
TOMPKINS
CHENANGO
SCHUYLER
NEW YORK
DELAWARE
GREENE
CHEMUNG
TIOGA
BROOME
BINGHAMTON
NEW YORK STATE ELECTRIC & GAS CORP.
N.Y.
PA.
CENTRAL HUDSON GAS & ELECT. CORP.
PENNSYLVANIA ELECTRIC CO.
BRADFORD
SUSQUEHANNA
ULSTER
E-26 GRAHAMSVILLE
SULLIVAN
WAYNE
P-15 LUMBERLAND (METAUQUE)
E-23 SWINGING BRIDGE
E-24 MONGAUP
E-25 RIO
WYOMING
LACKAWANNA
SULLIVAN
E-27 WALLENPAUPACK
P-17 LUMBERLAND (DELAWARE)
ORANGE AND ROCKLAND UTILITIES INC.
ORANGE
SCRANTON
PIKE
METROPOLITAN EDISON CO.
N.Y.
N.J.
WILKES BARRE
LUZERNE
PENNSYLVANIA POWER & LIGHT CO.
SUSSEX
ROCKLAND
COLUMBIA
MONROE
NORTHUMBERLAND
MONTOUR
E-22 P-8 KITTATINNY (YARDS CREEK)
BERGEN
CARBON
E-12 P-16 PORTLAND
NEW JERSEY POWER & LIGHT CO.
METROPOLITAN EDISON CO. & PENNSYLVANIA POWER & LIGHT (JOINT)
E-19 P-6 MARTINS CREEK
MORRIS
WARREN
PASSAIC
NORTHAMPTON
P-23 NORTH JERSEY
SCHUYLKILL
NEWARK
JERSEY CITY

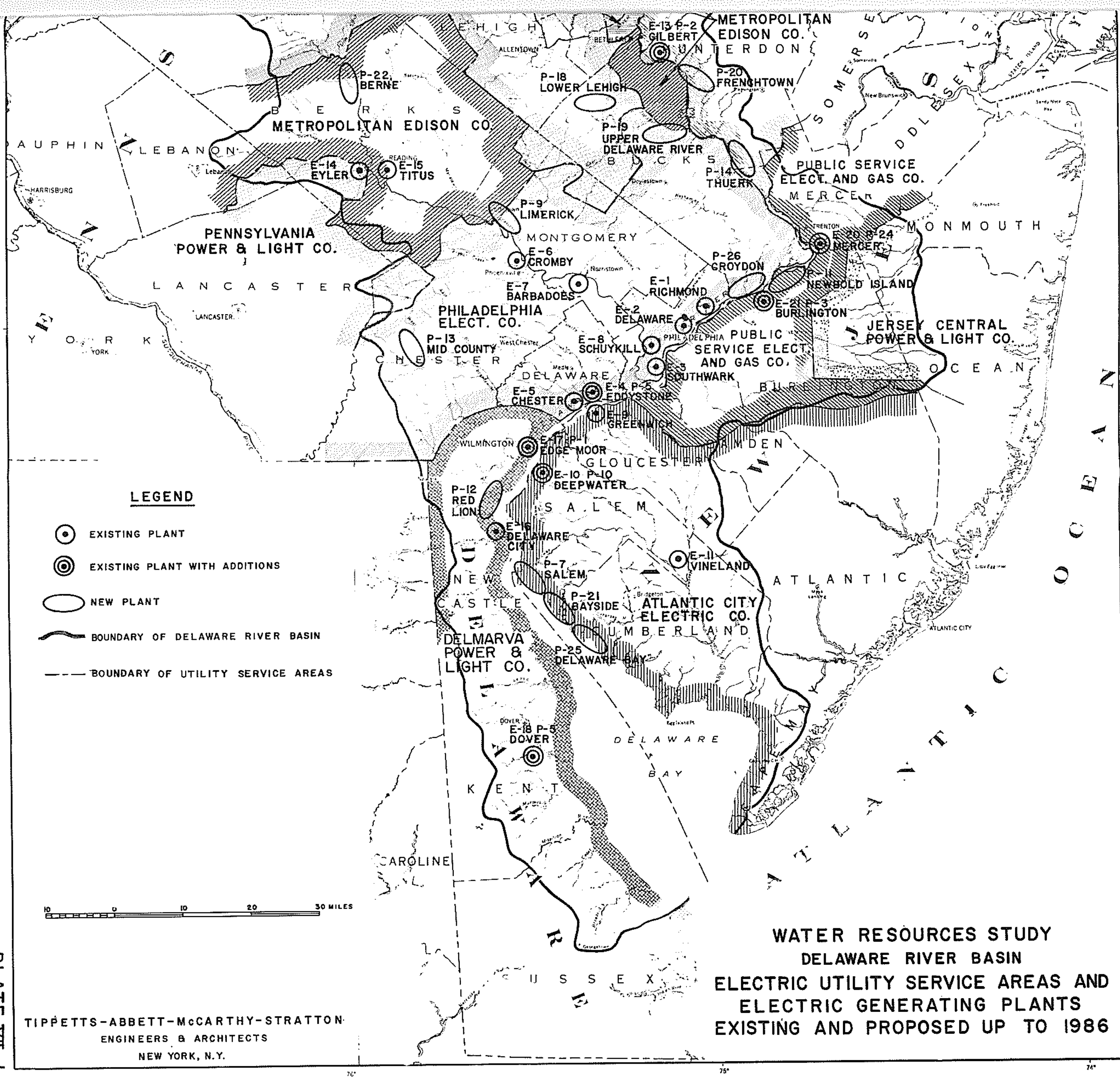
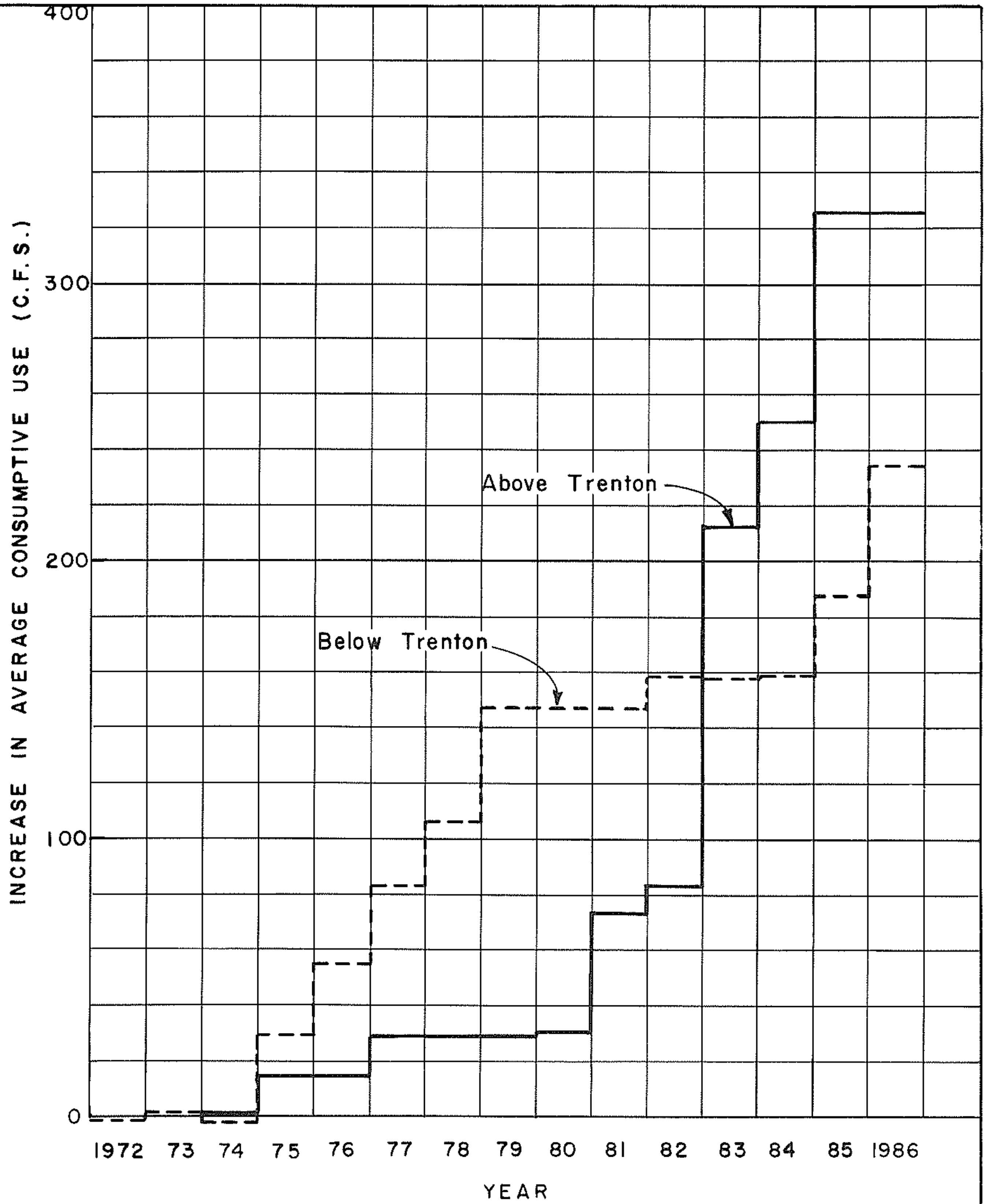

WATER RESOURCES STUDY
DELAWARE RIVER BASIN
ELECTRIC UTILITY SERVICE AREAS AND
ELECTRIC GENERATING PLANTS
EXISTING AND PROPOSED UP TO 1986
TIPPETTS-ABBETT-McCARTHY-STRATTON
ENGINEERS & ARCHITECTS
NEW YORK, N.Y.
LEGEND
EXISTING PLANT
EXISTING PLANT WITH ADDITIONS
NEW PLANT
BOUNDARY OF DELAWARE RIVER BASIN
BOUNDARY OF UTILITY SERVICE AREAS
10 0 10 20 30 MILES
METROPOLITAN EDISON CO.
PENNSYLVANIA POWER & LIGHT CO.
PHILADELPHIA ELECT. CO.
PUBLIC SERVICE ELECT. AND GAS CO.
JERSEY CENTRAL POWER & LIGHT CO.
ATLANTIC CITY ELECTRIC CO.
DELMARVA POWER & LIGHT CO.
E-13 P-2 GILBERT
P-20 FRENCHTOWN
P-22 BERNE
P-18 LOWER LEHIGH
P-19 UPPER DELAWARE RIVER
P-14 THUERK
E-14 EYLER
E-15 TITUS
P-9 LIMERICK
E-6 CROMBY
E-7 BARBADOES
P-26 CROYDON
E-20 P-24 MERCER
P-11 NEWBOLD ISLAND
E-21 P-3 BURLINGTON
E-1 RICHMOND
E-2 DELAWARE
E-8 SCHUYKILL
E-3 SOUTHWARK
P-13 MID COUNTY
E-5 CHESTER
E-4 P-5 EDDYSTONE
E-9 GREENWICH
E-17 P-1 EDGE MOOR
E-10 P-10 DEEPWATER
P-12 RED LION
E-16 DELAWARE CITY
E-11 VINELAND
P-7 SALEM
P-21 BAYSIDE
P-25 DELAWARE BAY
E-18 P-5 DOVER
ATLANTIC OCEAN
DELAWARE BAY

PLATE VII-1



WATER RESOURCES STUDY
DELAWARE RIVER BASIN
ESTIMATED FUTURE WATER CONSUMPTION
THERMAL POWER PLANT COOLING
1972 - 86

TIPPETTS-ABBETT-McCARTHY-STRATTON
ENGINEERS & ARCHITECTS
NEW YORK, N.Y.

PLATE VII - 2

Section VIII

ESTIMATES OF WATER BALANCE BASED ON REPETITION OF DROUGHT OF SIXTIES

A. Coordinating Committee Study

A reappraisal of the water resources of the Delaware River Basin was made in 1969 by a Coordinating Committee formed for this purpose and consisting of representatives of Federal,State,and Municipal organizations involved in water supply development in the basin. The study was in two parts: 1) A determination of the relation between flows diverted to New York City and minimum flows at Montague; 2) A study of the effectiveness of major reservoir projects in the DRBC Comprehensive Plan. Both parts of the study were based on the assumed recurrence of the drought of the 1960's, although the first part also evaluated the effect of the lesser drought of the 1930's.

1 - New York City Diversion: The reappraisal of the safe yield of New York City's Delaware system was made with the cooperation of the office of the Delaware River Master and the New York City Department of Water Resources. The methodology, limitations, results of the study are described in the draft report of the Coordinating Committee[1/]. The following conclusions of the Committee's study have been generally confirmed in this report.

a) The maximum uniform diversion rate that might be sustained during a repetition of the drought of the 1960's from the New York City reservoirs in the Delaware River Basin, while maintaining a minimum flow at Montague of 1750 cfs, is 746 cfs.

b) The total live storage of the three New York City reservoirs would have been utilized during the historic drought period.

2 - Yield Capability of Major Reservoir Projects in the DRBC Comprehensive Plan: The analysis and appraisal of the yield of the DRBC Plan reservoirs was made jointly by the U.S.Army Corps of Engineers, Philadelphia District, and the DRBC staff. In their study daily flows were

1/ Reference No.126

routed through the reservoirs for a range of minimum flows at Montague. The number of participating reservoirs for each flow condition at Montague varies and future New Jersey out-of-basin diversions are applied to certain reservoir combinations (see Table IV-4, Reference 126).

B. Corps of Engineers Reservoir Operation Computer Program

Early in 1971 another reservoir system analysis was made by the Corps of Engineers, based on Generalized Computer Program HEC-3, developed by the Hydrologic Engineering Center of the same agency in Davis, California. The input to the program, prepared by the Philadelphia District and the New York City Department of Water Resources, consisted of the unregulated monthly flows for the period June 1, 1961, to May 30, 1967. The program is applied so that the flows at Trenton are maximized while attempting to maintain minimum flow requirements elsewhere on the Delaware River and its tributaries. The maximization of the flows at Trenton is achieved by appropriate operation of the reservoirs which are assumed to be full at the beginning of the period of study. The study encompasses the entire river basin above the Delaware Estuary. Flows are analyzed at 11 reservoirs and at an additional 10 control points in the basin where the minimum flow requirements are set as shown on Table VIII-1.

In the computer program as applied by the Corps of Engineers, the three reservoirs of the New York City water supply system are assumed to be operating as one unit with the usable storage equal to the sum of the three component storages. The computer is assigned the task of maximizing the New York diversion (1240 cfs objective) while attempting to compensate for deficiencies (less than 1750 cfs) in the Montague discharge. For this purpose a special rule curve has been devised for the operation of the combined New York City reservoirs. This rule curve specifies releases that depend on the time of the year, condition of reservoir storage and flow objectives. Simpler rule curves are used for the other reservoirs in the system.

TABLE VIII-1

DELAWARE RIVER BASIN

MINIMUM FLOW REQUIREMENTS AND GOALS

Reservoir	Minimum Release (cfs)	Control Point	Min. Flow Requirement (cfs)
Wallenpaupack	0	Montague	1750
NYC Combined Res. 1/	19 2/	Belvidere	None
Tocks Island	2790	Walnutport	None
F.E. Walter	100	Bethlehem	None
Beltzville	35	Riegelsville	None
Aquashicola	15	Delaware-Raritan Canal	None 3/
Trexler	5	Trenton	3998 4/
Hackettstown	32	Pottstown	None
Nockamixon	5	Philadelphia	600
Maiden Creek	42	Delaware Estuary	None
Blue Marsh	45		

1/ Pepacton, Neversink and Cannonsville reservoirs used for water supply for New York City.

2/ Flow within the Delaware River Basin - does not include diversion to New York City. April to November minimum conservation release of 57 cfs is an additional requirement incorporated in the program.

3/ Requirement refers to river main stem - does not include diversion to New Jersey through the canal.

4/ Maximized low flow obtained in trials to satisfy all other limitations.

The results obtained by this application of the computer program indicate that:

(a) Due to the severity of the drought, the New York diversion requirement is not satisfied fully nor is the minimum flow requirement at Montague maintained at 1750 cfs. Twenty-five months during the drought Montague requirements are not met, and the New York diversions are reduced to 671 cfs, while 96.7 percent of the combined reservoir storage is used.

(b) The useable storage at Tocks Island is totally depleted for four months (three of them consecutive) during which the minimum release goal of 2790 cfs is not met.

(c) The supply of water to New Jersey through the Delaware-Raritan Canal is maintained at a rate of 80 cfs throughout the study period.

(d) The low flow at Trenton is maximized to 3998 cfs by the use of 99.0 percent of the total live storage in the reservoir system between Montague and Trenton.

(e) All other minimum flow requirements are met.

C. Criteria Used for the Studies in this Report.

For the purposes of the investigation undertaken for this report the following criteria have been adopted to be used in conjunction with the Corps of Engineers computer program.

1 - Flow at Montague: In the meeting of the Steering Committee for this study on September 29, 1971, it was decided to assume that the Supreme Court decree regarding the low flow at Montague would be strictly enforced during a recurrence of the drought of the 1960's. Therefore, the analyses were based on low flows at Montague never less than 1750 cfs.

2 - Reservoir Regulation Conditions: The water balance at key points was governed by the following three basic conditions:

(a) Operate the New York City reservoirs to maximize the total diversion to New York City while maintaining 1750 cfs at Montague.

(b) Maintain specified releases for conservation and other purposes to the fullest extent possible.

(c) Operate the system of reservoirs between Montague and Trenton to obtain the maximum possible sustained flow at Trenton.

In general the rule curves for reservoirs between Montague and Trenton were established so that the reservoirs were drawn down in critical periods to make up the difference between the flow at Trenton from the uncontrolled drainage areas and trial "objective flows" at Trenton until maximization is achieved.

3 - <u>Out-of-basin Diversions:</u> Major out-of-basin diversions considered are those to New York City (maximum 1240 cfs or 800 mgd) and to New Jersey (total of 619 cfs (400 mgd), including 464 cfs (300 mgd) in future authorization). The New York City diversions are obtained through reservoir operation as described in the previous paragraph.

The New Jersey diversions were applied to all stations below Riegelsville. However, present diversions of about 80 cfs (52 mgd) were already included in the computer program and were not subtracted from the flows in obtaining 1986 conditions.

4 - <u>In-basin Consumptive Uses:</u> In Sections VI and VII of this report existing and predicted non-power consumptive water uses and future requirements for electric generating stations have been compiled. For purposes of water balance and residual water use determinations these consumptive uses are grouped together in Table VIII-2.

5 - <u>Effect of Tocks Island Reservoir:</u> In view of possible delays in the construction of Tocks Island Reservoir, it was considered pertinent to examine the effect of that reservoir on residual river flows. As an

TABLE VIII-2

DELAWARE RIVER BASIN

FORECAST OF INCREASE IN 30-DAY AVERAGE CONSUMPTIVE WATER USE
(Future Out-of-Basin Diversions not Included)

Sub-basin No.	Consumptive Uses - cfs					Nearest Station Cumulative Total is Applied to
	Year 1986			Year 2020		
	Non-Power[1]	Power[2]	Cum. Total[3]	Non-Power[1]	Cum. Total[3]	
1	1.3	20.4	21.7	1.9	1.9	Montague
2[4]	5.6	79.3	106.6	20.6	22.5	Belvidere[4]
3	23.5	-	23.5	47.2	47.2	Bethlehem
2[4]	1.4	19.8	151.3	5.1	74.8	Riegelsville[4]
4	2.7	207.2	361.2	7.3	82.1	Trenton
Sub-total	34.5	326.7				
5	65.7	16.8	443.7	179.5	261.6	Delaware Estuary
6	26.1	80.9	107.0	60.5	60.5	Philadelphia
7	38.9	55.2	644.8	134.0	456.1	Delaware Estuary
8	18.7	3.2	666.7	57.9	514.0	" "
9	5/	30.7	697.4	5/	514.0	" "
10	6.5 5/	23.8	727.7	28.8 5/	542.8	" "
11	5/	23.2	750.9	5/	542.8	" "
12	5/	-	750.9	5/	542.8	" "
Total	190.4	560.5				

1/ From Table VI-3, where values are given in mgd.
2/ From Table VII-4.
3/ Flows are additive on main stem only.
4/ Eighty percent of Sub-basin 2 consumptive uses are applied to Belvidere and twenty percent to Riegelsville.
5/ Fresh water consumptive uses in Sub-basins 9 to 12 are assumed to be satisfied from ground water. Quantity shown for Sub-basin 10 represents consumptive use of brackish water for industrial cooling

additional criterion, therefore, it was decided to determine all water balances for two distinct cases, with and without Tocks Island operating.

6 - U.S. Fish and Wildlife Service Requirements for Benefit of Oyster Beds: Among the operational requirements for future main river reservoir projects the U.S. Fish and Wildlife Service has included the stipulation[2/] that all inflows other than flood flows (i.e. flows less than 70,000 cfs at Tocks Island) between April 1 and June 30 be released in order to inhibit drill activity at the Delaware Bay oyster beds. This requirement, which is considered applicable to Tocks Island Reservoir only, was not incorporated into the computer program but an estimate of its effects was made.

D. Adaptation of C of E Reservoir Systems Studies Program.

To comply with the criteria set forth in previous paragraphs, certain modifications in the application of the Corps of Engineers computer program were necessary, as follows:

1 - Flow at Montague: The program input was modified so that the flow limitation of not less than 1750 cfs at Montague was met at all times.

2 - Combined New York City Reservoir Rule Curve: In the Corps of Engineers computer program it was assumed that the combined inflow and storage of the three reservoirs would be operated as a unit. After examination of this assumption it was considered more realistic to treat the storage and inflow characteristics of each reservoir separately. For this purpose trial routing operations were made with the objective of maximizing the New York City diversions while supplementing Montague flows in strict compliance with the Supreme Court decree. As a result of this work a new rule curve was developed for the operation of the New York City reservoirs so that their operation would reflect their individual limitations. In the

2/ Information included in "Environmental Impact Statement, Tocks Island Lake", by the Corps of Engineers.

trial determinations the published USGS flow data, i.e., outflows, diversions and change in storage were used to determine the actual inflows into each reservoir, disregarding evaporation losses. The historic outflows of Lake Wallenpaupack and the published flow records at Montague were also used in determining the amounts to be supplemented from the combined New York City reservoirs. To incorporate the results of this work in the computer program the following changes were required.

a) Replacement of the rule curve for the operation of the combined New York City reservoirs.

b) Modification of Lake Wallenpaupack computer operation so as to yield the historic releases contributing to the local flow at Montague.

c) Adjustment of flow records for Montague, Belvidere, Riegelsville and Trenton, which reflect historic flows at Montague.

d) Revision of certain inflows of Bushkill Creek at Shoemakers, Pa. These inflows were the basis for the derivation of the Tocks Island local inflows, by correlation.

3 - Special Adaptations: To investigate the reservoir system in the event that Tocks Island reservoir is not in operation, it was necessary to modify the Tocks Island computer operation so that its inflows are passed through without regulation. Four final computer runs were made covering the following conditions:

Case 1: All reservoirs below Montague operating.
Case 2: Same as Case 1 but without Tocks Island.
Case 3: Only Tocks Island and Beltzville operating.
Case 4: Same as Case 3 but without Tocks Island, i.e., Beltzville only.

In Cases 3 and 4 redefining of the computer input for the eliminated reservoirs was required, so that their respective inflows would remain unregulated.

E. Results of the Studies

For comparison of the various cases studied (without the inclusion of projected consumptive uses and future diversions) Table VIII-3 was prepared on the basis of results at key points. Results of Corps of Engineers Run No. 2 are also shown.

The resulting hydrographs of monthly flows during the repetition of the drought of the 1960's are plotted for Montague, for the combined diversions to New York City, and for Trenton, and are shown on Plates VIII-1 and VIII-2 for Cases 1 and 2, respectively. Application of the remaining criteria described in Sub-section B was made as follows:

1 - Future Consumptive Uses and Out-of-Basin Diversions: The computer program as developed, does not include provisions for automatic computations of the effects of future consumptive uses and out-of-basin diversions on the Delaware River flows. Time limitations did not permit the required additional modifications of the program. Consequently, these effects were determined by simply subtracting the sum of such diversions and consumptive uses from the flow at each point of the river where they will be applied. Based on the assumption that these flow debits would be uniform throughout each drought year, the flows at Montague and Trenton have been modified to reflect 1986 conditions and are shown graphically on Plates VIII-1 and VIII-2 for Cases 1 and 2, respectively. A schematic presentation of the resulting minimum flows at various points in the Delaware River Basin is shown on Plates VIII-3 and VIII-4, covering Cases 1 and 2 for consumptive uses and out-of-basin diversions applicable to the year 1986.

2 - The Effect of Oyster Bed Requirements: In Sub-section C-6 above, reference is made to a request by the U.S. Fish and Wildlife Service that all highwater flows at Tocks Island in the period April 1 to June 30 that are less than 70,000 cfs be released to improve oyster culture in Delaware Bay. The rule curve under which Tocks Island Reservoir was

TABLE VIII-3

DELAWARE RIVER BASIN
SUMMARY OF RESULTS OF RESERVOIR SYSTEM ROUTING
DURING A REPETITION OF THE DROUGHT OF THE SIXTIES

(Projected consumptive uses and future diversions not included)

	Corps of Eng. Run No. 2 1/	Case 1	Case 2	Case 3	Case 4
Minimum Diversion to N.Y.C. from N.Y. City Combined Reservoirs (cfs)	671	776	776	776	776
Average Diversion to N.Y C. from New York City Combined Reservoirs (cfs)	939	909	909	909	909
Duration of Minimum Diversion from NY City Combined Reservoirs (Months out of 72 total)	25	33	33	33	33
Percent of Live Storage Used at the NY City Combined Reservoirs	96.7 2/	96.5 3/	96.5 3/	96.5 3/	96.5 3/
Minimum Flow at Montague (cfs)	1268	1750	1750	1750	1750
Duration of Shortage at Montague (Months out of 72 total)	25	0	0	0	0
Minimum Tocks Island Release (cfs)	1602	2333	Not applicable	2501	Not applicable
Duration of Tocks Island Reservoir. Releases less than 2790 cfs. (Months out of 72 total)	4	4	Not applicable	2	Not applicable
Percent of Total Live Storage Used Between Montague and Trenton	99.0 4/	97.4 4/	94.7 5/	97.2 4/	90.3 2/
Minimum Flow at Trenton (cfs)	3998	4348	3309	3693	2649

1/ Data from Corps of Engineers Run No. 1, not reflecting optimum reservoir operation (less diversion to N.Y. City and less utilization of storage between Montague and Trenton) have been omitted from this Table.
2/ Lowest combined storage in Sept. 1965
3/ Lowest combined storage in Nov. 1965
4/ Lowest total storage in Dec. 1964
5/ Lowest total storage in Nov. 1964

assumed to operate in the computer program does not provide for such releases which might be needed to fill the reservoir in critical years. However, a review of the print-outs for Cases 1 and 3 reveals that Tocks Island Reservoir fails to fill before April 1 only once in the entire period of drought. In April 1965 inflows of less than 70,000 cfs are stored, contrary to the requirement for the oyster beds.

If filling were not permitted in that month, the flow at Trenton would have to be reduced during subsequent months until the reservoir refills. It is estimated that the "objective" low flow at Trenton would have been reduced from 4348 cfs (Case 1) to about 4200 cfs in order to satisfy the oyster bed requirement. The storage in Tocks Island Reservoir would decrease from the full condition at the end of May 1964 to empty in November 1965, and would refill again by the end of March 1966.

3 - Evaluation of the Results: It should be emphasized that the value of the results obtained by this study is directly related to the assumptions made and that discretion should be applied in their use. For instance, the actual consumptive uses normally would vary throughout the year and therefore would not be a uniform reduction of flow, as applied herein. Conversely, if the consumptive uses and out-of-basin diversions had been incorporated in the input to the program, instead of merely being subtracted from the flows at various points, their routed effects would produce slightly different results than those shown on Plates VIII-3 and VIII-4.

The computer program, assumes reservoir operations which will guarantee a minimum flow of 1750 cfs at Montague in a repetition of the drought of the sixties. Furthermore, it was assumed that New York City would not be required to make up for future withdrawals for other purposes from the Delaware River Basin above Montague. Therefore, the projected consumptive uses in Sub-basin No. 1 would result in reductions of the minimum flow at that gage. This explains why a minimum of 1728 cfs is shown for 1986 on Plates VIII-3 and VIII-4.

The effect of the oyster bed requirements is only approximate. More precise results could have been obtained if this requirement had been included in the computer input.

On the basis of the assumptions and procedures used in this study, it may be concluded that:

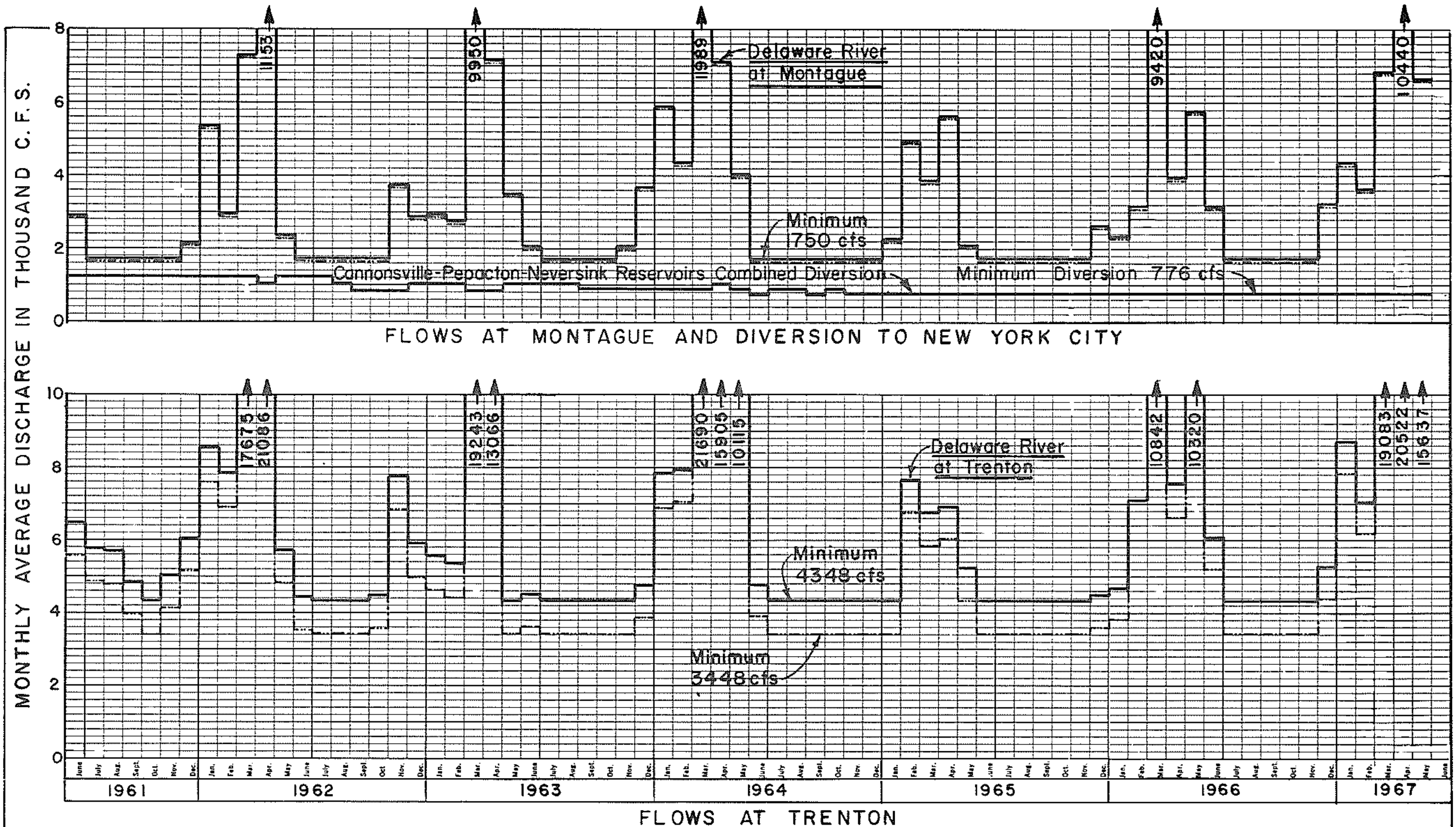
a) Tocks Island Reservoir, possessing about 63 percent of the total live storage between Montague and Trenton, will augment the flow at Trenton by about 1040 cfs.

b) The other reservoirs, (excluding Beltzville which is completed) offering 33 percent of the available live storage, will augment the Trenton flow by 660 cfs.

c) The sequence in which the components of storage become available has no effect on the total flow augmentation at Trenton.

d) The minimum flow at Trenton will be reduced by 1986 total proposed consumptive uses to 3448 cfs if all reservoirs including Tocks Island are built and operating by that time, and to 2409 cfs, if all reservoirs except Tocks Island are operating. If no reservoirs are built the minimum flow at Trenton will be reduced to 1749 cfs.

e) The DRBC flow objective of 3000 cfs at Trenton can be met with the proposed use, provided Tocks Island and approximately one half of the other proposed reservoir capacity become available by 1986.



NOTE:

Flow Adjustments for 1986 Proposed Consumptive Uses Include Average Power Generation Requirements.

LEGEND:

——— Flows as Affected by Optimum N.Y.C. Reservoir Operation & Minimim 1750 cfs Montague Requirement.

—··— Flows Adjusted for 1986 Proposed Consumptive Uses

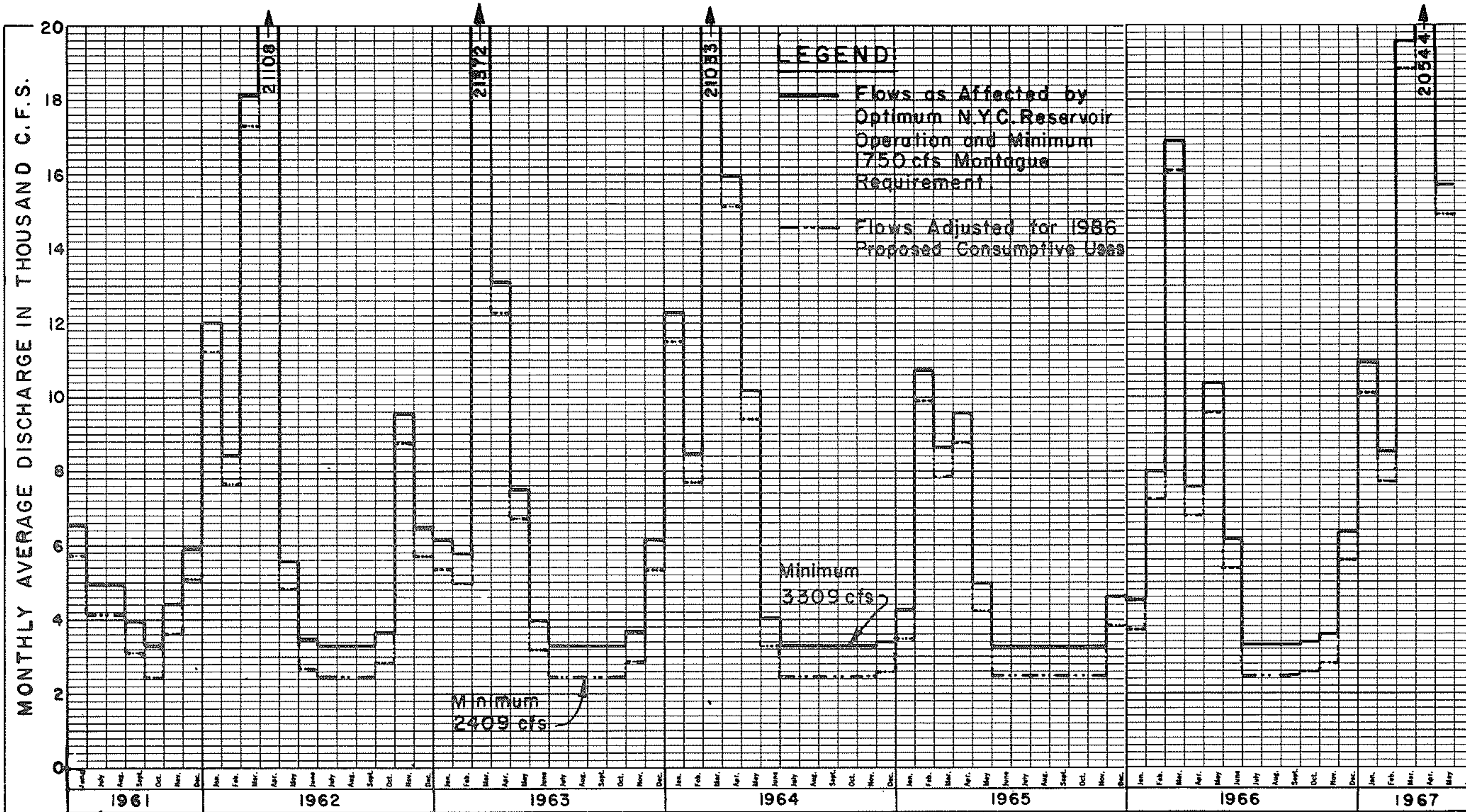
WATER RESOURCES STUDY
DELAWARE RIVER BASIN

FLOWS FOR OPTIMIZED OPERATION OF DRBC RESERVOIRS

IN REPETITION OF DROUGHT OF SIXTIES

CASE I: ALL RESERVOIRS OPERATING

PLATE VIII-1



FLOWS AT TRENTON

NOTES:

1 - Flows at Montague and N.Y.C. Reservoir Releases in Case 2 are Identical with Those in Case I. (See Plate VIII - I.)

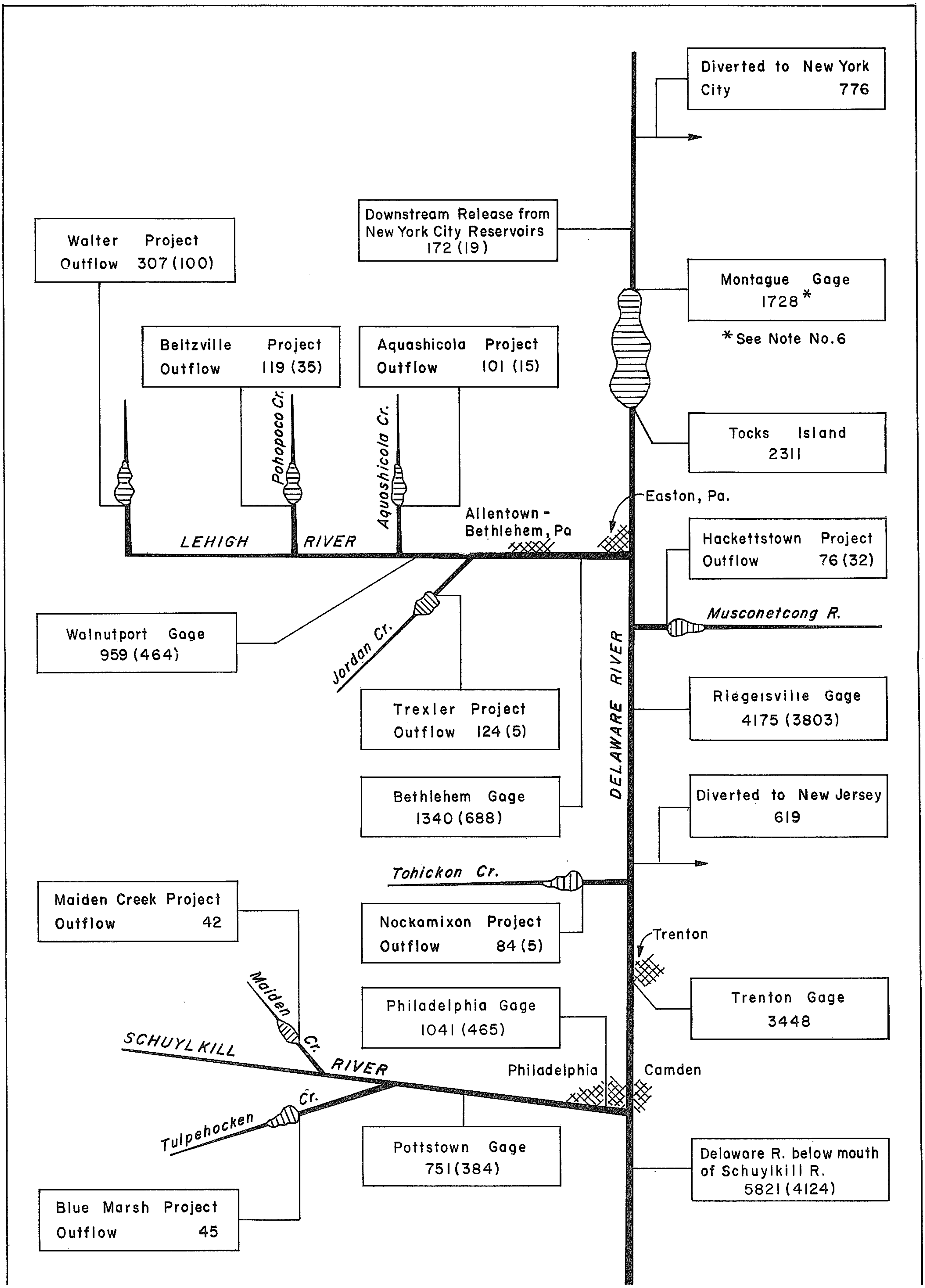
2 - Flow Adjustments for 1986 Proposed Consumptive Uses Include Average Power Generation Requirements

WATER RESOURCES STUDY
DELAWARE RIVER BASIN

FLOWS FOR OPTIMIZED OPERATION OF DRBC RESERVOIRS

IN REPETITION OF DROUGHT OF SIXTIES
CASE 2: ALL RESERVOIRS EXCEPT TOCKS ISLAND OPERATING

PLATE VIII - 2


Diverted to New York City 776
Downstream Release from New York City Reservoirs 172 (19)
Walter Project Outflow 307 (100)
Montague Gage 1728 *
* See Note No. 6
Beltzville Project Outflow 119 (35)
Aquashicola Project Outflow 101 (15)
Pohopoco Cr.
Aquashicola Cr.
Tocks Island 2311
Easton, Pa.
Allentown - Bethlehem, Pa
LEHIGH RIVER
Hackettstown Project Outflow 76 (32)
Musconetcong R.
Walnutport Gage 959 (464)
Jordan Cr.
DELAWARE RIVER
Trexler Project Outflow 124 (5)
Riegelsville Gage 4175 (3803)
Bethlehem Gage 1340 (688)
Diverted to New Jersey 619
Tohickon Cr.
Maiden Creek Project Outflow 42
Nockamixon Project Outflow 84 (5)
Trenton
Trenton Gage 3448
Maiden Cr.
Philadelphia Gage 1041 (465)
SCHUYLKILL RIVER
Philadelphia
Camden
Tulpehocken Cr.
Pottstown Gage 751 (384)
Delaware R. below mouth of Schuylkill R. 5821 (4124)
Blue Marsh Project Outflow 45

NOTES:

1. ALL FLOWS ARE IN C.F.S.
2. ALL PROPOSED DIVERSIONS AND CONSUMPTIVE USES, INCLUDING PROPOSED THERMAL POWER COOLING AS SHOWN ON TABLE VIII-2, HAVE BEEN CONSIDERED.
3. FLOWS ARE COINCIDENT WITH MAXIMUM TOTAL STORAGE DRAWDOWN WHICH OCCURRED ABOVE TRENTON IN DEC. 1964. FLOWS SHOWN IN PARENTHESIS ARE MINIMUM AT THOSE LOCATIONS AT SOME OTHER DATE.
4. YIELDS OF AUTHORIZED PROJECTS ARE SHOWN ON TABLE V-1.
5. MAIN RIVER FLOWS HAVE NOT BEEN ADJUSTED TO MEET OYSTER BED REQUIREMENTS.
6. SUSTAINED FLOW OF 1750 C.F.S. REDUCED BY 22 C.F.S. FOR PROPOSED CONSUMPTIVE USES ABOVE MONTAGUE.

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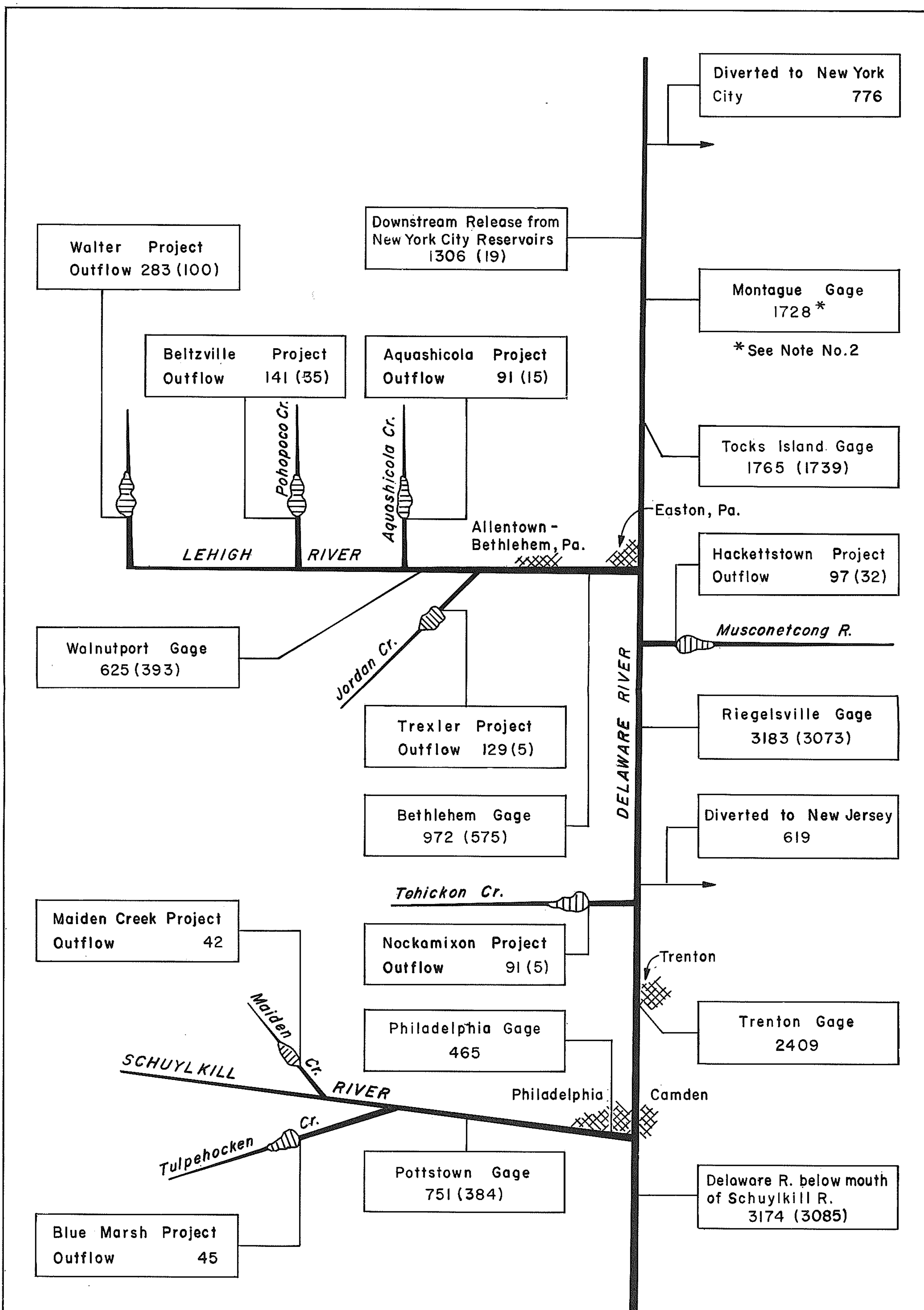
WATER RESOURCES STUDY
DELAWARE RIVER BASIN

MONTHLY REGULATED FLOWS
COINCIDING WITH MAXIMUM TOTAL
DRAWDOWN ABOVE TRENTON
1986 DEMANDS
CASE I: WITH TOCKS ISLAND PROJECT

PLATE VIII-3


Diverted to New York City 776
Downstream Release from New York City Reservoirs 1306 (19)
Walter Project Outflow 283 (100)
Montague Gage 1728*
*See Note No.2
Beltzville Project Outflow 141 (35)
Aquashicola Project Outflow 91 (15)
Tocks Island Gage 1765 (1739)
Pohopoco Cr.
Aquashicola Cr.
Easton, Pa.
Allentown - Bethlehem, Pa.
LEHIGH RIVER
Hackettstown Project Outflow 97 (32)
Musconetcong R.
Walnutport Gage 625 (393)
Jordan Cr.
DELAWARE RIVER
Trexler Project Outflow 129 (5)
Riegelsville Gage 3183 (3073)
Bethlehem Gage 972 (575)
Diverted to New Jersey 619
Tohickon Cr.
Maiden Creek Project Outflow 42
Nockamixon Project Outflow 91 (5)
Trenton
Maiden Cr.
Philadelphia Gage 465
Trenton Gage 2409
SCHUYLKILL RIVER
Philadelphia
Camden
Tulpehocken Cr.
Pottstown Gage 751 (384)
Delaware R. below mouth of Schuylkill R. 3174 (3085)
Blue Marsh Project Outflow 45

NOTES:

1. ALL FLOWS ARE IN C.F.S.
2. ALL PROPOSED DIVERSIONS AND CONSUMPTIVE USES, INCLUDING PROPOSED THERMAL POWER COOLING AS SHOWN ON TABLE VIII-2, HAVE BEEN CONSIDERED.
3. FLOWS ARE COINCIDENT WITH MAXIMUM TOTAL STORAGE DRAWDOWN WHICH OCCURRED ABOVE TRENTON IN NOV. 1964. FLOWS SHOWN IN PARENTHESIS ARE MINIMUM AT THOSE LOCATIONS AT SOME OTHER DATE.
4. YIELDS OF AUTHORIZED PROJECTS ARE SHOWN ON TABLE V-1.
5. MAIN RIVER FLOWS HAVE NOT BEEN ADJUSTED TO MEET OYSTER BED REQUIREMENTS.
6. SUSTAINED FLOW OF 1750 C.F.S. REDUCED BY 22 C.F.S. FOR PROPOSED CONSUMPTIVE USES ABOVE MONTAGUE.

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WATER RESOURCES STUDY
DELAWARE RIVER BASIN

MONTHLY REGULATED FLOWS
COINCIDING WITH MAXIMUM TOTAL
DRAWDOWN ABOVE TRENTON
1986 DEMANDS
CASE 2: WITHOUT TOCKS ISLAND PROJECT

PLATE VIII-4

Section IX

INVESTIGATIONS OF ADDITIONAL WATER SUPPLIES

A. Previous Studies

For the preparation of its Delaware River Basin Report (completed in 1962)[1/], the U.S. Army Corps of Engineers conducted a comprehensive survey of reservoir sites throughout the basin for possible construction for flood control, water supply and other purposes. As a result, 12 reservoirs were subsequently incorporated into the DRBC Comprehensive Plan. Eight sites were authorized by Congress for construction by the Corps of Engineers and the remaining four are being undertaken by the States of New Jersey, Pennsylvania and Delaware. These projects are described in Section V.

B. Other Projects Under Consideration

Additional storage for low-flow augmentation may be obtainable from a number of projects presently planned or under consideration.

Development of the Kittatinny Mountain Pumped Storage Project which will use Tocks Island Reservoir as its lower pool, will, under the proposed design eliminate the need for a conventional hydroelectric plant at Tocks Island. In this event, the lower limit on Tocks Island drawdown which had been set by minimum head requirements of the conventional turbines can be reduced. This would make available an additional 70,000 acre-feet of water supply storage in the Tocks Island reservoir, thus increasing its safe yield as limited by periods of extreme drought. [2/]

Other reservoir projects are being considered to provide releases during periods of low flow to compensate for consumptive use at proposed new power generating stations. One such project is a pump-in

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1/ Reference No. 130
2/ Reference No. 146

reservoir in the upper Schuylkill River Basin which would be operated in conjunction with the proposed Berne Generating Station (see Table VII-2). Similar arrangements are under consideration for other proposed generating plants.

C. New Factors Affecting Present Study

This section deals primarily with the identification of additional potential reservoirs which might be developed for water supply for thermal-electric power generation. A resurvey of the basin was performed to locate reservoir sites which had not been included in the Basin Plan but which, under circumstances prevailing at the present time, might prove favorable for the intended purpose. Some factors which made the present survey different from that conducted by the Corps of Engineers are given below.

1. Drought of the '60's. Subsequent to preparation of the Corps of Engineers study and adoption of the DRBC Plan, the drought of the '60's occurred. This prolonged drought was more severe than those recorded in earlier years and which had been used to establish water yield criteria for the Corps' study. Therefore, in this phase of the work, greater emphasis was placed upon appraising water availability at possible reservoir sites.

2. Pump-in Reservoirs. The Corps' study did not include consideration of pump-in projects, i.e. off-channel reservoirs into which flood waters are pumped and stored for later release during dry periods. The economics of water supply, particularly for large users, is presently more favorable to this type of project than 10 years ago.

3. Development in the Basin. This factor is more of a deterrent to reservoir development when compared with conditions in 1960. Residential, commercial, recreational and highway development is taking place at a rate which in many areas will make reservoir sites much more difficult to acquire. Increased concern for environmental and ecological effects further inhibits possible reservoir development.

4. <u>Alternative Projects.</u> The DRBC Plan was adopted almost 10 years ago. Although some projects have proceeded towards construction, others have not moved as rapidly as anticipated and it is possible that some may not be implemented. Although an original assumption for the study was that the DRBC Plan projects would be constructed as scheduled, it was decided during the course of the study that alternative projects should be considered in certain cases.

D. Screening Methodology

Initial screening was performed through map studies. The 70 reservoir sites covered in the Corps of Engineers study were all located on USGS topographic maps and examined for possible re-consideration. A cursory review was made of sites identified by the Soil Conservation Service, but in general the drainage areas were too small to be of interest. In addition, a thorough examination was made of the USGS maps to identify other sites for conventional reservoirs, and particularly pump-in reservoirs, worthy of consideration. A total of 101 projects were examined.

The following initial screening criteria were used:

1. No reservoir should preempt an authorized DRBC project; however, sites were studied as alternatives to DRBC projects which might not be constructed.
2. Minimum drainage area should be 30 square miles for a conventional reservoir project. No minimum was set for pump-in projects.
3. In only exceptional circumstances should embankments be more than 3000 feet long or 200 feet high
4. Sites containing urban developments, main transportation arteries, scenic areas and other interferences which could make land acquisition extremely difficult were dropped from consideration.

5. Main stem reservoirs on the Delaware River and on large tributaries with drainage areas greater than 600 square miles were not considered.

6. Pump-in reservoirs were limited in location to a reasonable distance (up to 10 miles) from the water source.

The initial screening process reduced to 51 the number of possible projects identified for further consideration. A field reconnaissance was made of all of these projects. The DRBC Plan projects were also inspected. During the field reconnaissance each project site was appraised for its topographic and geologic suitability for reservoir development, for the difficulties associated with land acquisition and relocations and for environmental considerations.

Following field reconnaissance, the above factors were balanced against the potential scale (yield) of reservoir development and the sites were given one of the following classifications:

1. Inspected and Eliminated (24 sites): Sites considered prohibitively costly due to land values, extensive relocations or incipient urban development.

2. Low Priority (6 sites): Sites which, for the above reasons, were considered costly and very difficult to acquire.

3. Priority (14 sites): Sites with good development potential but difficult to acquire.

4. High Priority (7 sites): Sites with good development potential and only moderately difficult to acquire.

A preliminary plan for reservoir development was prepared for each Priority and High Priority Site. These plans were developed only in sufficient detail to estimate project yield and approximate cost.

The yield of conventional reservoirs was determined by mass-curve analysis of the runoff in the drought of the '60 s. Yield is the maximum sustained discharge during critical dry periods less required downstream releases and evaporation losses. Reservoir size was established either by site conditions or by the amount of storage required to regulate the runoff during the critical period. Yield of pump-in reservoirs along the Delaware was based generally upon three months of pumping and eight months of release. Yield of tributary pump-in reservoirs was based on pumping-release cycles governed by the mass curve of runoff in the drought of the '60's.

Project costs were estimated by making approximate quantity take-offs for major project components and applying unit prices. Weighted average land costs were estimated on the basis of present development observed in the reservoir area and anticipated growth. Relocation costs were estimated by using standard cost multipliers for various types of facilities.

E. Summary of Additional Water Supply Sources

Table IX-1 presents summary data on additional sources of water supply in the various Delaware River sub-basins. Indicated yields are over and above discharges which will result from implementation and operation of all projects as proposed in the DRBC Plan.

It should be pointed out that these water supply projects have been studied only to the extent that they are identified additional sources of water supply in the river sub-basin in which they are located. Approximate costs have been estimated. It was not within the scope of this study to determine where the additional water would be used or how it would be conveyed to the point of use. Neither was it possible, with the data available, to rank alternative projects or assign priorities.

One other factor relates to the several pump-in reservoir projects receiving water from the Delaware River. Individually, they are practicable pump-in sites to develop, but in the aggregate, there would not be enough water available to develop all of them, even if the river were completely unregulated. Moreover, as described in Chapters IV and V, runoff in the basin is not only subject to flow regulation, by existing and planned reservoirs, but it is also

TABLE IX-1

DELAWARE RIVER BASIN

SUMMARY OF ADDITIONAL WATER SUPPLY SOURCES

Sub-basin	Project	Type	Classification	Usable Storage (ac.ft.)	Yield (cfs)	Capital Cost ($ per ac.ft.)	Annual Cost 1/ ($ per cfs)
1	D-120	Conv	High Priority	40,000	50	-	-
	D-120 (alt)	Pump	High Priority	213,000	390	410	30,600
	D-122	Conv	High Priority	30,000	40	-	-
	D-122 (alt)	Pump	High Priority	230,000	425	410	31,000
	LX-100	Conv	Priority	48,000	60	-	-
	LX-100 (alt)	Pump	Priority	48,000	180	980	34,200
2	D-1	Pump	Priority	83,000	155	445	35,000
	D-4	Pump	High Priority	92,000	230	460	23,300
	D-4 (alt)	Pump	High Priority	430,000	800	275	20,400
	D-5	Pump	Priority	98,000	180	550	41,000
	D-125	Conv	Priority	42,000	80	1020	65,300
3	L-120	Conv	High Priority	60,000	100	230	7,500 2/
4	D-9	Pump	Priority	108,000	200	530	37,000
	D-10	Pump	High Priority	150,000	280	495	34,200
	D-11	Pump	Priority	52,800	100	820	58,100
5	D-126	Conv	Priority	60,000	90	1,120	89,500
6	S-2	Pump	Priority	65,000	200	670	28,000
	S-3	Pump	Priority	36,000	140	835	27,100
	S-4	Pump	Priority	22,500	130	1,250	27,700
	S-5	Conv	Priority	50,000	90	840	57,800
	S-6	Pump	High Priority	42,000	110	970	48,300
	S-7	Pump	High Priority	25,000	70	960	35,500
	S-111	Conv	Priority	18,000	35	1,540	97,400
	S-115	Conv	Priority	-	180	-	22,800
7	D-101	Conv	Priority	18,000	55	-	-
	D-101 (alt)	Conv	Priority	33,000	85	1,330	62,400

1/ Includes average annual costs for operation, maintenance, debt service, energy for pumping, and etc. Based on the procedure recommended by the FPC in hydroelectric project evaluation (Reference 149) and an annual interest rate of 7.75%. for non-Federal and 4.88% for Federal financing.

2/ Based on assumed Federal financing.

subject to operational restrictions under the Supreme Court Decree and other controls imposed by DRBC. The effect of this upon potential pump-in reservoirs may be illustrated by the following examples:

- If the requirement for a minimum discharge of 1750 cfs at Montague prevails, there is little likelihood that large pump-in reservoirs upstream from Montague are feasible. This is because Delaware flows in excess of 1750 cfs which might be available for pump-in are needed to refill the Tocks Island Reservoir during critical periods.

- If high spring releases from Tocks Island are required to mitigate the oyster problem in the estuary, virtually no water would be available for main stem pump-in reservoirs during critical periods.

The foregoing examples show the uncertainties that affect the use of pump-in reservoirs served from the main stem of the Delaware River. Similar restraints may develop on tributaries to the Delaware River. The reservoirs selected in this study represent an array of possibilities from which projects may be selected to supply particular water supply needs.

The computer studies described in Section VIII provide a frame-work which might indicate the scope of such development under the assumptions used. These studies (Plate VIII-1) indicate that for 1965 conditions, some 550,000 acre-feet in excess of the regulated minimum Trenton discharge would pass that gage. Regulation of these excess flows at pump-in reservoirs would increase the Trenton regulated flow by an additional 680 cfs.

However, the location and number of these projects which can be developed will depend upon the manner in which the DRBC Comprehensive Plan evolves in firming-up the regulation of the river system.

A brief discussion of additional water sources in each sub-basin follows:

Sub-basin 1. Three projects are identified and each could be developed either as a conventional or pump-in reservoir. Since all of these are located upstream from Montague, development depends upon modifying the required New York City reservoir releases to satisfy minimum flows at Montague. Pump-in projects at D-120 and D-122 are alternative to one another since it is unlikely that sufficient river flow for both would be available under any circumstances. In fact under present operating regulations and assumed existence of Tocks Island storage, neither would be feasible at the scale indicated. This may not be the case for pump-in at LX-100 which would regulate the flow of the Lackawaxen Basin.

Sub-basin 2. Three of these projects are pump-in reservoirs using the Delaware River as a water source. D-1 is located upstream of Montague and is subject to the same restrictions as the projects in Sub-basin 1. D-4 and D-5 are downstream from Tocks Island. D-4 (alt) is a very large project of the same order of magnitude as Tocks Island. D-125 is a tributary project.

Sub-basin 3. Project L-120 is a modification to an existing project (F.E. Walter) which would provide approximately 60,000 acre feet more water supply storage than contemplated in the DRBC Plan. Physical limitations to this modification were not studied in detail.

Sub-basin 4. The three projects are pump-in reservoirs along the main stem of the Delaware upstream from Trenton.

Sub-basin 5. D-126 is a tributary reservoir.

Sub-basin 6. Projects S-2, S-3, S-5, S-6 and S-7 are all supplements or alternatives to DRBC's Maiden Creek project. The objective of further examination of these projects, together with gravity diversion from the Schuylkill into the Maiden Creek basin (S-115), is to select the most feasible combination of projects which could develop up to an additional

280 cfs in the Schuylkill basin upstream from Tulpehocken Creek. Projects S-4 and S-111 were selected primarily due to their proximity to possible large power generation sites.

Sub-basin 7. Project D-101 is a tributary reservoir which can be enlarged by connecting it with a reservoir on an adjacent tributary.

To summarize, a considerable number of opportunities exist for development of additional water supply in the Delaware River Basin. With certain exceptions, approximate capital costs range between $400 and $1200 per acre-foot of storage and annual costs per additional cfs produced range between $20,000 and $60,000. Many of these projects are alternatives to one another so that all could not be built. Selection and development of any project will require more detailed study, not only of the site itself, but of its relationship to the overall scheme of regulation of the river system.

Section X

ADDITIONAL STUDIES TO ASSIST POWER PLANT PLANNING

This section discusses the scope of the more important additional studies that would be an extension and refinement of the work described in this report, and that would assist in power plant planning and siting in the Delaware River Basin.

A. Hydrologic Basis for Design of Reservoir Systems

The systems studies (Section VIII)and the yields of the proposed reservoirs (Section IX) described in this report have been based on a repetition of the drought of the 60's. To develop a better basis for evaluating the capability of alternative reservoirs and basin systems, additional studies utilizing more normal hydrologic periods and less severe drought periods such as occurred in the 30's are needed. Synthetic hydrology provides a method for developing the required data.

Synthetic streamflow methods are based upon using available hydrologic data to develop new sequences of flows (for even hundreds of years) that are statistically indistinguishable from the original data. In the past ten years, capabilities for analyzing complicated water resources systems have been vastly increased by operations research techniques employing the electronic computer. This ability to create such synthetic records permits simulation of systems operation to be carried on through a long period subject to average and extreme magnitudes of hydrologic events. Project and system studies using the records so developed would be of substantial value in power plant planning and siting, by indicating the order of risk involved in using and depending upon different amounts of water in future years at different locations in the Delaware River Basin.

B. Salinity - Flow Relationship

The studies of salinity - flow relationships in this report (Section III) were based only on certain published data. Further investigation should include a comprehensive search for additional salinity-flow data for the Delaware Estuary and other similar estuaries, definition and implementation of a field program to obtain improved data, and additional analytical work to confirm and refine present interpretation of behavior of the estuary.

Fluctuations in the relation between flow and salinity in the tidal reaches of the Delaware Estuary below Trenton and in Delaware Bay require extensive study in order to establish the ranges of fresh water flow that are needed to control salinity to acceptable levels. Diurnal fluctuations in salinity under a range of flows and tides should be better understood. Other important points are the nature of the mixing phenomena in the estuary, variations in salinity under steady flow as well as variable flow, the effect of wind, and effects of withdrawals in the lower estuary.

C. Additional Water Balance Studies

The water balance studies for this report were restricted to certain conditions, among which were use of 30-day average flows, a controlled minimum flow of 1750 cfs at Montague, and a fixed system of reservoirs. However, the Corps of Engineers' computer program used in the present study can be adapted and used for a wide variety of different assumed criteria and conditions.

Among the different criteria and conditions that should be studied as a continuation of the present work are the effects of different flows at Montague and diversions to New York City, large releases in the spring to benefit the oyster beds, less rigid requirements in the flows at Trenton, the interrelation between possible main river pump-in storage projects and Tocks Island Reservoir, the inclusion or omission of various tributary storage projects, and the effect of changes in proposed out-of-basin diversions. A thorough and detailed review of the Corps of Engineers program and its input data should precede the performance of new studies to assure the validity of the results.

Upon completion of the additional hydrologic studies recommended in A. above, new programs can be prepared to examine the more important variables, using the synthetic hydrology as program input.

D. Detailed Analysis of Potential Water Storage Projects

The determinations of yield, layouts of project components and cost estimates for the proposed on-channel and pump-in reservoir projects presented in this report have been based only on generally available information. For example,the use of USGS sheets for dam layouts is far from satisfactory and the resulting quantity estimates can be considerably in error. Also the field inspections were necessarily very brief. Before a decision can be made to proceed further with the implementation of any of these projects more comprehensive engineering and economic analyses are required. These additional studies should be of sufficient depth to allow decisions to be made to proceed with land acquisition, subsurface exploration and definitive design in the event a project continues to appear favorable. The first step could be to obtain topographic maps of the dam and reservoirs sites to suitable scales. Aerial photography methods with a minimum of ground control could be used.

With the new topography and the results of a more detailed examination of the surface geology, alternative layouts could then be made for the different project features and comparative cost estimates prepared. Although a program of sub-surface investigations would be desirable at this time, additional information on geology can be obtained by photo-interpretation, or other publicly available sources of geological data. A re-evaluation of the capacity and yield of each reservoir site would also be conducted utilizing the results of the recommended hydrologic and systems studies as well as any additional hydrographic data which become available.

By this process of upgrading the engineering on the projects, those reservoirs having the greatest merit can be identified and assigned a higher priority.

APPENDIX A

LIST OF REFERENCES

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