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Folder 8/5: Coordinating Committee for the reappraisal of the water supply resources of the Delaware River Basin and service area, 1967-1969

DELAWARE RIVER BASIN COMMISSION
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JAMES F. WRIGHT
EXECUTIVE DIRECTOR

March 7, 1969

Dr. Maurice K. Goddard
Department of Forests and Waters
512 Education Building
Harrisburg, Pennsylvania

Dear Dr. Goddard:

Enclosed herewith is a preliminary copy of Chapters I - IV of the Report of the Coordinating Committee for the Reappraisal of the Water Supply Resources of the Delaware River Basin and Service Area. These chapters are in partial response to DRBC Resolution 67-4 adopted on March 29, 1967. They represent factual studies done on certain stated assumptions by the committee and do not reflect the position of the Delaware River Basin Commission or its staff.

The yield re-analysis data developed in Chapters I - IV are predicated on a reoccurrence of the drought of August 1961 through May 1967. The probable frequency of that drought as it affects the yield of the New York City reservoirs in the Delaware River Basin is included in Chapter II. The yields presented are based upon an assumed constant uniform withdrawal rate.

Other studies, either now in progress or to be initiated in response to Resolution 67-4, include the following:

1. Use of synthetic hydrology methods for determining yield.

2. Use of seasonal variations in demand and its effect on yield.

3. Analysis of future water supply demands of the Basin and Service Area.

4. Comparison of Supply and Demand.

5. Investigation of Alternative Methods of Equating Future Supply and Demand.

Any conclusions and recommendations which will be forthcoming from DRBC staff will await the completion of these additional studies by the Coordinating Committee. In the meantime, Chapters I - IV are being made available as the factual results so far produced by the Committee under the certain assumptions stated.

Sincerely,

James F. Wright

Enc.

CHAPTER I

INTRODUCTION

1. SCOPE. The water supply resources of the Delaware River Basin contribute to the economic and social well-being of a segment of the population of the nation far in excess of the population residing within the Basin's boundary. It is estimated that some 25,000,000 people reside in the Delaware River Water Service Area. The planning and development of water supply resources in the Delaware River Basin prior to the Northeast drought [1] that began in 1961 were based upon historical data which did not include the record-breaking low runoff experienced after 1961. The six-year drought which began in 1961 accumulated a deficit of well in excess of a full year's precipitation and runoff, a condition which had not been recorded in previous meteorologic and hydrologic data. Since the six-year drought may have directly affected the adequacy of existing and planned future water supply facilities included in the Delaware River Basin Commission's Comprehensive Plan, the Commission resolved to reappraise the long-term water supply resources available to the Delaware River Basin and its service areas.

[1] Droughts are defined as periods when crops fail to mature for lack of rainfall or when precipitation is insufficient to support established human activities. Drought conditions prevail when rainfall is deficient or poorly distributed in time or area; or when precipitation is concentrated in a few heavy rainfalls that drain away rapidly. Droughts impose a critical demand (1) upon works designed to furnish a continuous and ample amount of water and (2) upon streams expected to carry away or assimilate domestic and industrial effluents or to provide protection from natural salinity intrusion.

2. BACKGROUND OF INVESTIGATION. 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 (1954) 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.

The Corps of Engineers in 1961 completed its report on the comprehensive survey of the water resources of the Delaware River Basin (H. D. 522, 87th Congress, 2nd Session). That report recommended for Congressional authorization eight major multiple purpose reservoir projects to satisfy the water supply needs of the Basin (as well as to provide benefits from other project purposes) to the year 2010. Those projects were subsequently authorized by Congress in the Flood Control Act of 1962 (P. L. 87-874 of October 23, 1962) and included in the Delaware River Basin Commission's Comprehensive Plan, Phase I.

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. The following articles pertaining to the United States Supreme Court Decree and allocations diversions and releases are extracted from the Delaware River Basin Compact:

3.3 Allocations, Diversions and Releases. The Commission shall have the power from time to time as need appears, in accordance with the doctrine of equitable apportionment, to allocate the waters of the basin to and among the states signatory to this compact and to and among their respective political subdivisions, and to impose conditions, obligations and release requirements related thereto, subject to the following limitations:

(a) The commission, without the unanimous consent of the parties to the United States Supreme Court decree in New Jersey v. New York, 347 U.S. 995 (1954), shall not impair, diminish or otherwise adversely affect the diversions, compensating releases, rights, conditions, obligations, and provisions for the administration thereof as provided in said decree; provided, however, that after consultation with the river master under said decree the commission may find and declare a state of emergency resulting from a drought or catastrophe and it may thereupon by unanimous consent of its members authorize and direct an increase or decrease in any allocation or diversion permitted or releases required by the decree, in such manner and for such limited time as may be necessary to meet such an emergency condition.

(b) No allocation of waters hereafter made pursuant to this section shall constitute a prior appropriation of the waters of the basin or confer any superiority of right in respect to the use of those waters, nor shall any such action be deemed to constitute an apportionment of the waters of the basin among the parties hereto: PROVIDED, That this paragraph shall not be deemed to limit or restrict the power of the commission to enter into covenants with respect to water supply, with a duration not exceeding the life of this compact, as it may deem necessary for a benefit or development of the water resources of the basin.

(c) Any proper party deeming itself aggrieved by action of the commission with respect to an out-of-basin diversion or compensating releases in connection therewith, notwithstanding the powers delegated to the commission by this compact may invoke the original jurisdiction of the United States Supreme Court within one year after such action for an adjudication and determination thereof de novo. Any other action of the commission pursuant to this section shall be subject to judicial review in any court of competent jurisdiction.

3.4 Supreme Court Decree; Waivers. Each of the signatory states and their respective political subdivisions, in consideration of like action by others, and in recognition of reciprocal benefits, hereby waives and relinquishes for the duration of this compact any right, privilege or power it may have to apply for any modification of the terms of the decree of the United States Supreme Court in New Jersey v. New York, 347 U.S. 995 (1954) which would increase or decrease the diversions authorized or increase or decrease the releases required thereunder, except that a proceeding to modify such decree to increase diversions or compensating releases in connection with such increased diversions may be prosecuted by a proper party to effectuate rights, powers, duties and obligations under Section 3.3 of this compact, and except as may be required to effectuate the provisions of paragraphs IIIB3 and VB of said decree.

3.5 Supreme Court Decree; Specific Limitations on Commission. Except as specifically provided in Sections 3.3 and 3.4 of this article, nothing in this compact shall be construed in any way to impair, diminish or otherwise adversely affect the rights, powers, privileges, conditions and obligations contained in the decree of the United States Supreme Court in New Jersey v. New York, 347 U.S. 995 (1954). To this end, and without limitation thereto, the commission shall not:

(a) Acquire, construct or operate any project or facility or make any order or take any action which would impede or interfere with the rights, powers, privileges, conditions or obligations contained in said decree;

(b) Impose or collect any fee, charge or assessment with respect to diversions of waters of the basin permitted by said decree;

(c) Exercise any jurisdiction, except upon consent of all the parties to said decree, over the planning, design, construction, operation or control of any projects, structures or facilities constructed or used in connection with withdrawals, diversions and releases of waters of the basin authorized by said decree or of the withdrawals, diversions or releases to be made thereunder; or

(d) Serve as river master under said decree, except upon consent of all the parties thereto.

The most critical drought of recorded history in the Delaware River Basin prior to 1961 was experienced in the early 1930's. That drought was used as the design drought for determining the safe yield 1/ of the major reservoir facilities in New York City's Delaware Basin Reservoirs, which are operated according to the constraints set up in the Supreme Court Decree, and also for estimating the yield of the major projects included in the Commission's Comprehensive Plan.

Several times since 1954 the storage of the New York City's Delaware system was drawn down a significant amount. Near the end of 1964 the reservoirs were

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1/ Safe Yield - that part of the maximum dependable draft from a reservoir that can be supplied to a water supply system simultaneously with deducting the parts of the draft required for conservation and other downstream releases. The maximum dependable draft for the purpose of this report is based on the assumption of a repetition of the severest drought of record.

drawn to depletion for a day (December 26, 1964). Although the exercise of "filling and drawing down" is normal and expected for reservoirs, the depletion was unusual and experienced under less than maximum drafts. The situation became so acute in July 1965 that the Delaware River Basin Commission, after public hearing, and pursuant to Article 10.4 of the Delaware River Basin Compact, declared a water supply emergency in the Basin and temporarily modified the requirements of diversion and releases by attempting to equitably apportion the remaining supplies available in the Basin. The Commission's emergency measures continued from July 7, 1965, through March 15, 1967, when conditions allowed a return to full operation under the Supreme Court Decree. Because of the very large drain upon the storage of the reservoirs in 1964 and 1965, it appeared that the yield of the reservoir areas during the 1960's was less than the yields in previously known droughts. It was desirable that the yield of the areas during the 1960's be recomputed as soon as the drought showed realistic signs of abatement. During 1967 the runoff of the general area improved to such an extent that it seemed apparent that the drought was broken.

3. AUTHORIZATION FOR INVESTIGATION. On March 29, 1967, the Delaware River Basin Commission resolved in Resolution 67-4:

1. The Commission hereby finds that it is necessary and desirable to provide for a study of the adequacy of existing and planned water supply sources and storage facilities available to the Delaware River Basin and its service area in view of changes in the hydrology evidenced by drought experience.

2. The Executive Director is authorized and directed to arrange

> for such a study to be undertaken and completed at the earliest possible date, in cooperation with the U. S. Army Corps of Engineers and other federal agencies, the States of the Basin and the Cities of New York and Philadelphia. He shall provide for periodic progress reports to the Commission, and such further investigations, public hearings, research projects and reports, as he may deem appropriate to the purposes of this resolution. He is further requested to prepare for Commission consideration and action such proposals for revision or amendment of the Comprehensive Plan, and for policies and projects, as he may deem necessary or desirable in view of the results of such study.

4. COOPERATION AND COORDINATION. It was apparent that to carry out the intent of Resolution 67-4, the Commission staff would have to call upon and work closely with all Federal, State and local organizations involved with water supply development in the Basin and service area. To assure the full range of coordination found to be necessary, two steps were taken. The first was the establishment of the Coordinating Committee for the Reappraisal of Water Supply Resources of Delaware River Basin and Service Area composed of representatives of those agencies involved in water supply development. The second was the making of specific assignments for accomplishment of studies and preparation of the report. The Coordinating Committee, of which the DRBC staff representative acted as chairman, convened at about two-month intervals to review progress of the work and to coordinate matters pertaining to the report. The Coordinating Committee was constituted as follows:

Agency or Organization Represented	Committee Member
U. S. Department of the Army	Col. W.W.Watkin, Jr. (to Sept. 1968)
Corps of Engineers, Phila. District	Col. James A. Johnson Joseph F. Phillips (alt.)
Corps of Engineers, NEWS Study	Frank McGowan
Office of Delaware River Master	J. V. B. Wells Robert E. Fish (alt.)
Delaware Water & Air Resources Commission University of Delaware	John M. Karanik Robert D. Varrin
State of New Jersey N.J. Department of Conservation & Economic Development-Division of Water Policy and Supply	George R. Shanklin Robert E. Cyphers (alt.)
State of New York New York State Conservation Department	F. W. Montanari Edward A. Karath (alt.)
Commonwealth of Pennsylvania Pa. Dept. of Forests and Waters	Marshall Goulding John E. McSparran (alt.)
City of Philadelphia Water Department	Samuel S. Baxter Joseph V. Radziul (alt.)
City of New York Dept. of Water Resources - Bureau of Water Supply	Abraham Groopman George Mekenian (alt.)
Delaware River Basin Commission	Herbert A. Howlett Robert L. Goodell (alt.)

5. ASSIGNMENTS. The overall study outline was prepared and specific assignments were made by the staff of the Delaware River Basin Commission. That outline and assignment schedule is included as Appendix A to this report.

CHAPTER II

REANALYSIS OF YIELD OF NEW YORK CITY SYSTEM

6. DESCRIPTION. The New York City System is comprised of three major reservoir systems, the Croton system, the Catskill system and the Delaware system. The Croton system is located east of the Hudson River, some 25 miles north of New York City. The system, comprising twelve impounding reservoirs and several small controlled lakes, drains an area of 375 sq. mi. of the Croton watershed. The total impoundment capacity above minimum operating levels[1] is about 87 billion gallons (bg). The new Croton Aqueduct, that conveys the water to the City, has a capacity of 290 mgd, but an average of only 140 mgd of this can be used for direct gravity distribution. The remaining capacity of the aqueduct can be utilized by employing three electric pumping stations located in the city, and pumping is instituted whenever analysis indicates that the Croton system has a greater comparative storage than the other reservoirs. Another 125 mgd from the Croton system can be delivered to the city via the Delaware Aqueduct by gravity and hydraulic pumping.

The Catskill System is on the eastern slopes of the Catskill Mountains some 100 miles from New York City. The larger of its two reservoirs, the Ashokan, has a capacity above minimum-operating level of 123 bg, on a 257 square mile drainage area of the Esopus Creek. Schoharie Reservoir, holding 18 bg above minimum

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[1] The minimum operating level is the lowest level of the reservoir water surface at which a draft can be maintained in the withdrawal aqueduct at its operating capacity.

operating level, diverts the northerly flow of 314 sq. mi. of watershed of the Schoharie Creek into Ashokan Reservoir via the Shandaken Tunnel. The Catskill Aqueduct has the capacity to deliver 590 mgd from Ashokan Reservoir to New York City.

The Delaware System on the western and southern slopes of the Catskill Mountains is over 100 miles from the city. Work began on the system after a 1931 decree of the U.S. Supreme Court secured for New York City the right to develop the Neversink and East Branch, Delaware River. This work was delayed, first by the depression of the late 1930's and then by World War II. The Delaware Aqueduct can deliver water to the city at the rate of 890 mgd at maximum water surface elevation in Rondout Reservoir. At the head of the aqueduct is Rondout Reservoir with a capacity above minimum-operating level of 50 bg and a drainage area of 95 square miles. The reservoir is located on Rondout Creek, a tributary of the Hudson River, not the Delaware. Three impoundments, Neversink, Pepacton and Cannonsville Reservoirs, on tributaries of the Delaware River divert water into Rondout Reservoir. Neversink and Pepacton Reservoirs have capacities above minimum-operating level and watershed areas of 35 bg and 93 sq. mi. and 140 bg and 375 sq. mi., respectively. Hydroelectric plants have been constructed by two investor-owned utilities at the outlet of the Neversink Tunnel and at the outlet of the East Delaware Tunnel into Rondout Reservoir. In settling prior riparian right claims and in an agreement between the utilities and the City of New York, water in excess of specified amounts supplied by the City is paid for annually to the City at specified rates. In 1954, the city secured further authorization to construct the Cannonsville Reservoir on the West Branch of the Delaware River. This impoundment containing 96 bg above the minimum-operating level, drains a watershed area of 450 square miles.

The New York City System impounds in eighteen reservoirs a combined capacity of 548 bg above minimum-operating level from a total drainage area of 1,959 square miles. Two marginal sources are also available to the City. First is the Long Island System, on the island's south shore, where water is obtained from infiltration galleries and driven wells. A number of ponds provide for ground water recharge. This source can produce 30 mgd. Second are the wells in Staten Island with a dependable yield of 5 mgd.

In addition, there are two private water companies that furnish approximately 60 mgd from wells in Queens to a population of about 650,000 in that borough.

7. EMERGENCY SOURCE OF SUPPLY--CHELSEA PUMPING PLANT. The City of New York, on July 14, 1965, made application to the New York State Water Resources Commission for approval for the taking of an emergency supply of water to the extent of 100 mgd from the Hudson River for use by the City. The City proposed to reconstruct its former pumping station on property owned or to be reacquired by the City on the east bank of the Hudson River adjacent to its Shaft 6 of the Delaware Aqueduct near Chelsea in Dutchess County.

The New York State Department of Health concluded, as a result of water quality studies, that the river water could be used and made safe for the City's need on an emergency basis if appropriate safeguards were observed. These safeguards included multiple chlorination and dilution with upland water followed by normal storage periods in the West Branch and Kensico Reservoirs and supplemented by such taste, odor and turbidity control measures in those reservoirs as conditions dictated. That department recommended to the Water Resources Commission that the City of New York be given permission to use the water supply for the purpose intended, that a maximum possible dilution with upland water be achieved at least to the extent of not to exceed one part of river water in every five parts of total water going through the aqueduct and that the Commission reserve the right to require discontinuance of pumping if it was found that the concentration of river water was excessive and could not effectively be treated.

The Water Resources Commission, on September 1, 1965, approved the application of the City, subject to the following conditions and recommendations:

CONDITIONS

A. Under this decision and approval the City of New York, in order to obtain an emergency supply of additional water, may pump from the Hudson River, in the vicinity of Chelsea into its Delaware Aqueduct an amount of not to exceed 100 million gallons of water in any one day for use in the water supply system of that city.

B. New York City must provide a monitoring raw water program satisfactory to the Commission to determine the quality changeability of this water and, if in the opinion of the Commission, changes occur which indicate there may be definite hazards attendant upon the use of this proposed supply, its use must be discontinued or the rate of pumping reduced.

C. The Commission also reserves the right to require the city to cease pumping at the proposed pumping station or to reduce the rate of such pumping whenever, in the opinion of the Commission, the continuation of such pumping will endanger the supply or quality of the raw water in the water supply intakes of the various municipalities or other civil divisions of the State located along the Hudson River above Chelsea now taking or proposing to take a water supply from that river.

D. This approval shall be limited to a period of 5 years or for the duration of the present water emergency as determined by the Commission, whichever is shorter, after 10 days notice to all parties of record and after a hearing thereon, if requested. Nothing in this decision shall be construed to require the city to demolish this plant at the expiration of the term of this approval ......

RECOMMENDATIONS

In addition to the above conditions of the decision, the Commission emphasizes that it is imperative for the city not only to continue its present water conservation practices, but that, also, it must constantly make every effort to find and implement new and additional conservation measures. The Commission also strongly urges the city to institute universal metering at the earliest possible date.

The Board of Water Supply completed construction of the Chelsea Pumping Plant on March 20, 1966, and from that date to January 13, 1967, 21.37 bg were pumped from the Hudson River for use by the City. The station is presently being maintained on a complete stand-by basis. Pumps are alternately run to insure serviceability. The water pumped is returned to the river.

8. YIELDS OF THE DELAWARE SYSTEM PRIOR TO THE DROUGHT OF THE SIXTIES.

In the Amended Decree of the U. S. Supreme Court dated June 7, 1954, New York

City was authorized to divert water to its municipal supply system from its reservoirs in the Delaware River Basin and was required to release water at times to the Delaware River designed to maintain certain minimum rates of flow at the gaging station at Montague, New Jersey. Since September 1, 1955, diversions and releases have been made from Pepacton and Neversink Reservoirs, the second phase of development of the Delaware River Basin System. The third phase began when the Cannonsville Project was completed and its reservoir first filled to the extent that 50 billion gallons above the lowest outlet were available for diversion and release. This occurred on March 31, 1967.

Diversions of the equivalent of 490 mgd were authorized by the Decree for the second phase of development and of 800 mgd for the third phase. The Decree specified that compensatory releases were to be made from one or more of the New York City reservoirs and were to be designed to maintain a minimum basic rate of flow at Montague of 1,525 cfs during phase two, and, it was further specified, that an excess quantity of water, depending upon New York City consumption, be released beginning June 15 each year and continuing not later than the following March 15. The Decree further specified that compensatory releases under the third phase were to be designed to maintain a minimum basic rate at Montague of 1750 cfs with an excess quantity of water to be released as under the second phase. The U.S. Supreme Court Decree set limits on the determination of such excess as follows:

1. 83 percent of the amount by which the estimated consumption during a year is less than the City's estimate of the continuous safe

yield from all its sources without pumping.

a. the estimated increase in consumption is limited to 7.250 billion gallons a year greater than the previous maximum annual consumption.

b. the safe yield of existing sources, without pumping, shall be estimated not less than 1,355 mgd before Cannonsville and not less than 1,665 mgd after Cannonsville (plus any net increase from new developments without pumping before 1993).

2. Not more than 70 billion gallons in any "seasonal period" between June 15 and the following March 15.

3. Excess water is to be designed for release in 120 days, and the maximum design rate to be maintained at Montague is 2650 cfs.

In order to study independently the adequacy of the New York City Reservoirs to provide water for diversion to New York City and for releases to the Delaware River, the River Master made an earlier investigation of the yields of the reservoir drainage areas of phases two and three. The report on that investigation is summarized in the "Report of the River Master of the Delaware River for the period December 1, 1958 - November 30, 1959 dated June 1960. It was determined in that investigation from a mass diagram of the combined runoff from the reservoir drainage areas that was prepared by New York City for the Supreme Court exhibit, that the severe drought within the period 1929-1935 was the most critical of any that occurred during the period 1905-1954 and it was selected for investigation of storage requirements.

The following paragraphs are extracted from the Summary of the River Master's Report, "....The yield investigation of the reservoir drainage area conducted by the River Master indicated that for a drought such as in the period 1929-35, the two reservoirs could supply a uniform diversion rate of 490 mgd and could make compensatory releases designed to maintain the minimum basic rate of 1,525 cfs at Montague, except for a few days when the capacity of the release gates was inadequate by small amounts. The study further showed for design rates at Montague above about 1,620 cfs that the daily releases would generally be adequate although restricted by the capacity of the release gates on some days, and that a lowered uniform diversion rate would be necessary to supply a portion of the excess release water.

In the future stage of development beginning when Cannonsville Reservoir is completed and first filled to 50 billion gallons, the City may divert the equivalent of 800 mgd and must make compensatory releases to Delaware River from Cannonsville, Pepacton, and Neversink Reservoirs. Releases will be designed to maintain a minimum basic rate of flow at Montague of 1,750 cfs, and, until the City's estimated consumption approximates the dependable yield of its total reservoir system, obtainable without pumping (1,665 mgd), such higher seasonal design rate as may be afforded by the excess release quantity. The reservoir yield investigation made by the River Master indicated that the reservoirs could sustain a uniform diversion rate of 800 mgd and could make releases designed to maintain the minimum basic rate of 1,750 cfs at Montague. The study further showed for the design rates at Montague above about

1,990 cfs that a lowered uniform diversion rate would be necessary to supply a portion of the excess release water. ...."

9. YIELDS OF THE DELAWARE SYSTEM BASED ON THE DROUGHT OF THE SIXTIES.

Both the office of the Delaware River Master and the New York City Department of Water Supply, Gas and Electricity were requested as a part of their efforts for this study to reappraise the safe yield of New York City's Delaware System based on the drought period of June 1, 1961 - May 31, 1967 (see Appendix A, Item II of Study Outline). The studies by the two organizations were carried out as parallel but separate work, generally using the same methodology to check on the accuracy of the computations.

In the analysis, the total amount of water available was considered to include full reservoirs at the beginning of the period, plus inflow to the reservoirs during the time required for the reservoirs to deplete. The three reservoirs were analyzed in combination. The draft requirements were as follows:

(1) Diversion to New York City water supply.

(2) Release to maintain specified flow rates of Delaware River at Montague.

The release is made at "conservation" rate when a larger rate is not required to maintain the applicable minimum rate at Montague. (Conservation rates are minimum releases to maintain at all times a suitable stream flow below the reservoirs.) The computations were based upon several design rates at Montague because those rates, rather than the diversion rates, facilitated ease in computations. Two design rates are specified in the decree for the three reservoir stage of development--1,750 cfs as a minimum basic rate and 2,650 cfs as a maximum excess release rate. Those two rates as well as several lower rates were used to develop the relationship.

For each reservoir the useable capacity was that above the point of maximum depletion or minimum full-operating level. The useable capacity for each reservoir is as follows:

Pepacton Reservoir	140,190 mg
Neversink Reservoir	34,941 mg
Cannonsville Reservoir	95,706 mg

It was assumed that the three reservoirs would be operated as a unit so that, after considering inflow, the contents of the reservoirs would be maintained at equal percent capacity. It was assumed also that the combined capacities of the release gates could accommodate all releases and this was found to hold true in all cases. Monthly flow data were used chiefly but daily data were substituted for months of the critical period. The following results shown in Table II-1 were obtained and merely indicate the variation in the diversion - release relationship over a wide range:

TABLE II-1

RELATIONSHIP OF DIVERSIONS AND RELEASES - NYC DELAWARE RESERVOIRS - DROUGHT OF SIXTIES

Design Rate at Montague cfs	Diversion Rate mgd River Master	Diversion Rate mgd New York City
1,750 and 2,650 1/	225	235.7
1,750 and 2,200 1/	354	
1,750 2/	482	482.3
1,700 2/	502	
1,525 2/	576	579.1
1,400 2/		622.1
1,200 2/	680	683.3
1,000 2/		734.6
950 2/	743	
0 3/	821	822.5
0 4/	848	848.1

1/ The 2,650 and 2,200 cfs rates are for excess release period only.

2/ No excess releases.

3/ Conservation releases only.

4/ Excluding all downstream releases.

The results as shown in Table II-1 and as determined separately by the River Master and New York City representatives compare very favorably and well within the reliability range of the basic data.

The River Master plotted the design rates versus the diversion rates as shown in Figure II-1. Figure II-1 provides a curve from which the maximum uniform diversion rate may be determined for any design rate of the Montague Formula for the three reservoirs and such diversion may be sustained by the reservoirs during a critical drought period similar to that of the 1960's. Also shown in Figure II-1 is the curve for the drought of the 1930's developed by similar techniques and as described in paragraph 8.

Figure II-2, also developed by the River Master, shows that the period of critical drawdown of the reservoirs for a diversion rate of 482 mgd and a design rate of 1750 cfs (without excess releases) at Montague was from filled reservoirs in May 1964 to depleted reservoirs in November 1965 (18 months). The inflow to the reservoirs during the spring months in 1962-64 was sufficient to fill the reservoirs to capacity or near capacity each year. In 1967, the storage in the reservoirs was increasing but had not yet reached capacity by the end of the study period.

The graphs of variation in reservoir contents for other rates of diversion and design rates at Montague would be similar to those of Figure II-2. However, for higher diversion rates, the period of critical drawdown extends 30 or more months to depletion.

10. YIELD OF THE SURFACE WATER SUPPLY SYSTEM OF NEW YORK CITY.

Studies by the Board of Water Supply and the Department of Water Supply, Gas and Electricity, prior to 1961, had determined that the dependable supply of the NYC municipal system, without the minor and marginal sources, was 1,800 mgd.

a. Catskill-Croton-Rondout components. In 1961, there were records covering 54 years for the Catskill System and 93 years for the Croton System. In determining the dependable supply for those systems, using mass diagram techniques, 25 percent of reservoir storage was held in reserve for contingencies, and not added to the runoffs, leaving only 75 percent of storage for maintaining demand. This was done for several reasons, as follows:

1. To provide a reserve storage for a drier period than any experienced in the past.
2. To allow for the effect of silting which has probably reduced the available reservoir capacity. (The extent of this reduction is not known).
3. To compensate for that quantity of storage which is unavailable at full aqueduct delivery. (Approximately 20 billion gallons cannot be drawn from the reservoirs at the full capacity of the aqueducts because of hydraulic conditions.)
4. To have a reserve supply if the spring runoff is delayed during a period as dry as that upon which the dependable supply is based.

Evaluation of the records prior to 1961 established that the drought of 1929-31 represented the period of least runoff. It was determined that the dependable supply for the Croton-Catskill systems was 880 mgd and for the Rondout watershed, 120 mgd.

b. Delaware River Basin components. Similar analyses by the Board of Water Supply indicated that after meeting the basic release obligations, the Delaware Basin watersheds were capable of delivering 490 mgd without the Cannonsville development and 800 mgd with it.

The yields discussed above were based on figures for years prior to the drought of 1961-67. The Department of Water Supply, Gas and Electricity was requested as part of this study to make similar estima es based on the recent drought. Table II-2 shows the results of those studies, as well as the yields based on the drought of the 1930's.

TABLE II-2

YIELD OF THE NEW YORK CITY
SURFACE WATER SUPPLY SYSTEM

System	Yield-mgd: Drought of 1930's	Yield-mgd: Drought of 1960's	Critical Period
			Start drawdown to 75% depletion of total storage
Catskill 1/	555	470	May 3, 1964-Nov. 1, 1966
Croton 1/ w/pumping)	325	240	May 23, 1964-Dec. 27, 1966
w/o pumping)	(175)	(165)	
			Start drawdown to point of refill
Rondout	120	100	May 9, 1962-June 1, 1968
			Start drawdown to 100% depletion of useable storage
Delaware 2/	800	480	May 17, 1964-Nov. 18, 1965
Total	1800	1290	

1/ Yields shown for Catskill-Croton System based on combined operation.

2/ Based on maintaining design rate of flow of Delaware River at Montague of 1750 cfs.

Based on the above data the yield of the New York City system has been reduced as follows: Catskill 15%, Croton 26%, Rondout 17%, Delaware 40%, and total of all systems 28%.

The current total safe yield of the New York City system was compared with the safe yield without pumping included in the U.S. Supreme Court Decree which was based on the critical period prior to 1954. The current estimate of safe yield without pumping is 1,225 mgd compared to 1,665 mgd in the Decree or a reduction of 26 percent as shown in Table II-3.

TABLE II-3

NEW YORK CITY SOURCES OF SUPPLY -
SUMMATION OF SAFE YIELD
(WITHOUT PUMPING) 7/ MGD

System	Prior to Drought of 1960's	After Drought of 1960's
Catskill 1/	555	470
Croton 2/	175	165
Rondout	120	100 3/
Delaware 4/	800	480
Bronx	5	5
Byram	5	- 5/
Richmond Wells	5	5
Total	1665	1225 6/

1/ Total useable storage at time of computation - prior to 1960 - 150.061 bg, after 1960 - 147.441 bg. (Flashboards removed from Ashokan in 1962 (deteriorated) reducing useable storage by 2.6 bg.)

2/ Total useable storage at time of computation - prior to 1960 - 103.075 bg, after 1960 - 94.637 bg. (Four feet of permanent spillway crest removed from Cornell Dam after Hurricane Connie and Diane in 1955 for structural safety.)

3/ Safe yield for Rondout has not yet been firmed - falls within range of 94 to 104 mgd.

4/ Based on maintaining design rate of flow of Delaware River at Montague of 1750 cfs.

5/ Byram watershed diverted water to Kensico Reservoir. Byram and Wampus Lakes were sold. The diversion tunnel was sealed.

6/ 1963 New York City consumption was 1294.7 mgd (including outside communities.)

7/ Without pumping of surface sources, Richmond Wells would require pumping.

11. CONSERVATION RELEASES - NEW YORK CITY DELAWARE RESERVOIRS.

Numerous inquiries were directed during the drought and more recently to DRBC, New York City and New York State regarding the adequacy of the conservation releases that are required from the New York City Delaware Reservoirs. According to information furnished by the New York State Conservation Department the subject of minimum flows or conservation releases from the New York City water supply reservoirs was introduced for the first time in testimony at the hearing on Cannonsville Reservoir before the New York State Water Power and Control Commission (predecessor to the present Water Resources Commission), in the spring of 1950.

The Commission made the conservation releases a condition of their approval of Cannonsville Reservoir and specified that the "City of New York must, upon completion of this project, release from this reservoir at least 5 million gallons of water daily between December 1 of each year and April 15 of the succeeding year and at least 15 million gallons of water daily during the remaining portion of each and every year for the maintenance of a suitable stream flow below the dam."

After the Cannonsville agreement, the Board of Water Supply offered to consider, retroactively, conservation releases from Rondout, Neversink, and Pepacton Reservoirs. Similar minimum flow formulae were developed for these reservoirs, as follows:

	Nov. 1 - Apr. 7 (incl.)	Apr. 8 - Oct. 31 (incl.)
At Downsville Dam	4 M.G.D.	12 M.G.D.
At Neversink Dam	3 M.G.D.	10 M.G.D.
At Merriman Dam	3 M.G.D.	8-10 M.G.D.

The Board agreed they would "endeavor to make" minimum releases of water for the conservation of fish life in the streams immediately below the several dams then under construction.

The agreement for releases from Pepacton and Neversink Reservoirs acquired legal status when it was made a part of the New York State Supreme Court proceedings on acquisition of riparian rights downstream from the dams. The City of New York has no legal obligation to make conservation releases from Rondout and discontinued them during the recent drought.

On a per square mile of drainage area controlled basis it is noted that the conservation releases now required during the April to November period are Cannonsville - 0.052 csm, Neversink - 0.163 csm, and Pepacton - 0.049 csm.

The exact basis for determining the specific conservation release values has not been identified. Apparently, consideration was given primarily to the fishery resource in relation to prior drought flows and spawning periods. The conservation releases are frequently submerged in the releases required at Montague under the Amended Decree. The validity of complaints about the adequacy of conservation releases has not been evaluated by an objective study. Such a study may be undertaken within the next several years under auspices of a Regional Water Resources Planning and Development Board proposed for the New York portion of the Delaware River Basin under existing State law.

12. <u>DROUGHT FREQUENCY</u>. As a part of the yield studies accomplished by the Office of the Delaware River Master, the Committee requested that office to also investigate the probable frequency of drought as it affects the yield of the New York City Reservoirs in the Delaware River Basin. That investigation resulted

in a report entitled "Probability of Allowable Yield of New York City Reservoirs in the Delaware River Basin" by Clayton H. Hardison, U.S. Geological Survey, Washington, D. C., (1968). The following paragraphs were extracted from that report:

Presentation of Results

The curves in figure II-3 (figure 1 in referenced report) define the yield of Neversink, Pepacton, and Cannonsville reservoirs in the headwaters of the Delaware River Basin when these reservoirs are used for flow augmentation of Delaware River at Montague, N.J., and for water supply for New York City. The curves show that allowable yield depends greatly on the risk of deficiency.

The curves in figure II-3 (figure 1 in referenced report) summarize the relations between minimum basic rate of flow at Montague and allowable diversion rate from the New York City reservoirs for selected probabilities of deficiency expressed in percent. The curve for the 5 percent chance of deficiency, for example, shows that with a basic rate of 1,750 cfs, the allowable diversion rate is 790 mgd. In other words, if the indicated minimum basic rate and indicated allowable diversion rate were maintained, the reservoirs would become empty in 5 percent of the years or at an average recurrence interval of 20 years. A deficiency, however, is not equally probable every year because the lower the contents at the start of the year, the greater the chance of deficiency; years of deficiency could tend to be grouped and still satisfy the definition of 5 percent of the years.

The curves for the droughts of the 1930's and the 1960's, which are shown on figure II-3 (figure 1 in referenced report) for comparison, were previously computed by the Delaware River Master by routing observed or estimated inflows. The position of these curves compares favorably with the frequency of the 18-month and 30 month low flows experienced during these droughts as obtained from frequency curves developed by combining distributions of yearly flow and of 6-month low flows. These computations show that the minimum 18-month and minimum 30-month flow during the drought of the 1930's have a recurrence interval of 12.5 and 15.5 years, respectively, or a probability of about 7 percent, and show that the minimum 18-month and minimum 30-month flow during the drought of the 1960's have a recurrence interval of 500 years and 400 years respectively or a probability of about 0.22 percent.

The basis for the family of curves shown in figure II-3 (figure 1 in referenced report) is explained later in this report, but regardless of the computational details and the validity of the assumptions, the position of the curves with respect to each other would not change appreciably. Different assumptions could result in curves that give diversion rates 50 mgd higher or 50 mgd lower than those shown, but the amount of such a change would probably be less than that resulting from an arbitrary change in the allowable chance of deficiency. The allowable diversion for a deficiency once in 20 years for example is about 100 mgd larger than that for a deficiency once in 50 years.

The computations in this report assume that flow from the drainage area between the New York City reservoirs and Montague including releases from privately owned power plants can be predicted accurately several days in advance so that releases can be made only when needed. When unexpected inflow during the time required for water to travel from the reservoirs to Montague cause the minimum basic rate at Montague to be exceeded, the amount of the release is wasted insofar as this analysis is concerned and would thus decrease the allowable yield shown in figure II-3 (figure 1 in referenced report).

It should be noted that the historical period of record used in the study was 62 years and this record was assumed to be representative of long-term conditions. As pointed out by the author, other technically acceptable methodology for computing flow frequencies could be used; however, it is not expected that the results would change appreciably.

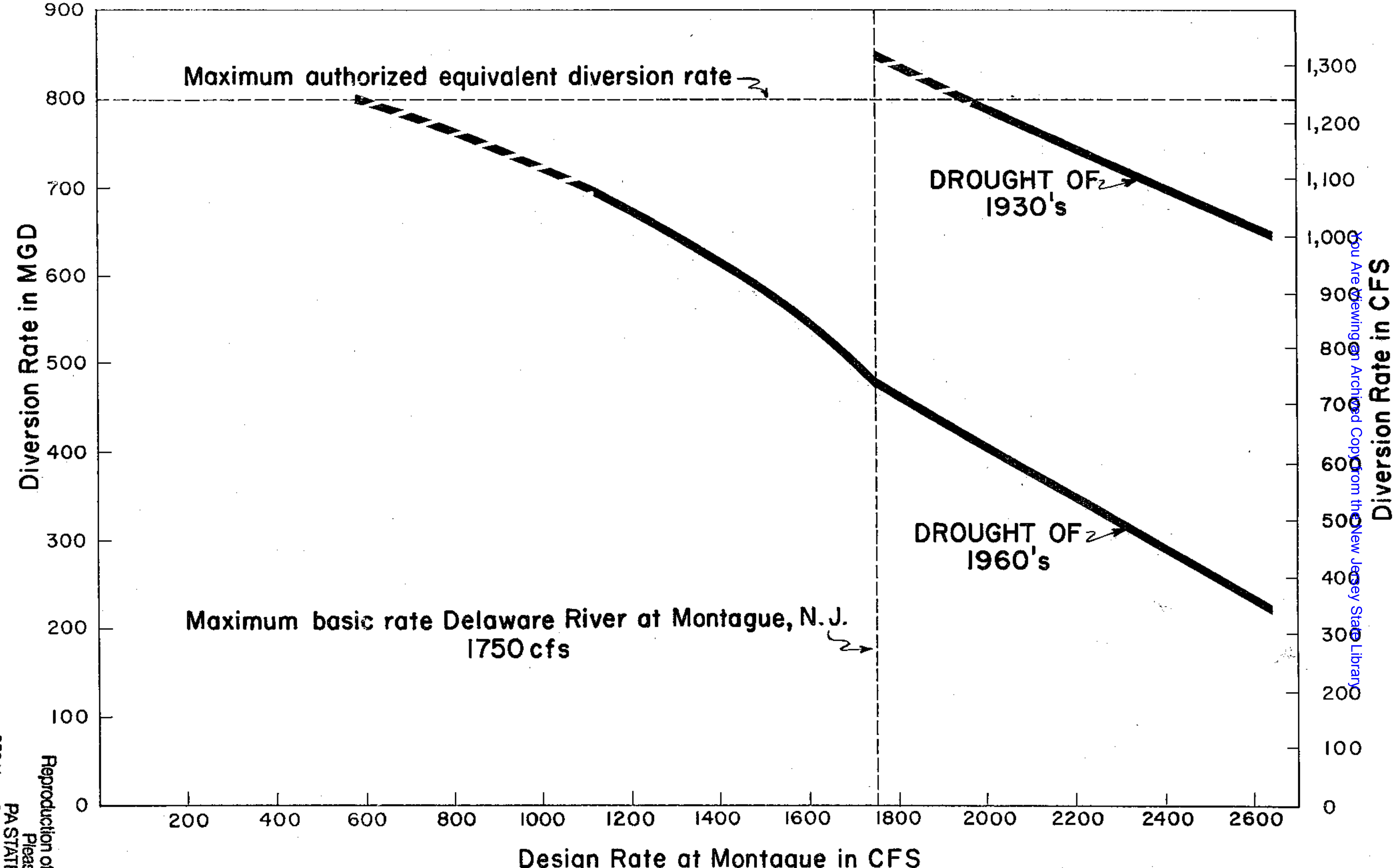

FIGURE II-1—Maximum uniform diversion rate that might be sustained during droughts similiar to those of 1929–35 and 1961–67 from New York City reservoirs in the Delaware River Basin while maintaining selected design rates of flow of the Delaware River at Montague, N.J.

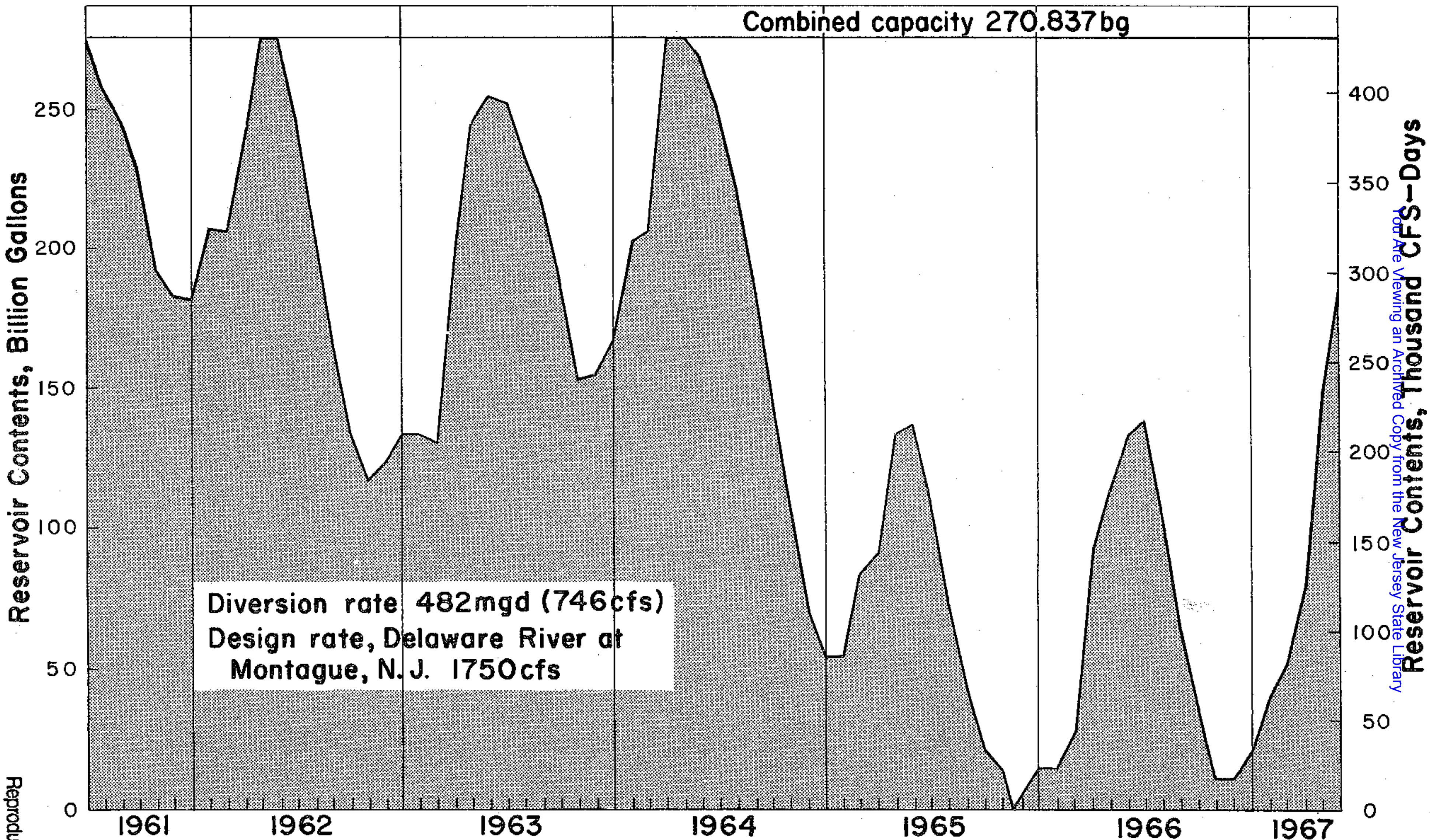

FIGURE II-2 — Combined usable contents of New York City reservoirs in Delaware River Basin as defined by simulated operation study 1961-67

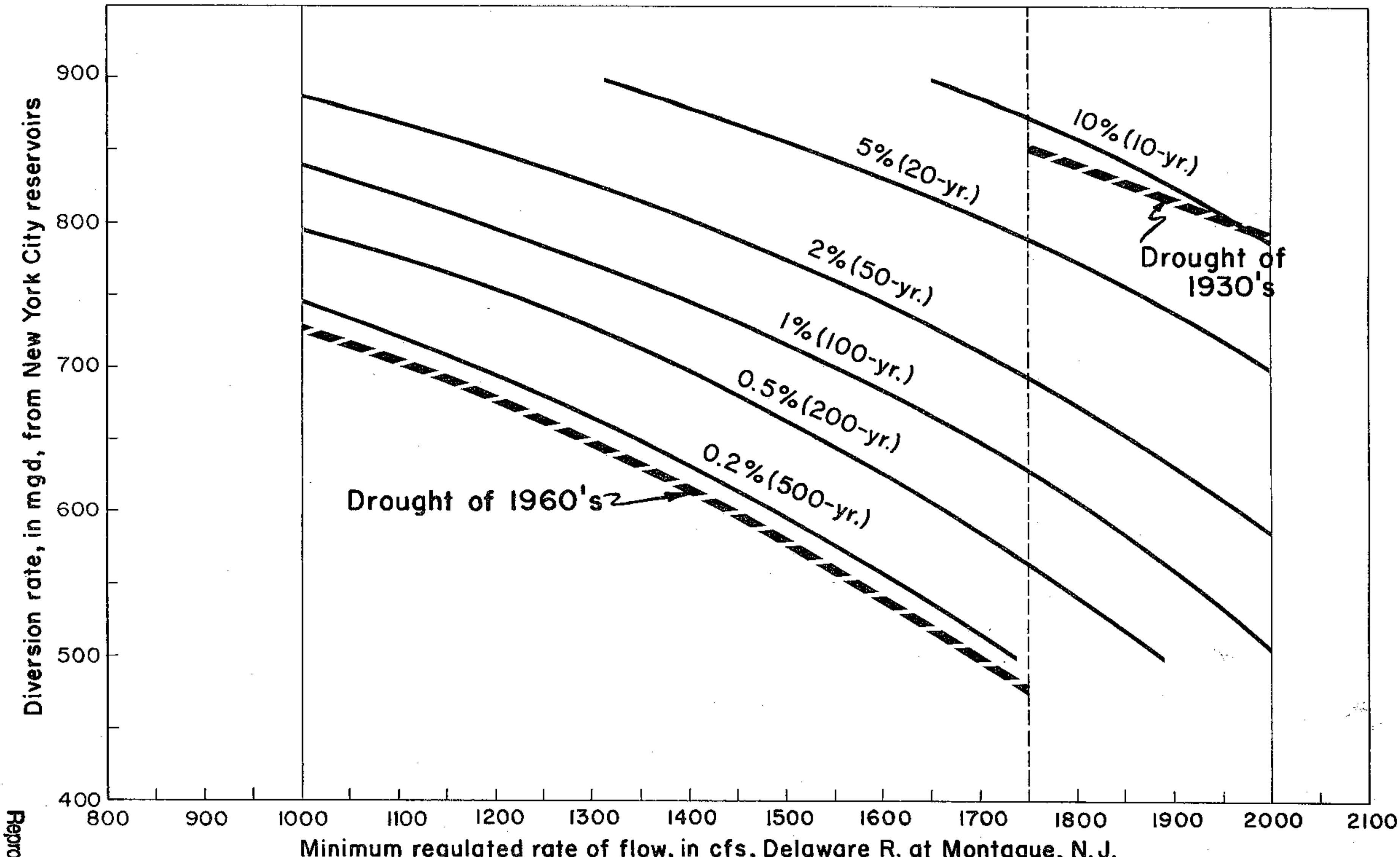

FIGURE II-3—Allowable diversion from New York City reservoirs in the Delaware River Basin and corresponding minimum regulated rate of flow, Delaware River at Montague, N.J., for the usable storage capacity of 271 billion gallons available in the reservoirs. Parameter is the percent of years that the reservoirs would become empty and the corresponding recurrence interval in years.

CHAPTER III [1]

REANALYSIS OF YIELD OF NORTHERN NEW JERSEY SYSTEMS

13. DESCRIPTION OF NORTHERN NEW JERSEY WATER SUPPLY RESOURCES. The New Jersey Department of Conservation and Economic Development has defined the Northeastern Metropolitan area of New Jersey, or Region I of the State, as including the Counties of Bergen, Passaic, Hudson, Essex, Morris, Union, Somerset, Middlesex, and that portion of Hunterdon County lying within the Raritan River Basin. Some 4.7 million persons, two-thirds of the total population of New Jersey, reside in this region and the bulk of the commerce and industry of the State is located within its borders.

The major sources of water supply for this region, other than that of the Delaware, is derived from the surface waters of the Hackensack, Passaic and Raritan River Basins. Of these the Hackensack and the Pequannock, Wanaque and Rockaway tributaries of the Passaic Basin have already reached or are approaching the practicable limits of optimum development and substantial development of the Raritan Basin has been realized by the construction of the Spruce Run and Round Valley reservoirs on the South Branch tributary. The smaller, unregulated Rahway and Elizabeth Rivers of the region have no dependable supply [2] of fresh water, are highly polluted and their

1/ This Chapter was prepared by the Division of Water Policy and Supply, New Jersey Department of Conservation and Economic Development in cooperation with the DRBC staff.

2/ Dependable supply, as used in this Chapter, is defined as an overall term used to indicate the developed sustained capability of a surface or underground source which may be limited by the hydrology of the stream, the plant capacity of a pumped supply, the hydraulic capacity of the transmission system or by legal determination.

basins are developed to a point which rules out their use as a source of surface water supply. Development of the upper reaches of the Wallkill River, a tributary of the Hudson River located in New Jersey westward of the Northeastern Metropolitan area currently is not contemplated. Figure III-1 shows the major drainage basins which comprise Region I.

The earliest water systems in Northern New Jersey were developed by private companies. However, a trend towards municipal water development became noticeable in the late nineteenth and early twentieth centuries. Between 1916 and 1925 several developments were also undertaken by groups of communities associated with water districts or commissions. Today all three arrangements exist.

Presently the North Jersey Metropolitan area is served by some 90 separate water systems. Most are small in size and derive their source of supply from ground water resources. Over eighty percent of the total public supply for the area, however, is furnished by only eight systems: the Newark and Jersey City municipal systems, the Hackensack, Elizabethtown, Middlesex and Commonwealth private water companies, the Wanaque operated by the North Jersey District Water Supply Commission for eight municipalities of the Metropolitan area, and Passaic Valley Water Supply Commission, the operating agency for three additional communities. There are many inter-connections and water exchange agreements between the components of this maze, but except in the time of an extreme drought emergency, there is no central control or coordinated operation of the systems.

HACKENSACK RIVER BASIN 1/

The Hackensack River Basin, located in the States of New York and New Jersey has a drainage area of 113 square miles above the Oradell Reservoir at head of tide. It has been developed to its practicable limits by the Hackensack Water Company as a source of supply to meet the needs of most of Bergen County's population of over 700,000 persons residing in the basin. Storage is provided by four reservoirs with a combined capacity of 12.7 billion gallons. The older reservoirs of the system at Woodcliff Lake and Oradell were constructed in 1905 and 1921, respectively. DeForest Reservoir, the largest and only one located in New York State was completed in 1956, and the Lake Tappan facility was placed in operation in 1966. In addition to the "safe yield" of 75 mgd developed by the regulated flows of the Hackensack River, the supply is supplemented by out-of-basin diversions of 10 mgd from Sparkill Creek, Saddle River and Hirschfeld Brook and by some 5 mgd from ground water sources. Due to commitments of 10 mgd from the DeForest Reservoir for use in New York State, however, the total dependable supply of the Hackensack Water Company system in New Jersey is reduced to 80 mgd. Releases from the system for downstream low flow control are not required.

PASSAIC RIVER BASIN

The most important basin as a source of water supply for the New Jersey Metropolitan area is the Passaic. With the upper limits of the Ramapo and Wanaque

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1/ Refer to Figure III-2 for locations of physical works cited.

tributaries located in New York State, the Passaic River Basin has a drainage area of 762 square miles at Little Falls, the lowest limits of its use as a source of water supply and a total drainage area of 935 square miles at its mouth at Newark Bay.

Pequannock River Sub-Basin

Development of the Pequannock River Basin was undertaken as early as 1889 by the East Jersey Water Company. At the turn of the century the City of Newark purchased this company and a major portion of the Pequannock watershed thereby providing for optimum development of the source and its protection from pollution. Of the total drainage area of 84.7 square miles at its confluence with the Wanaque River, the City of Newark has developed 63.7 square miles at Macopin Intake and five upstream reservoirs: Canistear, Oak Ridge, Clinton, Echo Lake and Charlotteburg. The Macopin, Canistear, Oak Ridge and Clinton Reservoirs were constructed prior to 1900. Echo Lake was completed in 1925, and Charlotteburg, the latest addition, was placed in operation in 1961.

A safe yield of 50 mgd developed by the 14.8 billion gallons of storage in the reservoirs of the system is approaching the optimum practical limits of development for the basin. Minimum release flows from the reservoirs for downstream use are not required.

In addition to those impoundments of the City of Newark, two small reservoirs, Kikeout and Apshewa with a combined capacity of 1.0 billion gallons on a drainage area of some six square miles provide a local source of water supply for the Borough of Butler, located within the Pequannock drainage area below the City of Newark watershed.

Rockaway River Sub-Basin

Development of the Rockaway River drainage basin as a source of water supply for Jersey City was begun by private interests and construction of the Boonton Reservoir and transmission system were completed in 1904. In 1910 the facilities were taken over by Jersey City which has continued to operate the system. The Rockaway River has a total drainage area of 133 square miles, 116 square miles of which provide the watershed for the 7.6 billion gallon Boonton Reservoir. In 1948, additional upland storage was provided by completion of the 3.4 billion gallon Split Rock Pond impoundment on the Beaver Brook tributary. A third reservoir, Longwood Valley, with a capacity of 2.45 billion gallons, which will also be used in conjunction with a 5.5 bg reservoir on the Musconetcong basin for pumped storage electric power generation and water supply releases to the lower reservoir has been approved for construction. The present safe yield of 65 mgd provided by the 11 bg storage capacity of Boonton and Split Rock Pond reservoirs will be increased by some 13 mgd upon construction of the Longwood Valley facility. Protection of the water quality of the watershed is provided by a sewage system to divert the waste of the communities of the watershed to a sewage treatment plant on the Rockaway River immediately below Boonton Dam. This plant, constructed by Jersey City in 1923, is now inadequate to meet the needs of the basin. Minimum flow releases from Boonton Reservoir are not required.

Wanaque River Sub-Basin

Construction of Wanaque Reservoir and transmission system was completed in 1930 by the North Jersey District Water Supply Commission acting as the design, construction and operating agencies for Newark, Bloomfield, Glen Ridge, Montclair, Kearny, Paterson, Passaic and Clifton. The reservoir, the largest in New Jersey prior to construction of the Round Valley reservoir by the State, has a capacity of 29.5 billion gallons and controls 90.4 square miles of the 108 square mile drainage area of the Wanaque River located in New York and New Jersey above its confluence with the Pequannock River. Greenwood Lake, a 14 billion gallon recreation facility situated above the Wanaque Reservoir across the New York-New Jersey border, is used only as a local source of water supply for several small communities along its shores. In 1953 the dependable supply of the Wanaque facility was increased by 25 mgd by the construction of pumping facilities to divert excess flows on the Ramapo River at the Pompton Lakes Dam into the Wanaque Reservoir.

Release requirements at Raymond Dam of the Wanaque Reservoir for downstream flow control, which are a minimum of 7 mgd when there is no spillage from Greenwood Lake, and up to a maximum of 10 mgd when discharge from the Lake is equal to or in excess of 3 mgd, reduces the dependable supply for use of the partners of the Wanaque-Ramapo system to 94 mgd.

Ramapo-Pompton Rivers Sub-Basin

The 160 square miles of the Ramapo River drainage area, above the Pompton Lakes Dam impounding a small recreational facility, is located in the States of New York and New Jersey. Water development on the Ramapo River is limited to the pumped storage facility at the Pompton Lakes Dam for the diversion of excess flows to the Wanaque Reservoir as discussed under that system. On the Pompton River below the junction of the Pequannock, Wanaque and Ramapo tributaries pumping facilities have also been constructed for the diversion of excess flows from a total drainage area of 355 square miles into the off-channel Point View Reservoir. This reservoir with a capacity of 2.9 bg was completed in 1965 by the Passaic Valley Water Commission to provide storage for augmentation of flows available for treatment and diversion at its Little Falls plant located below the junction to the Pompton and Upper Passaic Rivers.

Whippany Sub-Basin

Limited reservoir sites and increasing pollution problems are the most important factors which have deterred major reservoir development in the 72 square mile Whippany River watershed. Existing water storage impoundment is limited to the 360 million gallon Clyde Potts Reservoir of the Town of Morristown which controls a watershed of 2.2 square miles.

Upper Passaic Sub-Basin

The Upper Passaic River has a drainage area of 100 square miles above the Borough of Chatham where water is diverted from the Passaic and the Canoe Brook tributary to three off-channel reservoirs of the Commonwealth Water Company with a combined capacity of 2.8 billion gallons which provides a dependable supply of 11 mgd to augment the company's ground water resources.

Central Passaic Sub-Basin

Between Chatham and its junction with the Pompton River at Two Bridges the Passaic meanders on a flat gradient through swamps and flood plains of a prehistoric lake bed to Little Falls which has a basin drainage area of 762 square miles. Below this point, the quantity and quality of the river water is unsuitable for further use as a source of public supply. Initial development of diversion facilities for utilization of the Passaic at Little Falls was undertaken by the New York and New Jersey Water Company in 1895, and in 1927, the Cities of Paterson, Passaic and Clifton organized the Passaic Valley Water Commission to acquire and operate the facilities of the private water company. In 1966 the Commission increased the dependable supply of its Little Falls diversion facilities from 35 mgd to 75 mgd by increasing the capacity of its treatment works and the construction of its Point View Reservoir, a 2.95 bg pumped storage facility off the Pompton River for stream-flow augmentation. There are no passing flow requirements at the Little Falls plant for low flow control of the lower Passaic River.

As indicated above, and in Table 1, the 762 square miles above Little Falls of the total 935 square mile drainage area of the Passaic River Basin has reached a high degree of development. On-channel reservoirs with a total storage capacity of 56.7 billion gallons control 278 square miles of the upland watersheds to develop a safe yield of some 188 mgd. For the 484 square miles of drainage area uncontrolled by on-channel reservoirs, pumped storage impoundments of 5.8 billion gallons in addition to the excess capacity provided in the Wanaque Reservoir, and the diversion facilities at Little Falls provide an additional dependable supply of 111 mgd. Except for relatively small in-basin use the 300 ± mgd of water developed is diverted for single purpose use below Little Falls or outside of the Passaic Basin.

RARITAN RIVER BASIN

The Raritan River Basin, slightly larger than the Passaic Basin, is located entirely within the State of New Jersey with a total drainage area of 1105 square miles at Raritan Bay. At the confluence of the Millstone River at Bound Brook, the lowest point of the river used as a source of public water supply, the 779 square miles of drainage area is practically equal to that of the Passaic River at Little Falls. Major tributaries of the basin are the North and South Branches with drainage areas of 190 and 279 square miles, respectively, which join to form the Raritan River at Raritan and the Millstone River which has a drainage area of 287 square miles at Bound Brook.

While its natural flows have been used for power and water supply since colonial times, development of the high water supply potential of the Raritan, unlike that of the Hackensack and Passaic Rivers, was deferred until recently. Numerous schemes and proposals, however, were advanced through the years for development of the basin by both State and other water interests. No basin-wide action was taken, however, until enactment of the "New Jersey Water Supply Law" of 1958, which placed with the State the authority for long-range planning for the protection and orderly development of the surface and ground water resources of the State and provided the funds for the initial development of the Raritan River Basin to meet the immediate and near future needs of the northeastern metropolitan region, including the Lower Raritan Valley.

As authorized by the 1958 legislation, two reservoirs - Round Valley and Spruce Run - have been constructed in the South Branch Basin which have a total storage capacity of 66 billion gallons, approximately equal to the combined capacity of all other water supply storage facilities in the State.

Spruce Run Reservoir, with a capacity of 11.0 billion gallons is located on the 41 square mile watersheds of Spruce Run and Mulhockaway Creek, tributaries of the South Branch near Clinton. It was completed on schedule and substantially full by June 1964.

Round Valley, the largest water storage facility in the State, is a 55 billion gallon off-channel reservoir located some five miles southeast of Spruce Run Reservoir which is filled with excess flows of the South Branch of the Raritan River pumped at Hamden through a 3.5 mile force main. The drainage area of the South Branch Basin above the Hamden pumping station is 140 square miles. When required, Round Valley's two dams and dike can be economically raised to increase its capacity to 75 billion gallons in order to provide additional storage for pumped diversions from the Delaware River or other sources. The reservoir and force main were substantially completed during the fall of 1963 and pumping of excess flows at Hamden was initiated in December 1965. Statutes prohibit any diversion of water from the South Branch into Round Valley during the period June 15 to September 15. At the beginning of the fall 1968 pumping season the Round Valley Reservoir was slightly more than half full.

The Round Valley-Spruce Run Reservoirs will be operated as a multiple purpose streamflow augmentation project to (1) meet statutory minimum flow requirements of 40 mgd at Stanton on the South Branch of the Raritan River, 70 mgd at Manville and 90 mgd below the confluence of the Millstone River at Bound Brook and (2) provide water for sale for use in and outside the basin at a cost sufficient to amortize capital investments and meet maintenance and operating expenses. In order to fully utilize runoff from the entire drainage area of the Raritan River above Bound Brook, the State Water Policy and Supply Council by Order adopted December 5, 1964, determined "that the optimum use of the water stored in the Spruce Run and Round Valley Reservoir system can best be achieved by transmission of all of the stored water from both reservoirs to Bound Brook during the period of deficient natural flow, as provided for by statute ..." This policy for channel transmission and sale of all water in excess of minimum flow requirements, optimizes the use of the reservoir storage to develop a net sustained flow of 160 mgd for sale out of the basin at Bound Brook, more than double the amount which could be made available from the reservoirs by conventional transmission line deliveries on a sustained basis.

Releases were first made from Spruce Run Reservoir to augment low flows for quality control of the Lower Raritan River in the fall of 1964, and during the recent drought, storage was used for diversions at Bound Brook to the water-short metropolitan area through emergency connections. The reservoirs are now being operated to provide 70 mgd of water to the Elizabethtown Water Company at its pumping station and treatment plant at Bound Brook. Construction of a pipe line to provide the facilities for transmission of the balance of the yield of the Round Valley - Spruce Run system for use in the metropolitan area has lagged.

While the reservoirs will be operated primarily for water supply, both will be open for boating, fishing, bathing and other recreational purposes in accordance with the provisions of the 1958 law.

DELAWARE RIVER BASIN

For many years New Jersey has recognized the importance of the Delaware River as an essential source of water supply for diversion to the northeast metropolitan area of the State. Under the provisions of the U.S. Supreme Court Decree of 1954 - New Jersey v. New York, New Jersey's rights to Delaware River water were confirmed and diversions by the State of an average annual amount of 100 mgd out of the Delaware Basin without the construction of storage reservoirs to provide compensating releases was authorized.

At the present time such diversion of Delaware River water by New Jersey for potable and industrial water supply use as authorized by the 1954 Decree is made through the transmission facilities provided by the Delaware and Raritan Canal which starts at an intake at Bulls Island on the Delaware River above Lambertville, crosses the Delaware-Raritan divide at Kingston, and terminates at the Raritan River in New Brunswick.

The Delaware and Raritan Canal was constructed by private interests in about 1833 and for nearly a century served as an important artery for commerce and navigation from the Delaware River to the New York-New Jersey metropolitan area. Following World War I, however, its usefulness steadily declined, and in the 1940's the Canal was acquired by the State. The Trenton to Bordentown section was abandoned and filled and the Canal feeder from Bulls Island to Trenton and the Trenton-New Brunswick section were rehabilitated to provide the transmission facilities for the first State operated water supply project in the nation.

As now constructed the Canal is capable of a sustained delivery capacity of 75 mgd for use outside of the Delaware River Basin, but until a proposed balancing reservoir is constructed to provide storage for the allocated but unused portion of the flow during periods of low peak demand, the potential of the Canal is being realized only to the extent of a maximum annual average of 47 mgd.

GROUND WATER

In addition to the major surface water supplies discussed above, ground water is used to supplement the yields of major systems of the region such as the Hackensack, Commonwealth and Elizabethtown Water Companies. Ground water is the only source of supply for practically all of the many smaller water suppliers of the area. It is estimated that total use of ground water for the region as a source of public supply is approximately 150 mgd. Ground water also provides the major portion of the estimated 313 mgd self-supplied by industry and 30 mgd for irrigational use in the region.

Ground water resources in the Counties of Bergen, Passaic, Hudson, Essex and Union are limited and rapidly approaching optimum development. In the expanded portion of the northeastern metropolitan region comprising the Counties of Morris, Somerset, Middlesex and that portion of Hunterdon within the Raritan River Basin surplus ground water resources are still available for development.

14. SUMMARY OF DEPENDABLE SUPPLY - REGION I, NORTHERN NEW JERSEY.

Table III-1 shows a summary of the developed dependable public water supplies of Northern New Jersey. The information presented is factual except for the estimate of ground water yield which is based on best judgment. All surface supplies have been reanalyzed to evaluate the dependable supply based on the drought of the sixties. Each year new well sources are added and some change in the composite total dependable supply will be required.

TABLE III-1

DEVELOPED DEPENDABLE PUBLIC WATER SUPPLIES OF NORTHERN NEW JERSEY
(Based on 1960's Drought Conditions)

SUPPLY	MGD	
Round Valley-Spruce Run (N.J)	160	(1)
Wanaque (NJDWSC)	94	(2)
Hackensack Water Company	80	(3)
Passaic Valley W. S. Comm.	75	
Rockaway (Jersey City W. D.)	65	
Pequannock (Newark W.D.)	50	
Delaware & Raritan Canal (N.J.)	47	(4)
Elizabethtown Water Co.	26	(5)
Middlesex Water Company	21	(6)
Commonwealth Water Co.	21	
Perth Amboy Water Dept.	10	(7)
New Brunswick Water Dept.	5	(8)
78 Smaller Water Companies	70	(9)
TOTAL	724	

(1) Includes contractural sale of 70 MGD to Elizabethtown Water Company and 90 MGD currently uncommitted.

(2) Includes annual average diversion of 25 MGD from Ramapo River to storage in Wanaque Reservoir.

(3) Includes out-of-basin diversions and ground water supplies. Total has been reduced by 10 MGD New York State diversion grant.

(4) Delivery capacity expressed in average annual use. For lack of storage water must be sold on maximum daily demand charge basis. Amount includes contractural agreements for 22.5 MGD to Elizabethtown Water Company, 10.5 MGD to New Brunswick, 10 MGD to Middlesex Water Company, 10.5 MGD to smaller water companies, and for industrial use.

(5) Ground water supplies only. Does not include contractural agreements of 70 MGD from Round Valley-Spruce Run and 22.5 MGD from Delaware & Raritan Canal.

(6) Does not include 10 MGD contractural agreement from Delaware & Raritan Canal.

(7) Ground water sources in Sayreville Area adjacent to South River in Middlesex County.

(8) Does not include 10.5 MGD contractural agreement from Delaware & Raritan Canal.

(9) Primarily from ground water sources. Does not include 10.5 MGD contractural agreements from Delaware & Raritan Canal.

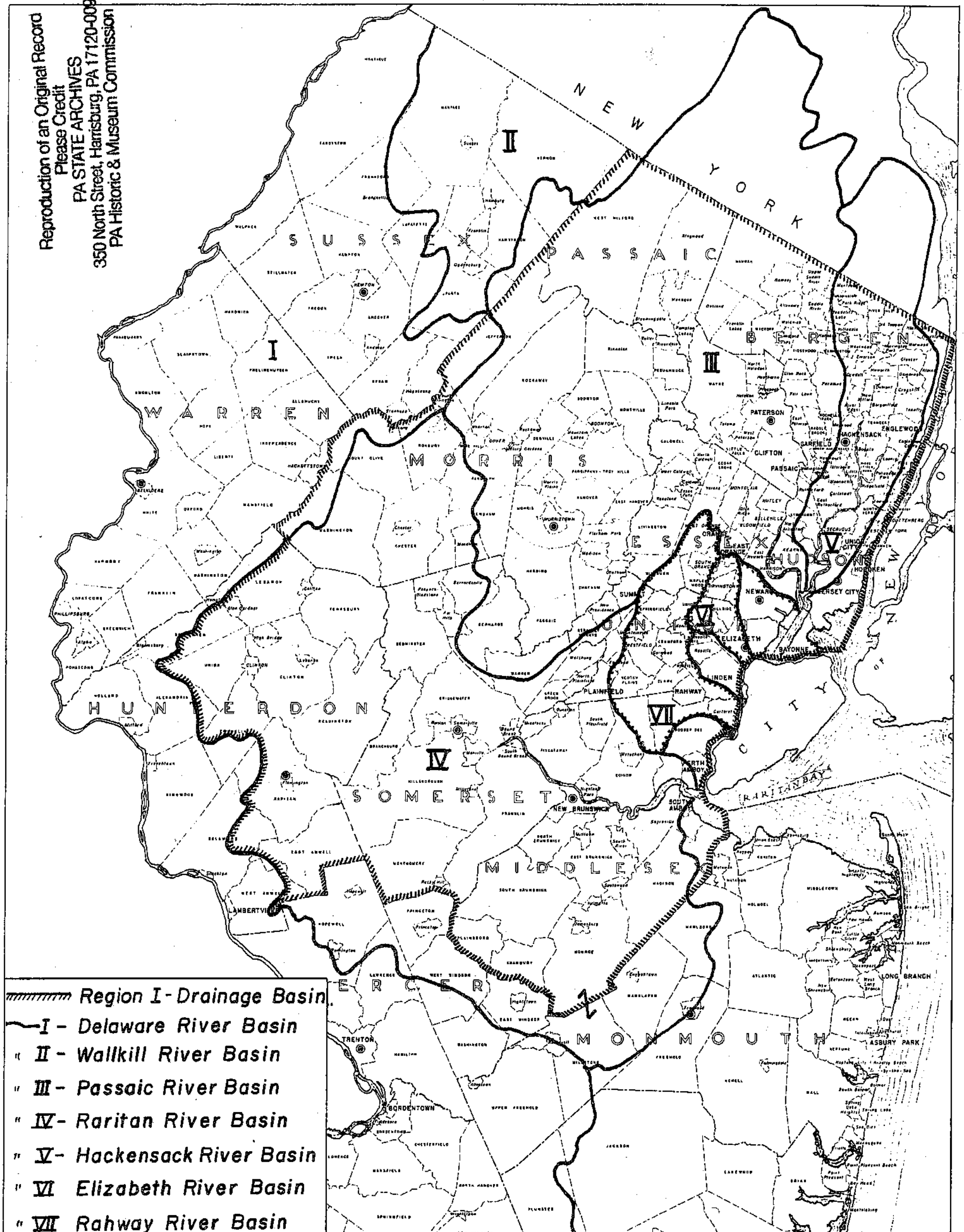

FIGURE III-1 – Major Drainage Basins of Region I – New Jersey

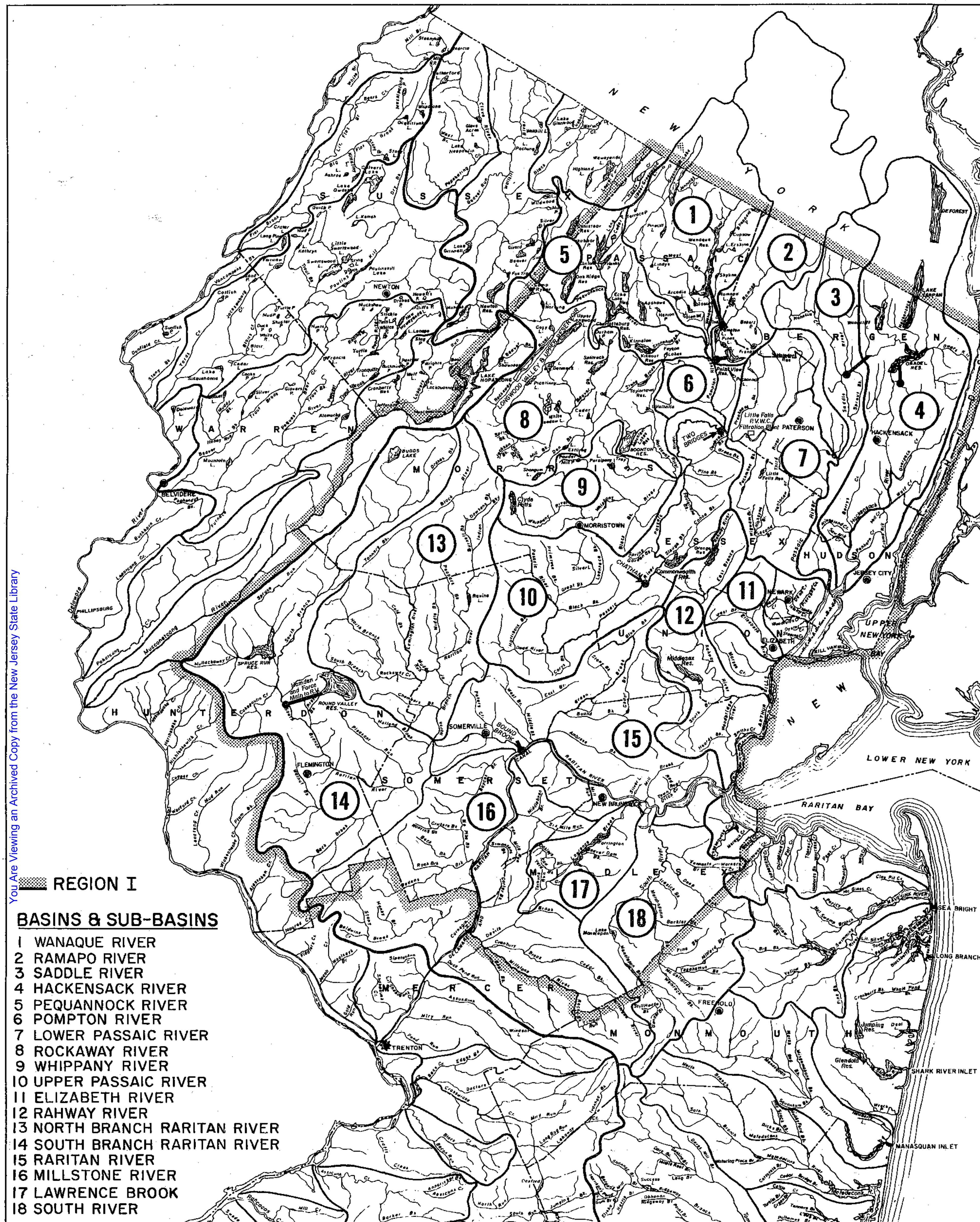

FIGURE III-2—Major Water Resource Development Projects—Region I, New Jersey

CHAPTER IV[1/]

Capability of Major Reservoir Projects in the DRBC Comprehensive Plan - Phase I

15. DESCRIPTION. The Delaware River Basin's Comprehensive Plan, Phase I, adopted March 28, 1962, provides a flexible, growing and evolving general framework for the orderly development of the water and related resources of the Basin. It includes both policies and projects and facilities which are required, in the judgment of the Commission, for the optimum planning, development, conservation, utilization, management and control of the water resources of the Basin, in light of present and foreseeable future needs. A principal source for selecting projects for inclusion in the Comprehensive Plan was the report on the Comprehensive Survey of the Water Resources of the Delaware River Basin (HD 522, 87th Cong. 2d Sess.) completed by the U.S. Army Corps of Engineers in 1961. That report recommended for congressional authorization eight major multiple purpose projects including Prompton (modification), Tocks Island, Francis E. Walter (modification), Beltzville, Aquashicola, Trexler, Blue Marsh and Maiden Creek. Those projects were authorized by Congress in the Flood Control Act of 1962 (P.L. 87-874 of October 23, 1962) and included in the DRBC Comprehensive Plan. In addition, several other major projects recommended in the Corps' report for non-federal development were included in the Comprehensive Plan, among them the Tohickon and Hackettstown Projects. To limit the scope of the studies for this investigation, and inasmuch as the primary area of interest was the

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1/ This Chapter was prepared by the U.S. Army Corps of Engineers, Philadelphia District, in cooperation with DRBC staff.

Basin above Trenton only those major projects located in that area are included as a part of this study.

16. REANALYSIS OF THE YIELD. Figure IV-1 shows the location of the eight major reservoir projects in the DRBC Comprehensive Plan included in this study and intermediate stream gaging stations which were evaluated to determine the effects of the recent (1961-1967) drought. The reservoirs are Prompton (Lackawaxen River), Tocks Island (Delaware River), F. E. Walter (Lehigh River), Beltzville (Pohopoco Creek-Lehigh River), Aquashicola (Aquashicola Creek-Lehigh River), Trexler (Jordan Creek-Lehigh River), Tohickon (Tohickon Creek-Delaware River) and Hackettstown (Musconetcong River-Delaware River). Table IV-1 lists the pertinent statistics for each reservoir and indicates its present state of development.

TABLE IV-1

Delaware River Comprehensive Plan Reservoirs

Reservoir	Sub-Basin	Drainage Area (Sq. Mi.)	Storage Allocated: Inactive Ac-Ft.	Inactive Mil Gal	Active Long-Term (1) Ac-Ft	Active Long-Term (1) Mil Gal	State of Development
Prompton	Lackawaxen River	59.5	3,400	1,100	28,000 (2)	9,100 (2)	Existing flood control only reservoir
Tocks Island	Delaware River	3627 (3)	96,300	31,300	366,000-(4) 464,000	119,000-(4) 151,000	Advance planning stage
F. E. Walter	Lehigh River	289	2,000	650	70,000(5)	22,800(5)	Existing flood control only reservoir
Beltzville	Pohopoco Cr.- Lehigh River	96.3	1,390	450	39,830	13,000	Under construction
Aquashicola	Aquashicola Cr.- Lehigh River	66	1,000	325	24,000	7,800	Future
Trexler	Jordan Cr.- Lehigh River	51.8	800	260	24,200	7,900	Future
Hackettstown	Musconetcong River	70	1,000	325	22,000 (6)	7,200 (6)	Advance Land Acquisition
Tohickon (7) (Nockamixon)	Tohickon Cr.- Delaware River	78	1,500	490	30,000	9,800	Under construction

(1) Active long-term storage is that storage available for direct withdrawal for water supply or for release downstream for water supply or water quality control. It is also used inplace for recreational purposes.

(2) Existing reservoir contains no permanent water supply storage, but has emergency water supply capability of 3,600 Acre-Feet.

(3) Includes drainage area controlled by three New York City reservoirs (915 sq. miles). Mongaup River dams owned by Orange and Rockland Utilities (202 sq. miles), Lake Wallenpaupack in the Lackawaxen River Basin owned by Pennsylvania Power and Light Co. (228 sq. miles), Prompton and Jadwin Reservoirs operated by the U.S. Army Corps of Engineers (124 sq. miles) and numerous smaller developments.

(4) Seasonal water supply pool.

(5) Existing reservoir has 2,000 Acre-Feet of storage presently allocated and used for conservation storage, is gated and has been used for emergency water supply storage.

(6) H.D. No. 522 recommended 22,000 Acre-Feet for active storage, but plans now being considered by State of New Jersey include a storage value of 38,000 Acre-Feet.

(7) For recreational use and emergency water supply.

Water use studies made prior to the recent drought indicated that the 1930-32 period was the driest of record. Yields based on analysis of these flows were determined for the Delaware Basin Report.1/ These yields are presented below in Table IV-2 for reference.

TABLE IV-2

Reservoir	Active Long-Term Storage allocated		Mean Monthly Pre-1960 Dependable Yield (1)	
	A.F.	Mill.Gal.	C.F.S.	M.G.D.
Prompton	28,000	9,100	66	43
Tocks Island	410,000	133,500	2,777 (2)	1,790
F.E.Walter	70,000	22,800	268	172
Beltzville	40,000	13,000	105	68
Aquashicola	24,000	7,800	78	50
Trexler	24,200	7,900	68	44
Tohickon	30,000	9,800	54	35
Hackettstown	22,000	7,200	85	55

(1) Dependable yield is the sustained constant draft which completely utilizes all of the active long-term storage during a repetition of the severest drought of record.

(2) Assumes a minimum flow at Montague of 1,750 cfs.

1/ H.D. 522, 87th Congress, 2d Session - 1962, Appendix M. pages M-93 and M-94A.

For these studies the inflow values to Tocks Island Reservoir were adjusted to reflect the releases from the New York City Delaware Basin System (including Cannonsville) as required by the 1954 Amended Supreme Court Decree. During the severe drought period during 1965-1966 the system was not operated strictly in accordance with the decree due to the severity of the drought and emergency regulations were implemented as noted in Chapter I. Because of the obviously limited amount of water available during the period, the flow for study purposes was reconstituted at Montague for several selected "design rates." As discussed in Chapter II, the diversions available to New York City for a range of Montague design flows, varying from 950 c.f.s. to 2,650 c.f.s., were computed.

The relatively dispersed character of the Comprehensive Plan reservoirs, the large uncontrolled drainage area downstream of these reservoirs, and the scope of the investigation indicated the desirability of a large-scale computer program as the most direct method of analysis. Accordingly, such a computer program was developed by the U.S. Army Engineer District, Philadelphia, to simulate reservoir use and streamflow routing during the period from June 1961 through May 1967. The details of the program, including a description, listing, sample input and output and program methodology, are presented in Appendix B.

Because of the location and relative size of Prompton Reservoir when compared to other reservoirs in the system and the fact that it and the power-recreation Lake Wallenpaupack are upstream of Tocks Island, the separate effects of these reservoirs were not included. The releases from the New York City System to maintain the flow at Montague are the important factors in this area. Studies made for modification of the project to include water supply storage have been accomplished [1] and include the evaluation of the "1960's" drought through 1966. It was concluded, therefore, that the relatively small yield from this project may be more easily added separately to the Tocks Island yield. The reconstitution of 1960's flows through Prompton water supply storage indicates a continuous yield of 68 c.f.s.

The yield capability of the comprehensive plan reservoirs requires evaluation of the following factors:

a. Montague flows under various different New York City reservoir operating constraints as to diversion and release rates.

b. Travel times between reservoirs and streamflow stations.

c. Individual reservoir continuous yield capability. [2]

d. The effects of variable storage in the largest reservoir, Tocks Island.

e. The effects of different out-of-basin diversions, other than to New York City.

f. The determination of the maximum sustained flow which can be maintained at Trenton with different combinations of Comprehensive Plan reservoirs.

g. Selection of a method of multiple reservoir use of water supply storage.

The reconstitution of Montague flows under a fully usable three-reservoir New York City Delaware system was prepared by the New York City Department

(1) U.S. Army Engineer District, Phila., Prompton Reservoir, Hydraulics and Hydrology Design Memorandum No. 10, dated October 1966.

(2) Future studies will consider the effect of variable draft rates and evaluation of consequences of different yield criteria.

of Water Resources, Bureau of Water Supply, as well as by similar independent computations made by the Delaware River Master as discussed in Chapter II. Data furnished for the lower basin yield study discussed herein consisted of information from which the reconstituted Montague flows (June 1, 1961 to May 31, 1967) could be computed for any desired "design rate."

The specific numerical information desired from the comprehensive plan reservoir yield study consists of the following:

1. The maximum sustained flow which can be maintained at Trenton for difference minimum flow rates at Montague between 1000 c.f.s. and 2650 c.f.s. with only Tocks Island Reservoir in operation.

2. The maximum sustained flow which can be maintained at Trenton for different minimum flow rates at Montague between 1000 c.f.s. and 2650 c.f.s. with Tocks Island and Beltzville Reservoirs in operation.

3. The maximum sustained flow which can be maintained at Trenton for different minimum flow rates at Montague between 1000 c.f.s., and 2650 c.f.s. with Tocks Island, Beltzville, Aquashicola, Walter, Trexler, Hackettstown, Tohickon and Prompton Reservoirs.

4. The constant withdrawal yields available from Tocks Island, Beltzville, Aquashicola, Walter, Trexler, Hackettstown, Tohickon and Prompton Reservoirs.

5. The additional potential yield available from use of Tocks Island storage between elevations 328 and 356 (77,000 A.F.). This condition was studied to reflect an extreme drought period when water supply needs would be considered of paramount importance.

6. The effects of out-of-basin diversion under the following two alternatives: 1/

a. 300 m.g.d. constant daily withdrawal from the Delaware River at Frenchtown, N. J.

b. 150 m.g.d. constant daily withdrawal from Tocks Island Reservoir and 150 m.g.d. constant daily withdrawal from the Delaware River at Frenchtown, N.J.

Travel times between reservoirs and key stream gaging stations were based on data developed for the Basin Report.2/ Data available from gaging stations along the Lehigh River and the lower Delaware for specific releases from Walter Reservoir were used to check applicable travel times. The results indicated that the Basin Report values, presented in Table IV-3 below, are quite variable within a probable range of ± 25 percent.

1/ Although a request has been made by New Jersey for future diversions, no approval has been granted at this time. (Feb. 1969)

2/ Appendix M, page M-64, House Document 522, 87th Congress, 2d Session, dated 1962.

TABLE IV-3

Reservoir-Streamflow Station Travel Times

Location	to	Location	Travel Times (Hrs.)
Tocks Island Reservoir		Belvidere	9
Belvidere		Riegelsville	6
Hackettstown Reservoir		Riegelsville	8.5
Walter Reservoir		Walnutport	20
Beltzville Reservoir		Walnutport	10
Aquashicola Reservoir		Walnutport	4
Walnutport		Bethlehem	16
Trexler Reservoir		Bethlehem	18
Bethlehem		Riegelsville	12
Tohickon Reservoir		Trenton	11
Riegelsville		Trenton	14

The method of reservoir operation selected was based upon making a daily minimum release, computing reservoir storage holdouts and their effects downstream to Trenton (adjusted flow) and allocating the difference between the desired Trenton flow and the adjusted Trenton flow (supplement). Reservoir storage holdouts are determined by subtracting mean daily diversions and mean daily minimum releases from the mean daily inflow into each reservoir. These individual holdouts are routed through intermediate stations to Trenton where the Trenton adjusted flow due to all the routed holdouts is determined. The allocation of the supplement required at

Trenton among the reservoirs was based on the available long-term storage left in each reservoir and the projection that the reservoir would be replenished in the following twelve months, using the minimum sequential inflow of record. See Appendix B for a more detailed explanation of the procedure. It was felt that the technique used would more fully utilize the storage in all the reservoirs and approach an optimum allocation. Table IV-4 presents the results of the computer study. Included are the length of critical drawdown (number of days to minimum storage for each reservoir), yields, maximum sustained Trenton flow achievable under the constraints imposed on upstream operation and the summation of the constant reservoir yield for six different operating conditions for flows at Montague of 1,000, 1,400, 1,750 and 2,650 cfs. The constant reservoir yields were not determined directly in the computer program; rather, they were determined from computer output data and use of the following equation:

$$Y = \frac{S}{D} + R + \frac{C-M}{D}$$

where:

Y = constant reservoir yield, in cubic feet per second.

S = a daily supplemental reservoir release during the period of critical drawdown, in c.f.s.-days.

D = Period of critical drawdown in number of days for storage to be depleted to minimum level.

R = Minimum reservoir outflow, c.f.s.

C = The usable water supply storage remaining in the reservoir on the day of critical drawdown, in c.f.s.-days.

M = The storage allocated for inactive sediment storage in c.f.s.-days.

SUMMARY TABLE IV-4

STORAGE YIELD DATA - DELAWARE BASIN PROJECTS

Condition Code*	Montague Design Flow (MGD)	MINIMUM STORAGE ATTAINED IN EACH RESERVOIR: Tocks Island (MG)	F.E. Walter (MG)	Beltzville (MG)	Aquashicola (MG)	Trexler (MG)	Hackettstown (MG)	Tohickon (MG)	Date of Maximum Drawdown	DEPENDABLE YIELD OF EACH RESERVOIR (Gross): Tocks Isl. ** (MGD)	F.E. Walter ** (MGD)	Beltzville ** (MGD)	Aquashicola ** (MGD)	Trexler ** (MGD)	Hackettstown ** (MGD) ***	Tohickon ** (MGD)	Total of Individual Reservoir Yields (MGD) **	Maximum Trenton Maintainable Flow (CFS)	(MGD)
A	650	31521	181	913					26/12/64	1428 (G)		57 (I)					1485	3302	2146
B	650	31691	152						26/12/64	1428 (G)							1428	3199	2079
C	650	6193	- 55						26/12/64	1580 (H)							1580	3423	2225
D	650	31581	36	489					26/12/64	1428 (G)		57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1325	3226	2097**
E	650	31718	122	632					26/12/64	1277 (G)		57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1325	3226	2097**
F	650	36115 (a)	4508 (a)	2897 (a)	1662 (a)	1247 (b)	327 (c)	1483 (b)	(a) 26/12/64	1428 (G)	187 (G)	57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1812	3598	2337
	(1000 cfs)								(b) 25/12/65										
									(c) 11/02/66										
A	910	31578	286	1178					26/12/64	1639 (M)		57 (O)					1696	3612	2348
B	910	31643	151						26/12/64	1639 (M)							1639	3510	2282
C	910	6395	99						26/12/64	1706 (M)							1706	3736	2428
D	910	31787	103	538					26/12/64	1639 (M)		57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	1534	3541	2302**
E	910	31604	68	569					26/12/64	1489 (M)		57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	1534	3541	2302**
F	910	37020 (a)	4846 (a)	3107 (a)	1792 (a)	1242 (b)	330 (c)	1490 (b)	(a) 26/12/64	1639 (M)	187 (N)	57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	2023	3905	2536
	(1400 cfs)								(b) 25/12/65										
									(c) 11/02/66										
A	1138	31572	281	1110					26/12/64	1843 (S)		57 (V)					1900	3935	2558
B	1138	31675	90						26/12/64	1843 (S)							1843	3832	2491
C	1138	6547	170						26/12/64	1977 (T)							1977	4057	2637
D	1138	31584	16	474					26/12/64	1843 (S)		57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	1737	3859	2508**
E	1138	31704	101	593					26/12/64	1692 (S)		57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	1737	3859	2508**
F	1138	39590 (a)	5238 (b)	3260 (c)	1927 (b)	1261 (c)	322 (d)	1538 (c)	(a) 27/12/64	1843 (S)	187 (U)	57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	2226	4197	2727
	(1750 cfs)								(b) 26/12/64										
									(c) 25/12/65										
									(d) 11/02/66										
A	1723	31483 (a)	331 (b)	1955 (c)						2311 (TT)		57 (VV)					2368	4754	3090
B	1723	31653 (d)	315 (e)	348						2311 (TT)							2311	4672	3037
C	1723	6289 (b)	348 (c)						26/12/64	2309 (UU)							2309	4778	3106
D	1723	31703	53	477						2311 (TT)		57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2205	4638	3015**
E	1723	31597 (f)	80 (a)	530 (a)						2160 (TT)		57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2205	4638	3015**
F	1723	37011 (b)	5605 (a)	3511 (a)	2065 (a)	1364 (a)	330 (f)	1635 (f)	(a) 26/12/64	2311 (TT)	187 (M)	57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2694	5006	3251
	(2650 cfs)								(b) 12/02/66										
									(c) 28/09/64										
									(d) 7/02/65										
									(e) 24/11/64										
									(f) 11/02/66										
									(g) 25/12/65										

Tocks Islan
F.E. Walter
Beltzville
Aquashicola
Trexler
Hackettstow
Tohickon

1 6,207 M
2 652 M
3 Variabl
4 22,657
5 1235 M.
and 1
6 65 M.G.
7 New Jer

G - 185
H - 177
I - 552
J - 544
K - 595
L - 577
M - 186

*Condition
A - Tocks
B Tocks
C - Tocks
D - All Re
300
E - All Re
150
from
F - All Cc

** Adjuste
*** Include

SUMMARY TABLE IV-4

STORAGE YIELD DATA - DELAWARE BASIN PROJECTS

ATTAINED IN EACH RESERVOIR				DEPENDABLE YIELD OF EACH RESERVOIR (Gross)							Total of Individual Reservoir Yields (MGD)**	Maximum Trenton Maintainable Flow	
rexler (MG)	Hackettstown (MG)	Tohickon (MG)	Date of Maximum Drawdown	Tocks Isl. ** (MGD)	F.E. Walter ** (MGD)	Beltzville ** (MGD)	Aquashicola ** (MGD)	Trexler ** (MGD)	Hackettstown ** (MGD) ***	Tohickon ** (MGD)		(CFS)	(MGD)
			26/12/64	1428 (G)		57 (I)					1485	3302	2146
			26/12/64	1428 (G)							1428	3199	2079
			26/12/64	1580 (H)							1580	3423	2225
			26/12/64	1428 (G)		57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1325	3226	2097**
			26/12/64	1277 (G)		57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1325	3226	2097**
1247 (b)	327 (c)	1483 (b)	(a) 26/12/64 (b) 25/12/65 (c) 11/02/66	1428 (G)	187 (G)	57 (I)	49 (G)	26 (J)	37 (K)	27 (L)	1812	3598	2337
			26/12/64	1639 (M)		57 (O)					1696	3612	2348
			26/12/64	1639 (M)							1639	3510	2282
			26/12/64	1706 (M)							1706	3736	2428
			26/12/64	1639 (M)		57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	1534	3541	2302**
			26/12/64	1489 (M)		57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	1534	3541	2302**
1242 (b)	330 (c)	1490 (b)	(a) 26/12/64 (b) 25/12/65 (c) 11/02/66	1639 (M)	187 (N)	57 (O)	49 (N)	26 (P)	37 (Q)	27 (R)	2023	3905	2536
			26/12/64	1843 (S)		57 (V)					1900	3935	2558
			26/12/64	1843 (S)							1843	3832	2491
			26/12/64	1977 (T)							1977	4057	2637
			26/12/64	1843 (S)		57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	1737	3859	2508**
			26/12/64	1692 (S)		57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	1737	3859	2508**
1261 (c)	322 (d)	1538 (c)	(a) 27/12/64 (b) 26/12/64 (c) 25/12/65 (d) 11/02/66	1843 (S)	187 (U)	57 (V)	49 (W)	26 (X)	37 (Y)	27 (Z)	2226	4197	2727
				2311 (TT)		57 (VV)					2368	4754	3090
				2311 (TT)							2311	4672	3037
				2309 (UU)							2309	4778	3106
			26/12/64	2311 (TT)		57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2205	4638	3015**
				2160 (TT)		57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2205	4638	3015**
1364 (a)	330 (f)	1635 (f)	(a) 26/12/64 (b) 12/02/66 (c) 28/09/64 (d) 7/02/65 (e) 24/11/64 (f) 11/02/66 (g) 25/12/65	2311 (TT)	187 (M)	57 (VV)	49 (WW)	26 (XX)	37 (YY)	27 (ZZ)	2694	5006	3251

NOTES

RESERVOIR INFORMATION

	Long Term Inactive Storage (MG)	Long Term Active Storage (MG)	Minimum Release (MGD)
Tocks Island	31391[1]	138,724[3]	975[5]
F.E. Walter	65[2]	587[4]	33[6]
Beltzville	452	12,986	23
Aquashicola	323	7,759	10
Trexler	316	8,023	3
Hackettstown	323	7,112[7]	21
Tohickon	485	9,699	3

1 6,207 M.G. for Condition "C"
2 652 M.G. for Condition "F"
3 Variable Rule Curve Used
4 22,657 M.G. for Condition "F"
5 1235 M.G.D., 1463 M.G.D. and 2048 M.G.D. for Montague Flows of 910 M.G.D., 1138 M.G.D. and 1723 M.G.D., respectively
6 65 M.G.D. for Condition "F"
7 New Jersey Proposes 12,378 M.G. to elevation 675.0

NUMBER OF DAYS TO REACH MAXIMUM DRAWDOWN

G - 185	N - 184	U - 188	UU - 613
H - 177	O - 551	V - 551	VV - 544
I - 552	P - 542	W - 184	WW - 185
J - 544	Q - 592	X - 548	XX - 549
K - 595	R - 574	Y - 598	YY - 597
L - 577	S - 192	Z - 579	ZZ - 610
M - 186	T - 191	TT - 260	

CONVERSION FACTORS

M.G.D. x 1.54 = D.S.F. or C.F.S.
M.G. x 3.07 = A.F.

*Condition Code
A - Tocks Island Reservoir and Beltzville Reservoir in Operation
B - Tocks Island Reservoir with Long Term Inactive Storage of 31,391 M.G.
C - Tocks Island Reservoir with Long Term Inactive Storage of 6,207 M.G.
D - All Reservoirs, except Walter Reservoir as authorized, in Operation with 300 M.G.D. Diversion from Frenchtown, N.J.
E - All Reservoirs, except Walter Reservoir as authorized, in Operation with 150 M.G.D. Diversion from Tocks Island Reservoir and 150 M.G.D. Diversion from Frenchtown, N.J.
F - All Comprehensive Plan Reservoirs in Operation

** Adjusted for Remaining Available Storage in Reservoir System
*** Includes Diversion from Lake Hopatcong, N.J.

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The maximum maintained Trenton flow achieved by operating plan, last column in Table IV-4, does not include the relatively minor effect of Prompton Reservoir.

The results are also plotted on Figure IV-2 at the maximum sustained Trenton flow versus the Montague flow for the several operating conditions.

The accuracy of the computed Trenton flows is dependent upon many factors. The two factors considered of major importance are the travel times and the method of reservoir operation. Based on a cursory analysis of the available data, it is concluded that improved estimates of the travel time could result in minor changes in the computed maintained Trenton flow.

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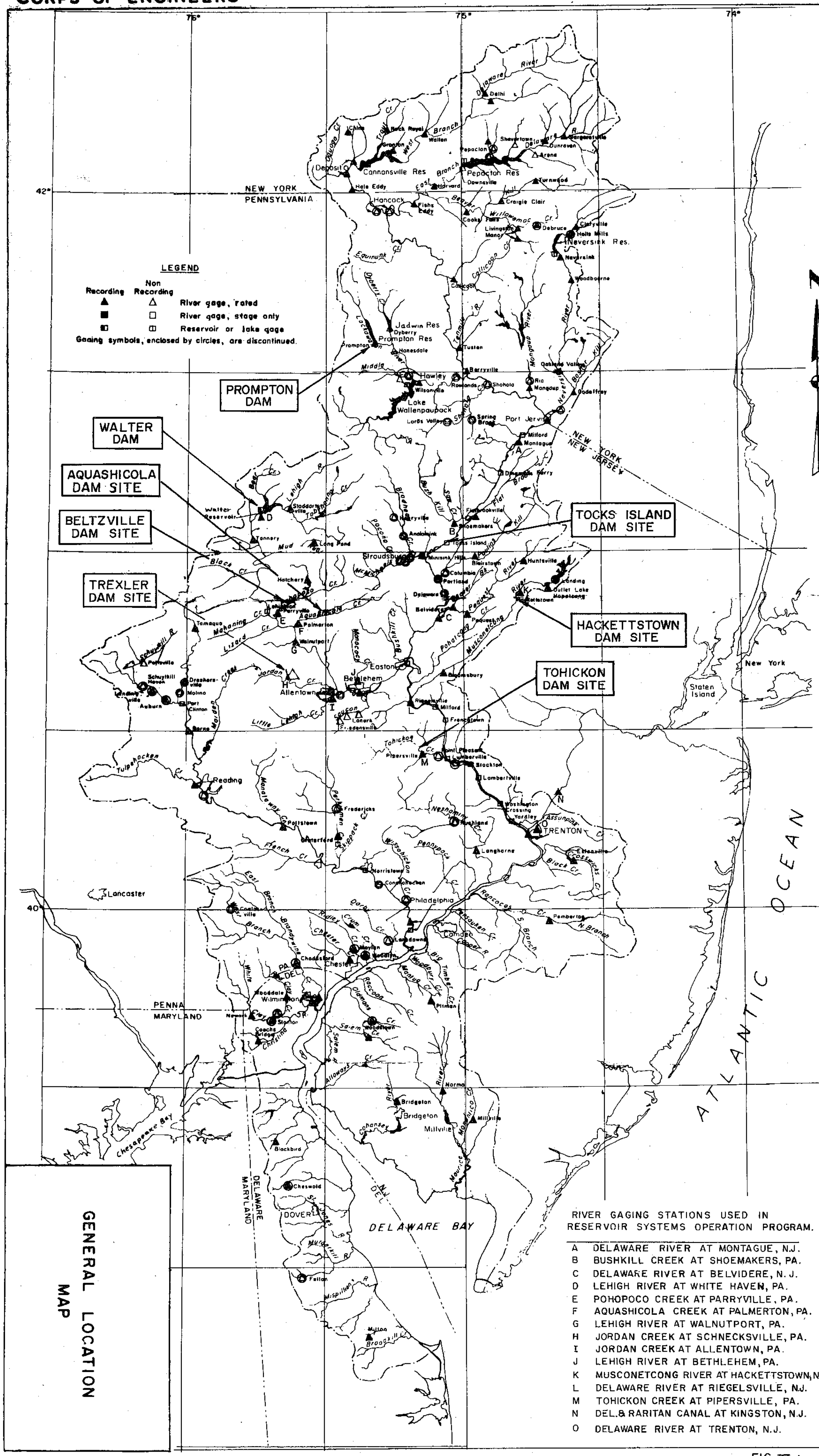

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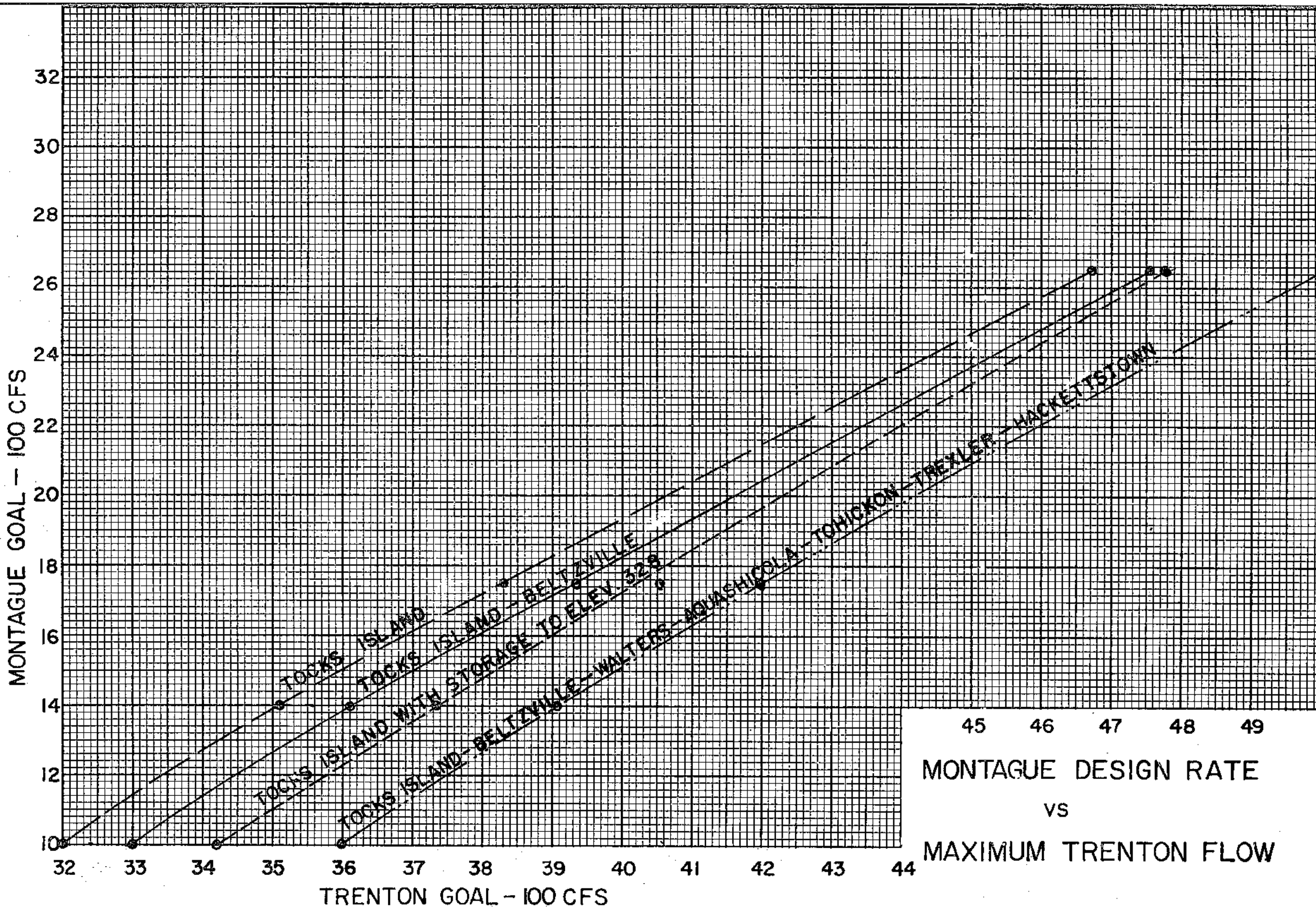

MONTAGUE DESIGN RATE VS MAXIMUM TRENTON FLOW

NAPEN-H 27 JUN 68

NOTE: Unadjusted for storage remaining in remainder of system on critical date.

FIG. IV-2