

Chapter II

Capability of the Delaware Reservoir System

The capability of the Delaware Reservoir System to provide the proposed conservation releases was analyzed by DEC using mathematical models in which operation of all three reservoirs was integrated to meet the New York City diversion demands up to 800 mgd, the flow requirement of 1750 cfs at Montague and the proposed conservation releases. The models are designed to balance storage in the reservoirs. Based on the analysis, a flexible operation scheme was developed to meet all the demands on the stored water. In this scheme diversions and releases would be made at varying rates according to rule curves based on total storage in the reservoirs. The scheme as viewed by DEC makes the most efficient use of available storage for diversions and releases that is hydrologically feasible.

Comparison of HEC and New York City Data Bases

The study for the March 1974 report was based on a 45-year period (1923-1967) of monthly reservoir inflow data obtained from the U. S. Army Corps of Engineers Hydrologic Engineering Center (HEC) in Davis, California. The data were based on available streamflow records that were adjusted to the desired locations by correlation techniques. A few discrepancies were noted in the inflow data for Cannonsville, Pepacton and Neversink Reservoirs for the 1960's. These were corrected using the same technique.

The data period includes two major droughts that represent exceptionally low water yield conditions. The analysis using these data showed that the water available for diversion to the City would average the allowable 800 mgd about 83 percent of the time on a monthly basis. The proposed conservation releases could be maintained about 67 percent of the months. The average diversion available to the City would be 770 mgd.

During review of the study results City staff advised that they had data on flows at the three Delaware reservoir sites prior to construction of the dams and data on yields of the three reservoir watersheds after the dams were built. The City data for the reservoir sites prior to construction were developed by correlations with downstream gages; the data after the dams were built were based on actual streamflow measurements. The HEC and City data were compared and it was found that average annual inflows based on the original HEC data for 1929-1959 and 1929-1967 are about 4 percent lower for Cannonsville Reservoir, 21 percent higher for Pepacton Reservoir and 2 percent higher for Neversink Reservoir. The total annual inflow for all three reservoirs is about 7 percent higher based on the HEC data. It was concluded that the City data were more reliable since they were based on more actual measurements.

Comparison of Safe Yields

Because of the City's concern about safe yield under extreme drought conditions a comparison of safe yields during the 1960's drought was also made. Based on the system operation analysis on a monthly basis for 1960-1967 system yields of 600 mgd and 590 mgd were obtained using the HEC and City data, respectively. These safe yields are higher than the following values determined independently in earlier studies in 1967:

- | | |
|--|---------|
| (i) Delaware River Master | 482 mgd |
| (ii) New York City Department of Water Supply,
Gas and Electricity | 482 mgd |
| (iii) Comprehensive Public Water Supply Study
for the City of New York and County of
Westchester | 510 mgd |

The lower safe yield estimates in the above three studies are due partly to the use of daily flow data instead of monthly data during the most critical period of the drought. Another important factor is a difference in the method of determining reservoir releases to meet the Montague flow requirement. In all three studies operation of the hydroelectric power plants were taken into account for meeting the Montague flow requirement. The DEC study was based on the HEC method which does not include the power plant operations.

The City data on inflows and the revised method of accounting for releases to meet the Montague flow requirement were used and the following safe yields were obtained for the 1960-1967 drought period:

- | | |
|--|---------|
| (i) System analysis on a monthly basis | 530 mgd |
| (ii) Mass diagram analysis on a monthly basis | 540 mgd |
| (iii) Mass diagram analysis using daily data for
the critical period of the sixties drought | 508 mgd |

A safe yield of 490 mgd was obtained for the system analysis on a monthly basis when the Montague flow requirement was increased to 1850 cfs to approximate the difference between using daily and monthly flows.

Similar comparisons were made using the HEC and City data for 1929-1959 and 1929-1967. The pre-1960's drought safe yield for the system was determined to be more than 800 mgd.

Drought-Criterion Rule Curves

The flexible operation scheme proposed in the March 1974 report was based on drought-criterion rule curves for releases and diversions. These were developed using the HEC data for the 45-year period, 1923-1967. The

rule curves define priorities for diversion and release operations. When the reservoir storage levels fell below the diversion-criterion curve at any time, drought operations were undertaken. If the operations were not changed as defined by the rule curves, severe shortages occurred.

The above rule curves were compared with the City's present control curves for the Delaware Reservoirs for 800 mgd diversion by DEC and City staffs. The City curves represent the amount of storage required at any time to fill the reservoirs by the following June 1, assuming various percentage years for net runoff. The drought-criterion rule curves were modified to reduce the shortages. The major change was a shift from normal to drought-warning conditions at higher storage levels and earlier in the year. The modified rule curves increase the City's water supply diversion capability by making an earlier cutoff of the proposed higher conservation releases. They also allow the City to divert 800 mgd for a longer period. The modified rule curves are shown in Figure 3.

Studies were made to examine reservoir operations during 1929-1960 and 1929-1973 using the City data on inflows and the City method of accounting for the Montague flow requirement of 1750 cfs. Diversions were made at various uniform rates and existing conservation release requirements were met. These studies confirmed the safe yield of 530 mgd for the 1960-1967 drought period. Using this input for reduced diversion operations during drought periods, several operation runs were made to study the capability of the system to provide diversions varying from 800 to 530 mgd and conservation releases varying from the proposed to the existing rate. The Montague flow requirement of 1750 cfs was also met. Flexible operation schemes based on the original and modified drought-criterion rule curves were examined to study the impact of modifying the rule curves. On the basis of the results the revised rule curves are recommended and have been used in further analyses.

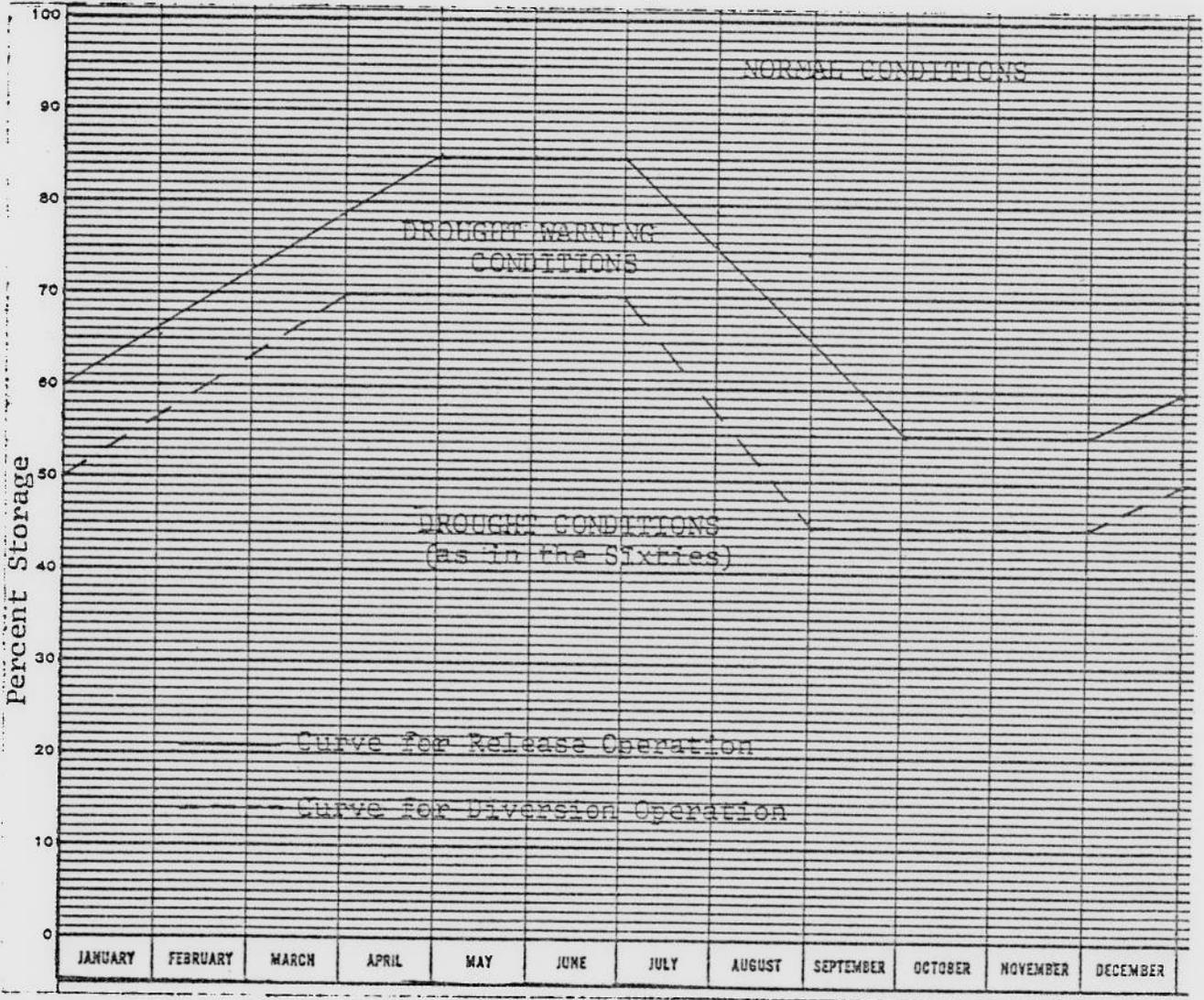
Additional System Operation Studies

Late in 1975 local citizens made proposals for additional computer runs utilizing higher releases from all three reservoirs during critical periods to alleviate stress conditions and to protect downstream fisheries. This requirement was factored into the analysis and the following additional computer runs were made with total releases of 600 mgd (100, 200 and 300 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively) for 30 critical days in conjunction with alternative present and proposed conservation release periods:

30-day scheme (year round)

30 critical days during July, August and September - Releases at 600 mgd (100, 200 and 300 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively)

335 other days - Proposed conservation releases of 32, 45 and 81 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively



NORMAL CONDITIONS - 800 mgd water supply and proposed conservation releases
 DROUGHT WARNING - 800 mgd water supply and existing conservation releases
 DROUGHT CONDITIONS - 530 mgd water supply and existing conservation releases
 Montague flow requirement of 1750 cfs to be met under all conditions

MODIFIED FLEXIBLE OPERATION
 NEW YORK CITY DELAWARE SYSTEM
 March 1976

Figure 3

90-day scheme (July - September)

60 summer days - Proposed conservation releases

30 critical days during July, August and September - Releases at 600 mgd

275 other days - Present conservation releases

120-day scheme (June - September)

90 summer days - Proposed conservation releases

30 critical days during June, July, August and September - Releases at 600 mgd

245 other days - Present conservation releases

DEC seasonal scheme

Because of present physical constraints on the release works at Cannonsville Reservoir, the proposed conservation release of 81 mgd cannot be made at a uniform rate. Therefore, seasonal releases are proposed as follows that would provide an equivalent amount of water on an annual basis:

107 summer days (June 1 - September 15) - Releases of 32, 45 and 217 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively

258 other days - Releases of 32, 45 and 29 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively

DEC original scheme

365 days - Proposed conservation releases of 32, 45 and 81 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively

The capability of the system to meet conservation releases varying from the above rates (during normal conditions) to the present minimum conservation rates (during drought and drought-warning conditions), City diversion demands up to 800 mgd, and Montague flow requirement of 1750 cfs was examined. The City inflow data for the 45-year period, 1929 to 1973, the revised drought-criterion level rule curves and the City method of accounting for releases to be made to meet Montague flow requirement were used in the above studies.

A minimum year-round flow of 1000 cfs is also needed in the Delaware River at Callicoon to improve the fisheries and to meet canoeing needs during spring and summer. This Callicoon flow requirement was not considered in detail in the system operation studies made for the March 1974 report. A preliminary analysis was made for the March 1974 report using average flow data for 1968-1970 for the spring and summer months of April - October.

The analysis indicated that the system is capable of maintaining an average flow of 1000 cfs at Callicoon during these months under normal conditions.

To study the Callicoon flow requirement further, the original system operation model was extensively revised to include Callicoon as an additional control point. Flow data at Callicoon were prepared for the 33-year period, 1941-1973. The City method of accounting for releases to be made to meet the Montague flow requirement was used for both Callicoon and Montague. The above five schemes were reexamined using the revised system model and the City inflow data for the 33-year period. The pertinent results are summarized in the following findings and presented in Table 1.

Findings

On the basis of system capability the 90-day scheme is the most favorable because the volume of releases is the lowest. The 120-day scheme, which has an additional 30 days of releases at the levels proposed in the March 1974 report, is the next most favorable. The Cannonsville seasonal scheme and March 1974 report scheme are the next most favorable with no significant difference between them. The 30-day scheme is the least favorable because the volume of releases is the largest. Long term average diversions that could be made to New York City are essentially the same for all schemes, ranging from 739 to 742 mgd. The Callicoon and Montague flow requirements would be met for all five schemes. The average conservation release would be highest for the 30-day scheme, 209 cfs, and lowest for the 90-day scheme, 107 cfs.

From the standpoint of fishery resources the 30-day scheme is the best because it would provide both for alleviation of thermal stress conditions and for enhancement of the existing fisheries. The 90-day and 120-day schemes would meet thermal stress conditions but would not improve fisheries because the existing low conservation releases would occur 70 to 75 percent of the time. The Cannonsville seasonal and March 1974 report schemes would only enhance fishery resources since they do not provide specifically for higher releases to meet thermal stress conditions. The Cannonsville seasonal scheme is less favorable because of the lower releases during the winter months.

In summary, the 90-day scheme is the most favorable with regard to system capability. The 30-day scheme is the most desirable to enhance, as well as protect, the stream fisheries.

30-day scheme

In this run the proposed 30-day releases of 600 mgd to relieve thermal stress conditions were made during normal conditions in the summer months of July, August and September in conjunction with the proposed minimum conservation releases. The analysis showed these release requirements were met 91, 94 and 91 percent of the three summer months of the 33-year period from Neversink, Pepacton and Cannonsville

Reservoirs, respectively. During remainder of the summer months when the proposed requirements could not be met the conservation releases were reduced to the present minimum conservation levels.

Because of the large draft on the reservoirs during the summer months, the proposed minimum conservation releases could be made only about 62, 64 and 61 percent of the other nine months of the study period from Neversink, Pepacton and Cannonsville Reservoirs, respectively. Consequently, conservation releases were made at the present minimum levels during the remainder of the period. In summary, the proposed conservation releases for the two periods could not be made 31, 28 and 31 percent of the months for the three reservoirs, respectively. For this scheme the average conservation release amounted to 209 cfs from all three reservoirs, or 69 percent of the target of 303 cfs.

90-day scheme

As in the above scheme, the proposed 30-day releases of 600 mgd to relieve thermal stress conditions were made in conjunction with the proposed minimum conservation releases during normal conditions in the summer months of July, August and September. However, the summer results are different because of different reservoir levels at the beginning of the summer period since only present conservation releases were made during the remainder of the year. The proposed releases were met 93, 95 and 93 percent of the summer months of the 33-year study period from Neversink, Pepacton and Cannonsville Reservoirs, respectively. During the remainder of the summer months, conservation releases were reduced to the present minimum levels.

The present minimum conservation releases proposed for the other nine months were met 90, 99 and 99 percent of the months from Neversink, Pepacton and Cannonsville Reservoirs, respectively. In summary, the proposed conservation release for the two periods could not be made 4, 2 and 2 percent of the months for the three reservoirs, respectively. For this scheme the average conservation release amounted to 107 cfs, or 74 percent of the target of 145 cfs.

120-day scheme

In this scheme the proposed 30-day releases of 600 mgd to relieve thermal stress conditions were made in conjunction with the proposed minimum conservation releases during normal conditions in the four summer months of June, July, August and September. This scheme is the same as the 90-day scheme except for the extra summer month of proposed minimum conservation releases. The proposed releases were met 90, 95 and 90 percent of the summer months of the 33-year study period from Neversink, Pepacton and Cannonsville Reservoirs, respectively. During the remainder of the summer months, conservation releases were reduced to the present minimum levels.

The present minimum conservation releases are proposed for the other eight months. These releases were met 97, 99 and 99 percent of the months from Neversink, Pepacton and Cannonsville Reservoirs, respectively. In summary, the proposed conservation releases for the two periods could not be made 6, 2 and 4 percent of the months for the three reservoirs, respectively. For this scheme the average conservation releases amounted to 136 cfs or 84 percent of the target of 161 cfs.

DEC seasonal scheme

In this scheme conservation releases at the proposed minimum levels of 32 mgd and 45 mgd were made at uniform rates from Neversink and Pepacton Reservoirs and at seasonal rates from Cannonsville Reservoir of 217 mgd from June 1 through September 15 and 32 mgd during the remainder of the year. The seasonal releases are equivalent to the proposed minimum release of 81 mgd on an annual basis. The proposed releases were met 70, 73 and 70 percent of the months from Neversink, Pepacton and Cannonsville Reservoirs, respectively. When the proposed releases could not be made they were reduced to the present minimum releases during remainder of the year. This occurred 30, 27 and 30 percent of the months for the three reservoirs, respectively. The average conservation releases amounted to 185 cfs, or 76 percent of the target of 245 cfs.

DEC original scheme

The original scheme of making the proposed minimum releases of 32, 45 and 81 mgd from Neversink, Pepacton and Cannonsville Reservoirs, respectively, was examined for comparison purposes. The proposed releases were made 71, 73 and 70 percent of months, almost the same as in the seasonal scheme. The average conservation releases were slightly lower amounting to 167 cfs, or 68 percent of the target of 245 cfs.

In all the above schemes, diversion of 800 mgd to the City, the Callicoon flow requirement of 1000 cfs and Montague flow requirement of 1750 cfs were met 77, 85 and 90 percent of the months of the 33-year study period (1941-1973). The long-term average diversion available to the City would have been about 740 mgd.

In addition to the five schemes discussed above the following two additional schemes were examined in March 1976 for comparison purposes:

Baseline scheme

365 days - Present conservation releases

Montague requirement - 1750 cfs (year round)

Callicoon requirement - none

DEC original scheme with excess release requirement

365 days - Proposed conservation releases

Montague requirements - 2140 cfs (1975-1976 excess release requirement) during the seasonal period, June 15-March 14, and 1750 cfs during the remainder of the year

Callicoon requirement - 1000 cfs

Findings

The baseline scheme requires the lowest volume of conservation releases of the seven schemes. The DEC original scheme with the added excess release requirement appears to be almost the same as the 30-day scheme proposed in the draft agreement.

Baseline scheme

In this scheme, conservation releases at the present minimum levels were examined for comparison purposes. The Montague requirement of 1750 cfs was included but not the Callicoon requirement of 1000 cfs. The present conservation releases were made 99 percent of months of the 33-year study period from all three reservoirs in the system. The average conservation release amounted to 40.7 cfs or about 98 percent of the target of 41.3 cfs.

DEC original scheme with excess release requirement

In this scheme, the effect of the present excess release requirement of 2140 cfs at Montague during the seasonal period, June 15 through March 14, was examined in conjunction with other proposed conservation releases in the DEC original scheme. The excess release requirement at Montague was applied only during normal hydrologic conditions along with the proposed conservation releases and the Callicoon flow requirement of 1000 cfs. The 1750 cfs flow requirement was applied for all conditions. The proposed releases were made 69, 71 and 69 percent of the months of the 33-year study period for Neversink, Pepacton and Cannonsville Reservoirs, respectively. These percentages are almost the same as for the seasonal and original schemes. The average conservation releases were 163 cfs, or 67 percent of the target of 245 cfs.

In the five schemes discussed previously the allowable diversion of 800 mgd to the City, the Callicoon flow requirement of 1000 cfs and the Montague flow requirement of 1750 cfs were met 77, 85 and 98 percent of the months of the 33-year study period. The lowest average annual diversion available to the City was 494 mgd in 1965, and the long-term average diversion was about 740 mgd.

In the baseline scheme, the allowable 800 mgd diversion was made 81 percent of the months of the study period. The Montague flow requirement of 1750 cfs was met 98 percent of the months as in the first five schemes. The lowest average annual diversion available to the City was 499 mgd in 1965, about a one percent increase compared to the first five schemes. The long-term average diversion was about 752 mgd, an increase of 1.6 percent compared to the first five schemes.

In the DEC scheme with the excess release requirement, the 2140 cfs flow requirement at Montague was met in 81 percent of the seasonal months examined for the 33-year study period. The basic Montague flow requirement of 1750 cfs was met 98 percent of the months of the study period as in all the other schemes. The Callicoon flow requirement of 1000 cfs was met 85 percent of the months as in the first five schemes. The allowable diversion of 800 mgd in the City was made 76 percent of the months. The lowest average annual diversion available to the City was 494 mgd in 1965 and the long-term average annual diversion was 735 mgd. Both these values are about the same as in the first five schemes.

TABLE 1 PERTINENT RESULTS OF COMPUTER RUNS

	Run #1 30-day Scheme	Run #2 90-day Scheme	Run #3 120-day Scheme	Run #4 DEC Seasonal Scheme	Run #5 DEC Original Scheme	Run #6 Base-line Scheme	Run #7 DEC Original Scheme + Excess Rel
I. <u>Reservoir Levels</u>							
Average drawdown (ft) on June 1 below crest level for							
- Neversink (N)	9.3	7.7	7.7	9.2	9.3	7.3	9.4
- Pepacton (P)	7.7	7.1	7.1	7.6	7.7	6.7	7.8
- Cannonsville (C)	5.9	5.5	5.5	5.6	5.9	5.1	5.9
Average storage on June 1 as percentage of usable storage							
- Neversink	95	97	97	95	95	98	95
- Pepacton	98	99	99	98	98	99	98
- Cannonsville	94	95	95	95	94	96	94
Frequency of storages above 90% usable	76% - (N)				76% (N)		76% (N)
storage on June 1 for the three reservoirs	79% - (P)				79% (P)		79% (P)
	79% - (C)	79%	79%	79%	79% (C)	79	79% (C)

The results presented are based on analyses of 33-year study period (1941-1973)

TABLE I (cont'd)

	Run #1 30-day Scheme	Run #2 90-day Scheme	Run #3 120-day Scheme	Run #4 DEC Seasonal Scheme	Run #5 DEC Original Scheme	Run #6 Base-line Scheme	Run #7 DEC Original Scheme + Excess Rel.
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Difference between average June 1 and Nov. 1 elevation (ft)

- Neversink	35.8	35.7	36.0	35.5	34.6	31.4	36.8
- Pepacton	39.6	38.7	39.1	39.2	38.2	34.0	40.8
- Cannonsville	32.7	32.3	32.5	32.5	32.0	26.8	33.4

1969 to 1973 operation:

June 1 storage as percentage of total storage	97 (N)	99 (N)	99 (N)	97 (N)	97 (N)	99 (N)	97 (N)
	100 (P)						
	100 (C)						

II. Diversion to NYC

Long-term average diversion (mgd)	739	742	742	740	740	750	735
Diversion (mgd) from							
- Neversink	17% of 739 or 125	18% of 742 or 134	17% of 742 or 126	17% of 740 or 126	17% of 740 or 126	18% of 750 or 135	17% of 735 or 125
- Pepacton	43% or 318	44% or 326	44% or 326	44% or 326	44% or 326	43% or 322	42% or 309
- Cannonsville	40% or 296	38% or 282	39% or 280	39% or 288	39% or 288	39% or 293	41% or 301

TABLE 1 (cont'd)

	Run #1 30-day Scheme	Run #2 90-day Scheme	Run #3 120-day Scheme	Run #4 DEC seasonal Scheme	Run #5 DEC original Scheme	Run #6 Base-line Scheme	Run #7 DEC Original Scheme + Excess
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Percent of months during the 33 -year study period 800 mgd diversion was met

	77	78	78	77	77	81	76
Lowest average annual diversion (mgd)	494 in '65	499 in '65	494 in '65				

Average diversion during 1969-1973 (mgd)

797

797

800

794

Diversion (mgd) during 1969-1973 from

- Neversink	17% of 797 or 135	19% of 797 or 151	19% of 797 or 151	18% of 797 or 143	18% of 799 or 144	20% of 800 or 160	17% of 794 or 135
- Pepacton	48% or 383	48% or 383	48% or 383	49% or 391	49% or 391	45% or 360	46% or 365
- Cannonsville	35% or 279	33% or 263	33% or 263	33% or 263	33% or 264	35% or 280	37% or 294

III. Conservation Releases

Average Conservation Release (cfs) from

- Neversink	41	24	27	35	35	10.5	34
- Pepacton	63	44	43	49	48	13.0	47
- Cannonsville	105	39	66	101	84	17.2	82
- Total	209	107	136	185	167	40.7	163
- Target	303	145	161	245	245	41.3	245
- Total as percentage of target	-- 69	74	84	76	68	98.5	67

TABLE 1 (Cont'd)

Run #1 30-day Scheme	Run #2 90-day Scheme	Run #3 120-day Scheme	Run #4 DEC Seasonal Scheme	Run #5 DEC Original Scheme	Run #6 Base-line Scheme	Run #7 DEC Original Scheme + Excess Rel.
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Percent of months during the 33-year study period proposed releases were made from

- Neversink	69	96	94	70	71	99	69
- Pepacton	72	98	98	73	73	99	71
- Cannonsville	69 (based on 12 mos.)	98 (based on 12 mos.)	96 (based on 12 mos.)	70 (based on 12 mos.)	70 (based on 12 mos.)	99 (based on 12 mos.)	69 based on 12 mos)
- Neversink	91	93	90	-	-	-	-
- Pepacton	94	95	95	-	-	-	-
- Cannonsville	91 (based on 3 mos.)	93 (based on 3 mos.)	90 (based on 4 mos.)	-	-	-	-

IV. Callicoon flow requirement (Callicoon gage - Lowest flow 194 cfs in 8/65; highest flow 14,316 cfs in 4/56)

Percent of months during the 33-year study period the Callicoon requirement of 1000 cfs was met

	85	85	85	85	86	-	85
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V. Montague flow requirement (Montague gage - Lowest flow in 8/65; Highest flow in 4/56)

Percent of months during the 33-year study period the Montague requirement of 1750 cfs was met

	98.2	98.2	98.2	98.2	98.2	98.5	98.2
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Lowest flow @ gage (cfs)
Highest flow @ gage (cfs)

	851	851	851	851	851	851	851
	22815	22901	22901	22815	22815	22901	22815

