ABSTRACT

SAFE YIELD COMPARISONS FOR THE 1960's AND 2000's DROUGHT IN THE PASSAIC RIVER BASIN

by
Stephanie R. Santos

The Passaic River Basin is a complex system of rivers, tributaries, reservoirs, and some of the largest water purveyors in the State of New Jersey. Located in the northeastern part of the State, it drains approximately 800 square miles of water that is used for distribution to the five major purveyors: North Jersey District Water Supply Commission, Passaic Valley Water Commission, Jersey City, Newark, and New Jersey American Water. These purveyors operate under a safe yield, which is defined by the New Jersey Department of Environmental Protection (NJDEP) as the amount of water that should be continuously available should the most severe drought of record occur in future conditions. The drought of record is widely accepted to be the mid 1960's drought; however, the State has experienced other drought conditions that have caused concern for the available water supply.

In 1984, a safe yield study was conducted for the Passaic River Basin by Dr. Robert Dresnack, Dr. Eugene Golub, and Dr. Franklin Salek of the New Jersey Institute of Technology, Civil and Environmental Engineering Department. That study established safe yield values utilizing sixty years of record, from 1921-1981, which concluded that the 1960's drought was the most severe during that time period. However, in the early 2000's, a drought occurred that could potentially have been more severe and created the need to evaluate the impact on the Passaic River Basin.

The purpose of this research is to create a model with five years of record, from 2000-2004, to analyze the water availability during the 2000's drought and compare it with values established for the 1960's drought. New Jersey has seen increases in population and development which will increase water consumption; therefore, it is important to monitor the water supply system to prevent potentially adverse effects. This model is created utilizing gaged stream flows, reservoir storage data, water diversions, withdrawals, and discharges from permitted users in the system.

SAFE YIELD COMPARISONS FOR THE 1960's AND 2000's DROUGHT IN THE PASSAIC RIVER BASIN

by
Stephanie R. Santos

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To my family for their love and support

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Population increases have played a role in water supply management in the Passaic River Basin, Figure 1.1, dating back to the 1800's. As cities became more populous and industrialization started to degrade water quality, purveyors began looking to acquire water from other sources within the state. Jersey City was unable to use the Passaic River to supply drinking water, so it purchased land and built what is now known as the Boonton Reservoir in 1902 (Open Space Institute, 2019).

Similarly, the City of Newark looked upstream to the Pequannock River to build reservoirs and pipelines that would supply potable water to the city as growing concerns of water quality in the Passaic River became evident. The system was first placed online in 1892 (NJDEP-DWM, 2005).

The State of New Jersey's population continues to grow and is estimated to be approximately 8.8 million as of 2019, which is an increase from a population of roughly 6 million in the 1960s (Census, 2021). The New Jersey Water Supply Management Act declares that water resources are a public asset that must be managed to "ensure an adequate supply and quality of water for citizens of the State, both present and future" (N.J.S.A. 58:1A-2, 2008).

In March 1984, a safe yield study was prepared for the Passaic River Basin by Dr. Robert Dresnack, Dr. Eugene Golub, and Dr. Franklin Salek of the New Jersey Institute of Technology, Civil and Environmental Engineering Department. The study was performed as part of a contract with the New Jersey Department of Environmental Protection (NJDEP) to determine the safe yields of the water purveyors operating within the Passaic River Basin. A FORTRAN model was developed by reconstructing sixty years of daily streamflow records, from 1921-1981, to establish the safe yields for the drought of record. This drought was determined to be the multi-year drought of the 1960's (Dresnack et al., March 1984).

Safe yield, or dependable yield, is defined by the State of New Jersey Water Supply Allocation Permits Rules as the "maintainable yield of water from a surface or ground water source or sources which is available continuously during projected future conditions, including a repetition of the most severe drought of record, without creating undesirable effects, as determined by the Department" (N.J.A.C. 7:19, 2020).

Drought watches, warnings, and emergencies have occurred since the drought of record in the 1960's. Table 1.1 is a summary of the most recent executive orders declaring water emergencies issued in New Jersey.

Table 1.1 Drought Emergency Executive Orders

E.O. No.	Date	Description	Governor
94	09/12/1980	Declares State of Water Emergency	Brendan T. Byrne
5	04/27/1982	Terminates EO #94 (Byrne)	Thomas H. Kean
97	4/17/1985	Declares State of Water Emergency	Thomas H. Kean
133	3/27/1986	Terminates EO #97	Thomas H. Kean
41	9/13/1995	Declares State of Water Emergency	Christine Todd Whitman
43	11/3/1995	Terminates EO #41	Christine Todd Whitman
98	8/5/1999	Declares State of Water Emergency	Christine Todd Whitman
102	9/27/1999	Terminates EO #98	Christine Todd Whitman
11	3/4/2002	Declares State of Water Emergency	James E. McGreevey
44	1/8/2003	Terminates EO #11	James E. McGreevey

Source: (http://nj.gov/infobank/circular/eoindex.htm) Last accessed March 2021

In the early 2000's, a drought occurred (executive order #11) which had the potential of being a more severe condition than the current drought of record in the 1960's.

Should the 2000's drought be a more critical event, the water supply system would be operating under a set of conditions that have the potential of causing undesirable effects.

This dissertation will discuss the historic conditions of the Passaic River Basin during the 1960's and 2000's drought conditions and the safe yields that are currently being utilized by the water purveyors who are responsible to supply water.

1.2 Description of the Passaic River Basin

The Passaic River Basin, Figure 1.1, is located in northeastern part of New Jersey and a southern portion of New York State with a drainage area of approximately 800 square miles within New Jersey.

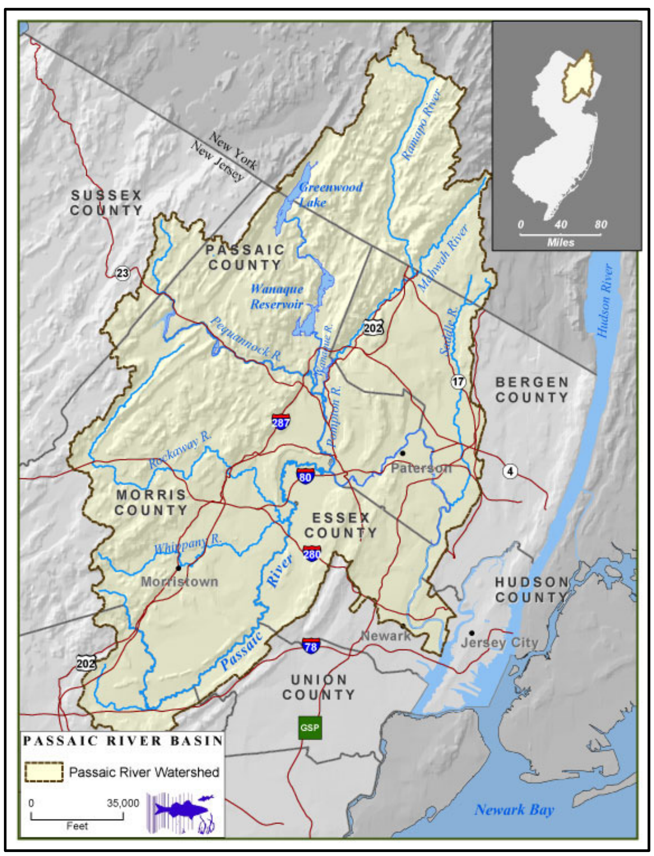

Figure 1.1 Passaic River Basin Map.
Source: (www.passaicriver.org/passaic-river-basin) Retrieved in March 2021

The watershed management areas are WMA 3, WMA 4, and WMA 6 that include the Pequannock, Pompton, Ramapo, Wanaque, Rockaway, Mid and Upper Passaic, Lower Passaic, and Saddle River watersheds. For this study, WMA 4 was only included for the area above USGS stream gage 01389500 (Passaic River at Little Falls NJ) which is the most downstream gage used for the model.

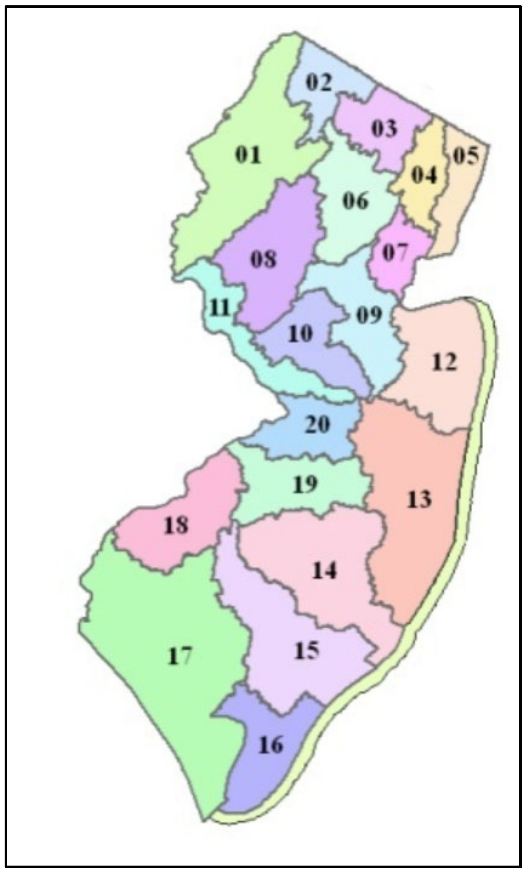

Figure 1.2 New Jersey Watershed Management Area Map.
Source: (www.nj.gov/dep/gis/digidownload/metadata/lulc02/wmaindexnew.html) Retrieved in March 2021

The Passaic, Pequannock, Pompton, Ramapo, Rockaway, Wanaque, and Whippany Rivers are the major waterways within the Passaic River Basin. The five major purveyors that divert water from this system of reservoirs and rivers are:

- City of Newark (formerly Pequannock Reservoir System)
- Jersey City
- New Jersey American Water (formerly Commonwealth Water Company)
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission

Table 1.2 provides information on the major reservoirs located within the Passaic River Basin and includes the total storage capacity and the date of completion for the reservoirs.

Table 1.2 Summary of Passaic River Basin Reservoirs

USGS Station Number	Reservoir Name	Reservoir Operator or Owner	Total Capacity (MG)	Drainage Area (mi^2)	Spillway Elevation (ft above sea level)	Date Completed
01379990	Splitrock	UWNJ/JC	3,306	5.50	835	1948
01380900	Boonton	UWNJ/JC	7,620[1]	119	305.25	1904
01382100	Canistear	Newark	2,407	5.60	1,086	1896
01382200	Oak Ridge	Newark	3,895	27.3	846	1880
01382300	Clinton	Newark	3,518	10.5	992	1889
01382380	Charlotteburg	Newark	2,964	56.2	743	1961
01382400	Echo Lake	Newark	1,630.5	4.35	893.5	1925
01383000	Greenwood Lake	State of NJ	7,140	27.1	618.86	1837
01384002	Monksville	NJDWSC	7,000	40.4	400	1988
01386990	Wanaque	NJDWSC	29,630	90.4	302.4	1927
01387860	Point View	PVWC	2,800	1.89	386	1964

[1] Total capacity with bascule gates open. Total capacity with bascule gates closed is 7.989 million gallons, with spillway elevation of 307.25 feet above sea level.
Source: Adapted and Modified from (Storck and Nawyn, 2001)

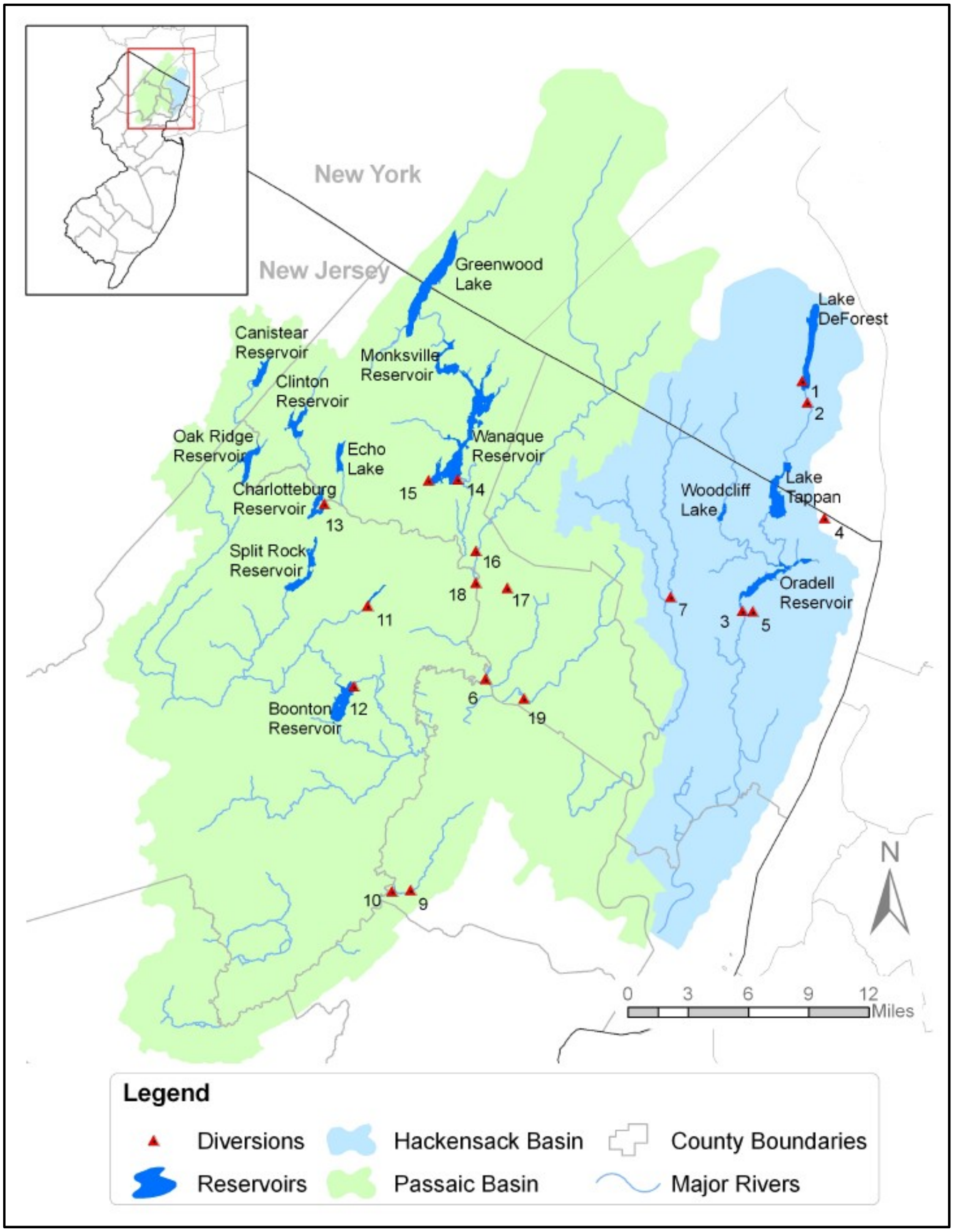

Figure 1.3 Passaic River Basin with reservoir and diversion points illustrated.
Source: (DGS 09-1, 2013)

Figure 1.3 illustrates the Passaic River Basin in green and shows the major surface water reservoirs and water diversions that were used in the development of the model. Table 1.3 provides a summary of the diversions shown as red triangles in Figure 1.3.

Point View Reservoir and the Canoe Brook Reservoirs, operated by Passaic Valley Water Commission and New Jersey American Water Co. respectively, are not shown on the map but are located near diversion point numbers 17 and 9/10.

Table 1.3 Diversion Descriptions for Figure 1.3

Map Label	Diversion Name	Diversion Owner	USGS ID
9	NJAWC Canoe Brook	NJ American Water Company	01379530
10	NJAWC Passaic River		01379510
12	Boonton Reservoir	Jersey City	01380800
13	Charlotteburg Reservoir	Newark	01382370
6	Pompton River to Wanaque Reservoir	North Jersey District Water Supply Commission	01388980
14	Wanaque Reservoir		01386980
15	Post Brook to Wanaque Reservoir		01387020
16	Ramapo River to Wanaque Reservoir		01387990
6	Pompton River to PVWC at Little Falls	Passaic Valley Water Commission	01388982
17	Point View Reservoir to Little Falls		01387959
18	Pompton River to Point View Reservoir		01388490
19	Passaic River to PVWC at Little Falls		01389490

Source: Adapted and Modified from (DGS 09-1, 2013)

Table 1.4 is a summary of the available storage in the reservoirs from various sources including the original 1984 safe yield study, three USGS reports, and the NJGS database. Most of the reservoirs have identical storages throughout the various sources, but some reservoirs have been reported differently. For this study, the DGS09-1 database was used to identify the storage of the reservoirs within the system with the exception of Point View and the three Canoe Brook Reservoirs which were not included in that database. Those reservoir values were taken from the NJ Water Supply Plan 2017-2022.

Table 1.4 Comparison of Reservoir Storage from Various Sources in Million Gallons (MG)

Source	Splitrock	Boonton	Canistear	Charlotteburg	Clinton	Echo Lake	Oak Ridge	Wanaque	Monksville	Point View	Canoe Brook (3)
	Jersey City		Newark					NJDWSC		PVWC	NJAWC
1984 Study	3,360	8,100	Combined Storage = 14,360					29,518	-	2,800	3,050
USGS 1993-96 Report	3,306	7,620[1]	2,407	2,964	3,518	1,630.5	3,895	29,630	7,000	2,800	-
			Combined Storage = 14,414.5								
USGS 2002 Water Year	3,310	7,620[2]	2,407	2,964	3,518	1,583[3]	3,895	29,630[4]	7,000	-	-
			Combined Storage = 14,367								
NJ Water Supply Plan 2017-2022	Combined Storage = 11,300		2,407	2,964	3,518	2,004	3,909	29,600	7,000	2,900	2,840
			Combined Storage = 14,802								
DGS 09-1	3,310[5]	7,366	2,407	2,964	3,518	1,583[3]	3,895	29,630[4]	7,000	-	-
			Combined Storage = 14,367								

[1] Total capacity with bascule gates open. Total capacity with bascule gates closed is 7.989 MG, with spillway elevation of 307.25 feet above sea level.
[2] 7,366 MG usable above elevation 259.75 feet
[3] 1,045 MG usable above elevation 880 feet. Provision for additional storage of 180 MG with flashboards.
[4] Capacity available by gravity at spillway level, 27,850 MG.
[5] Historically reported as 3,306

Sources: Adapted from (Dresnack et al., March 1984), (Storck and Nawyn, 2001), (Reed et al., 2003), (NJ Water Supply Plan, 2017), (DGS 09-1, 2013)

1.3 Research Objective

The objective of this research was to create a water mass balance model for the years 2000 to 2004 utilizing the following data:

- USGS steam flow gage data
- Reservoir storage
- Water purveyor diversions
- Pumping
- Surface water withdrawals
- Surface water discharges

This model, as well as the 1984 safe yield study, did not account for precipitation, evaporation, groundwater wells, bank storage, or infiltration since reported monthly reservoir storage data was available and would inherently account for these changes in the hydrologic cycle. Other assumptions were made that will be further discussed in later sections of the dissertation. The model also did not require the use of synthetic data as the necessary inputs were available for the time period for which the model was constructed.

The research had a main objective of evaluating the 2000's drought with the safe yield values developed in the 1984 safe yield study and determining if the current safe yields accepted by the NJDEP should be adjusted for the Passaic River Basin.

1.4 Structure of the Dissertation

This dissertation has been organized into five chapters. Chapter 1 provides introductory information on the research problem, objective, and structure of the dissertation. Chapter 2 will be the literature review of relevant previous work. Chapter 3 describes the methodologies used to develop the model. Chapter 4 will focus on the data processing and model development. Chapter 5 will summarize and conclude the results of this dissertation.

CHAPTER 2

LITERATURE REVIEW

2.1 1984 Safe Yield Study

The 1984 Safe Yield Study of the Passaic River Basin by Dr. Robert Dresnack, Dr. Eugene Golub, and Dr. Franklin Salek was developed to estimate safe yields for the five major purveyors by reconstructing historic daily flows for 60 years of record from 1921 to 1981.

Table 2.1 summarizes the reservoir storage, passing flow requirements, and safe yields established for that study. The complete operational description of the purveyors from the 1984 report are located within Appendix A of this dissertation.

Table 2.1 1984 Safe Yield Study Summary

Purveyor	Reservoir Storage (BG)	Passing Flow Restrictions (MGD)	Safe Yield (MGD)
Jersey City	Boonton - 8.1 Splitrock - 3.36	7	56.8
Newark	14.36 (5-Combined)	0.362	49.1
NJAWC	3.05 (3-Combined)	75 – Passaic River	10.8
NJDWSC	Wanaque - 29.518	10	95.1
PVWC	Point View - 2.8	88.5 – Pompton River	75 105 (utilizing Point View)

Source: (Dresnack et al., March 1984)

The model had two primary tasks of developing the simulation model and reconstructing daily flows. The conditions included in the model were the operational systems of the purveyors, the statutory passing flow requirements at various locations within the basin, and the existing basin infrastructure such as reservoirs and pump stations. The model also included the captures, releases, and diversions for various reservoirs in the system for the sixty years of daily record. Stream gage information was acquired from the United States Geological Survey and the purveyors provided records of reservoir volumes and diversions. The model did not account for precipitation, evaporation, groundwater wells, bank storage, or infiltration (Dresnack et al., March 1984).

With the exception of the North Jersey District Water Supply Commission, the safe yields estimated in the 1984 study are still the currently accepted values by the NJDEP. The New Jersey Water Supply Plan 2017-2022 has the safe yield of the NJDWSC listed as 190 MGD. The NJDWSC increased its safe yield estimate with the addition of the Monksville Reservoir, 7,000 MG of storage, and the completion of the Two Bridges Pump Station, which can divert up to 250 MGD from the Pompton River into the Wanaque Reservoir or the Oradell Aqueduct through a partnership with United Water of New Jersey (NJ Water Supply Plan, 2017).

The Monksville Reservoir and the Two Bridges pump station were not included in the 1984 study but were shown as potential proposed projects.

2.2 USGS 1993-96 Reconstructed Streamflow Report

The United States Geological Survey published a report titled Reconstruction of Streamflow Records in the Passaic and Hackensack River Basins, New Jersey and New

York, Water Years 1993-96 which was used as the primary reference for permitted surface water withdrawals and discharges in this dissertation. One of the initial steps of estimating safe yield values is to reconstruct streamflow records at USGS stream gages and establish natural flow conditions. This step requires the addition of water withdrawals and the removal of discharges from the gages downstream of these activities (Storck and Nawyn, 2001).

Methods of streamflow simulation described in the 1993-96 USGS report were not utilized for this model because the stream gages used for this model had continuous data for the 2000 to 2004 time period and therefore synthetic data development was not required.

The 1993-96 USGS report included a map with locations of point source discharges and surface water withdrawal sites within the Passaic River Basin. The model was creating utilizing this map to identify the location of discharge and withdrawal sites above the gages used for reconstruction in this study. The map also provided New Jersey Point Discharge Elimination System (NJPDES) and Water Allocation permit numbers that were used in conjunction with the NJGS databases to obtain the reported monthly discharges and withdrawals.

CHAPTER 3

MODEL METHODOLOGY AND DATA COLLECTION

3.1 Data Sources

The development of this model required the collection and organization of the following data sources:

Daily and Monthly Gaged Stream Flow

- USGS National Water Information System, Surface Water Data

Reservoir Storage

- NJDEP Division of Water Supply and Geoscience

  DGS09-1 Reservoir Storage and Related Diversions in the Passaic and Hackensack River Basins, 1898 to 2015

Water Purveyor Diversions

- NJDEP Division of Water Supply and Geoscience

  DGS09-1 Reservoir Storage and Related Diversions in the Passaic and Hackensack River Basins, 1898 to 2015

Surface Water Withdrawals and Point Source Discharges

- NJDEP Division of Water Supply and Geoscience

  DGS10-3 New Jersey Water Transfer Model Withdrawal, Use, and Return Data Summaries (1990-2018)

Unless otherwise noted, all the graphs and charts within this dissertation were created utilizing the raw data collected from the above sources.

Observed flows are those captured by the stream gages and reconstructed flows are those developed by removing human influences such as reservoirs that are designed to store water and alter the natural flow of the waterway. Table 3.1 provides a summary of the stream gages used in the model to reconstruct natural flows. The stream flows were reported as discharges in cubic feet per second (cfs) and were converted to million gallons per day (MGD) by dividing by 1.547.

DGS09-1 Reservoir Storage and Related Diversions in the Passaic and Hackensack River Basins, 1898 to 2015 and DGS10-3 New Jersey Water Transfer Model Withdrawal, Use, and Return Data Summaries (1990-2018) both contained data for monthly diversions made by the purveyors; however, the numbers were not identical. DGS09-1 reported data from 1898-2015 therefore this database was used for the purveyor diversions instead of DGS10-3 since data for the 1960's time period was available.

Table 3.1 Summary of USGS Stream Gages

USGS Gage Number	Description	Location	Drainage Area (mi ^{2})
01379000	Passaic River near Millington NJ	Bernards Township, Somerset County, NJ	55.4
01379500	Passaic River near Chatham NJ	Chatham Borough, Morris County, NJ	100
01380450	Rockaway River at Main Street at Boonton NJ	Boonton Town, Morris County, NJ	116
01381000	Rockaway River below Reservoir at Boonton NJ	Boonton Town, Morris County, NJ	119
01381500	Whippany River at Morristown NJ	Hanover Township, Morris County, NJ	29.4
01382500	Pequannock River at Macopin Intake Dam NJ	West Milford Township, Passaic County, NJ	63.7
01387000	Wanaque River at Wanaque NJ	Wanaque Borough, Passaic County, NJ	90.4
01388000	Ramapo River at Pompton Lakes NJ	Pompton Lakes Borough, Passaic County, NJ	160
01388500	Pompton River at Pompton Plains NJ	Wayne Township, Passaic County, NJ	355
01389500	Passaic River at Little Falls NJ	Totowa Borough, Passaic County, NJ	762

Source: (waterdata.usgs.gov/nj/nwis/current/?type=flow) Last accessed March 2021

DGS10-3 is a set of five Microsoft Access™ databases that organize permitted withdrawals and discharges by municipality or by Hydrologic Unit Code (HUC 14). The databases were used to compile the monthly surface water withdrawals and discharges in coordination with the 1993-96 USGS report which provided a map for these permitted locations. The DGS 10-3 database did not have monthly reported values for some of the several hundred point source discharges and surface water withdrawals illustrated in the 1993-96 USGS report which could indicate that those permitted users ceased to exist or did not report during the 2000 to 2004 time period. Those users were not included in this model.

Additionally, the databases were consolidated by removing any zero (0) value reported by a user or if the user reported ten or less instances of withdrawal or discharge. Those users were assumed to be temporary in nature and would not have had long lasting effects on the streamflow.

Lastly, the model did not include any of the withdrawals or discharges that occurred within the New York State drainage area of the Passaic River Basin.

The model inputs were simplified to the greatest extent practicable. The Passaic River Basin involves many complex and nuanced operational features with diversions, interconnections, pumping, and required passing flows; therefore, simplification where possible was utilized for model development.

3.2 Model Methodology

The model was developed as a water mass balance accounting model which is still a traditionally accepted practice for safe yield estimation. One of the initial and primary steps in developing a safe yield model is reconstructing gaged streamflow to mimic the flows without human intervention such as reservoirs, pumping, withdrawals, discharges, or diversions.

The reservoir storages within the Passaic River Basin for each purveyor that operated more than one reservoir were assumed to be combined and the calculation for change in storage was performed based on total values for each system. The equation for the change in storage of a reservoir is:

$$\Delta S = I - O \tag{3.1}$$

where:

ΔS = change in storage

I = inflow

O = outflow

The change in storage was calculated by subtracting the end of month storage from the end of month storage of the previous month in million gallons (MG). If the change in storage was negative, then the reservoir experienced a decrease in storage volume from one month to the next. This value was divided by the number of days in the month to obtain million gallons per day (MGD)

The reconstruction of stream flows at the gages is represented as Equation (3.2) which describes the addition and subtraction of the influences on the river to establish natural flows.

$$Q_{recon} = Q_{gaged} + \Delta S + D + W - R \pm P \qquad (3.2)$$

where:

Q_{recon} = reconstructed streamflow (MGD)

Q_{gaged} = gaged streamflow (MGD)

ΔS = change in storage (MGD)

D = diversions (MGD)

W = withdrawals (MGD)

R = discharges (MGD)

P = pumping (MGD)

The reconstructed flow was calculated in (MGD) as an average daily value for the month. The flow was then multiplied by the number of days in that month to convert the value to MG. The safe yields and passing flows (if required) were also reported in MGD and were converted to MG.

Equation (3.3) establishes the theoretical storage available for that system. The originally reported end of month storage (MG) is used to identify the start month to begin the drawdown. Beginning with the last month that the reservoir storage was reported full, the inflow calculated with Equation (3.2) is added to the storage with the safe yield and passing flow requirement being subtracted. The spreadsheet calculation will use the theoretical storage in the previous step as the S_s in the next calculation. The model will identify when the reservoir storage reached the lowest point of available storage. A comparison with the 1960's and 2000's drought was analyzed to estimate which time period would have yielded the lowest available storage.

$$S_x = S_s - SY - PF + Q_{recon} \tag{3.3}$$

where:

S_x = theoretical available storage (MG)

S_s = starting storage (MG)

SY = safe yield (MG)

PF = passing flow (MG)

Q_{recon} = reconstructed streamflow (MG)

If reservoir storage was not utilized, the model would calculate the reconstructed flow in Equation (3.2) but would not include the ΔS value. Appendix C of this dissertation provides schematic figures of the theory used to construct the model with further explanation for each of the five purveyors.

CHAPTER 4

MODEL DEVELOPMENT

4.1 Passaic River Basin Purveyor Operations

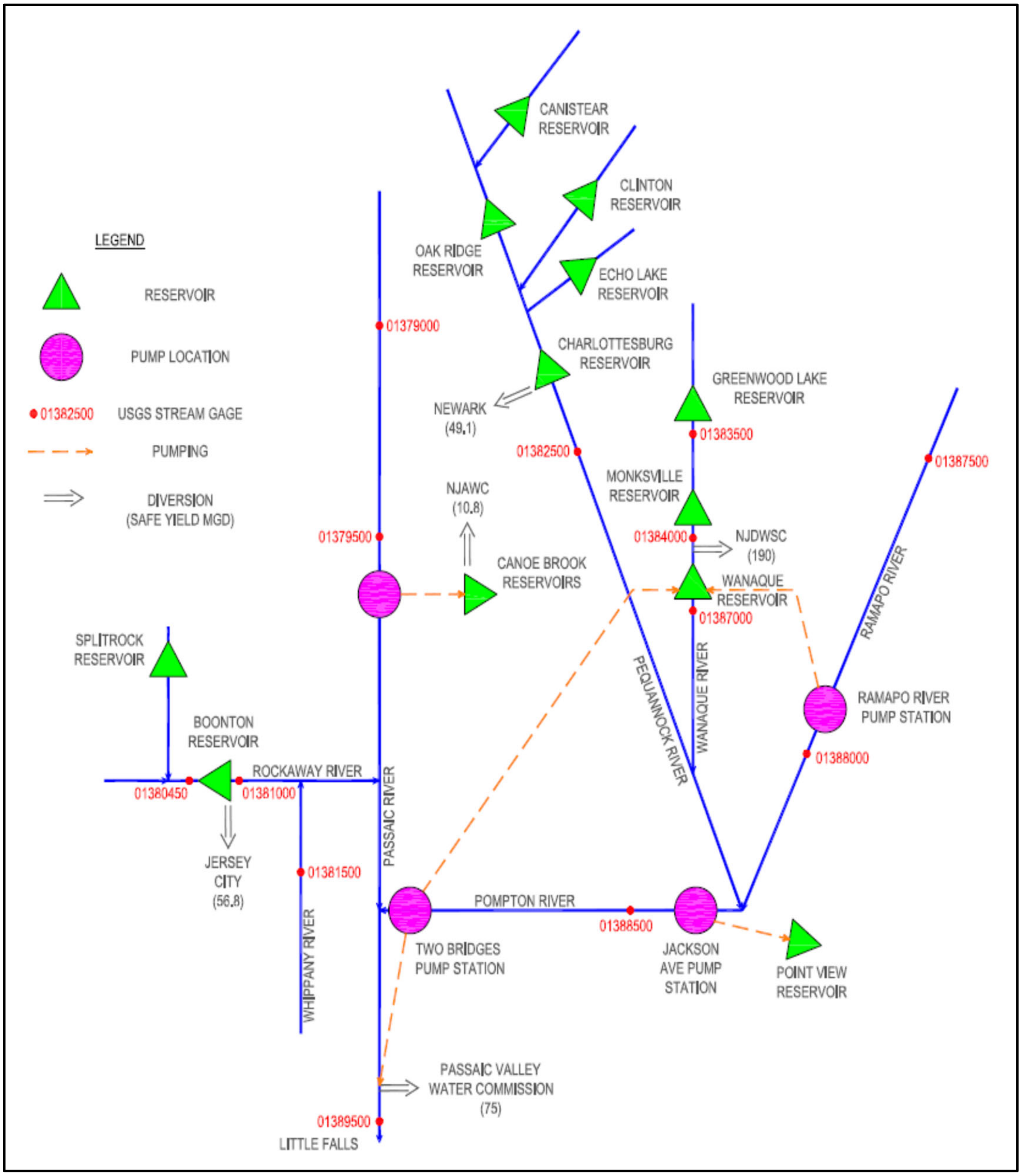

Figure 4.1 Passaic River Basin operation schematic map with reservoirs, USGS stream gages, pumping locations, and purveyor diversion locations adapted and modified from the 1984 Safe Yield Study.
Source: Adapted from (Dresnack et al., March 1984)

The Passaic River Basin consists of five major water purveyors that divert water from either reservoirs or intakes on the river. The Newark system consists of five surface water reservoirs that are on-stream and filled by gravity within the Pequannock River watershed with the diversion occurring at the Charlotteburg Reservoir.

The Jersey City system consists of two reservoirs that are on-stream and filled by gravity within the Rockaway River watershed with the diversion occurring at the Boonton Reservoir.

The New Jersey American Water Company diverts water by pumping from the Passaic River and Canoe Brook and has three off-stream reservoirs.

The North Jersey District Water Supply Commission receives water through three different sources. The Wanaque and Monksville Reservoirs are on-stream and can be filled by gravity within the Wanaque River watershed. The Wanaque Reservoir can also be filled by pumping water from the Ramapo River through the Ramapo River Pump Station and from the Pompton River via the Two Bridges Pump Station.

Passaic Valley Water Commission diverts water through an intake on the Passaic River at Little Falls. PVWC can also receive water from the Two Bridges Pump Station on the Pompton River and diverts water from the Pompton River to an off-stream reservoir via the Jackson Avenue Pump Station.

This chapter will provide greater detail on the operations of each purveyor and the model development. The model was developed to compare the time periods of 1963 to 1968 and 2000 to 2004 in order to evaluate if the 2000's drought may have been a more severe drought condition than the current drought of record in the 1960's.

Table 4.1 System Characteristics

Gravity System	Gravity and Pumped System	Pumped System
Jersey City *(Boonton and Splitrock Reservoirs)*	**North Jersey District Water Supply Commission** *(Pumping to Wanaque Reservoir Via Ramapo PS [1] and Two Bridges PS)*	**Passaic Valley Water Commission** *(Pumping into Point View Reservoir)*
Newark *(Canistear, Charlotteburg, Clinton, Echo Lake, and Oak Ridge Reservoirs)*		**New Jersey American Water Company** *(3 Reservoirs) Pumping from Passaic River and Canoe Brook [1]*

[1] No pumping from June 1 to September 30

The pumping operations are controlled by several factors. Some of the pumping locations are restricted during the summer months for water quality purposes within the waterways. Pumping is also restricted when stream flows do not meet the passing flow requirements at the stream gages. The operation of pumping is multifaceted in that the operator must balance the need to pump with the cost of pumping and ensuring that water is not lost due to spillage if too much water is pumped into the reservoirs.

The NJDWSC also operates pumps in a joint agreement with SUEZ, also known as United Water of New Jersey, where water can be pumped from the Ramapo River or Two Bridges Pump Stations and be re-directed to either the Wanaque Reservoir or a pipeline that will go to the UWNJ system via an interconnection.

4.2 The Newark System

The Newark System consists of a total of five on-stream surface water reservoirs that are filled by gravity from the Pequannock River and its tributaries. The system is modeled as one reservoir with a total storage capacity of 14.367 BG from the following reservoirs as reported by DGS 09-1:

- Canistear – 2.407 BG
- Charlotteburg – 2.964 BG
- Clinton – 3.518 BG
- Echo Lake – 1.583 BG
- Oak Ridge – 3.895 BG

During the drought periods, the combined total storage for the Newark system reached low values as described in Table 4.2. It should be noted that Charlotteburg Reservoir was completed in 1961 and was not reported full until March 1967.

Table 4.2 1960's vs 2000's Drought Newark Combined Reservoir Low Storage

End of Month 1960s	Reported Storage (MG) Full – 14,367	End of Month 2000s	Reported Storage (MG) Full – 14,367
8/31/1965	1,948	11/30/2001	6,770
9/30/1965	1,439	12/31/2001	6,178
10/31/1965	1,400	1/31/2002	5,855
11/30/1965	1,195	2/28/2002	5,040
12/31/1965	1,513	3/31/2002	5,646

Source: Table generated utilizing data from: (DGS 09-1, 2013)

The total combined storage for the Newark system is illustrated in Figure 4.2 within the five-year period for both the 1960's and 2000's drought. The graph clearly shows that the cumulative reported storage available in the system was less in the 1960's in comparison to the 2000's time period.

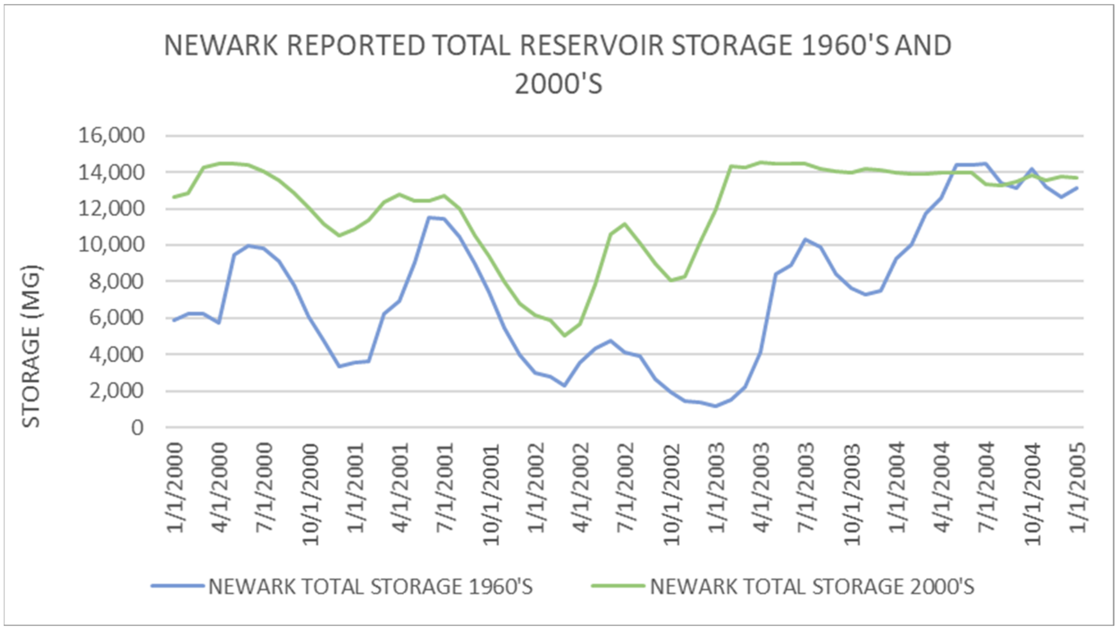

Figure 4.2 Total reported reservoir storage comparison for the Newark System for the five years of record in the 1960's and 2000's time periods.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

Figures 4.3 and 4.4 depict the reported end of month storage during the two drought periods for the five reservoirs individually. The 1960's drought appears to indicate that the 4 upstream reservoirs were being drawn down while Charlotteburg was being drawn down. In the 2000's drought, the upstream reservoirs were releasing at various points and maintaining a higher storage volume at Charlotteburg during the drought period. Graphs with the individual reported reservoir storage volumes can be found in Appendix B of this dissertation.

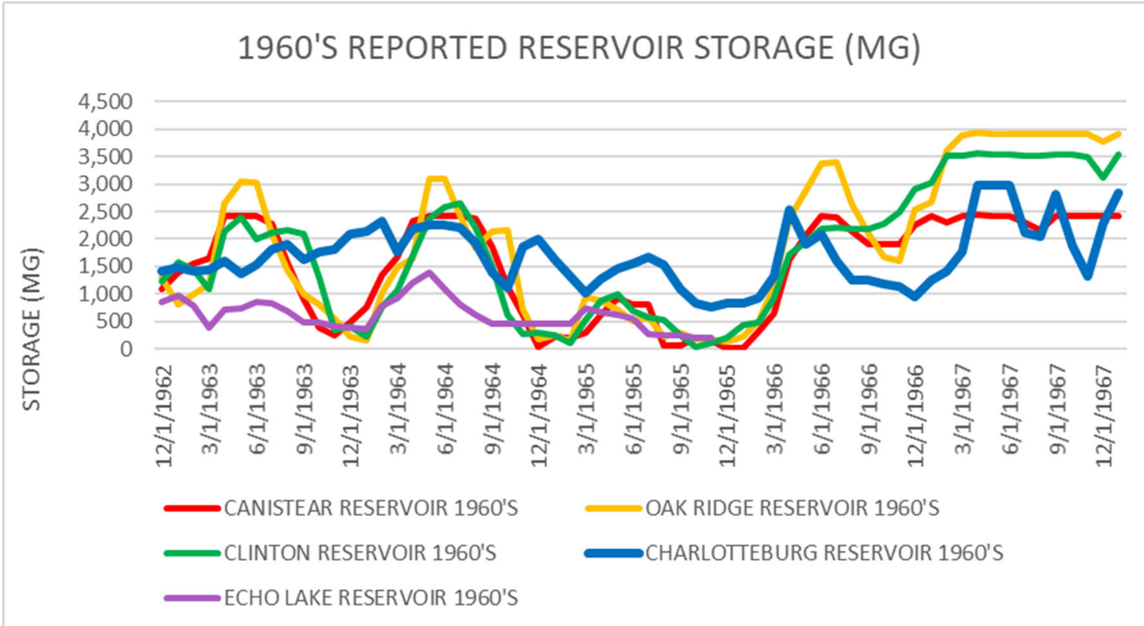

Figure 4.3 Newark System reported reservoir storage for the 1960's drought for all five reservoirs.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

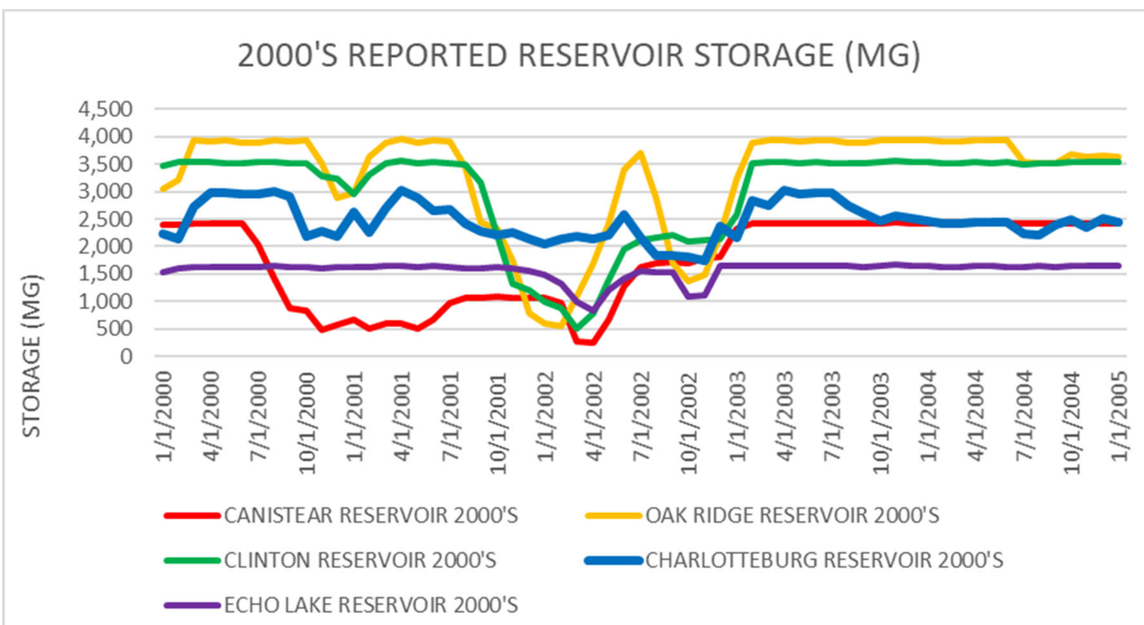

Figure 4.4 Newark System reported reservoir storage for the 2000's drought for all five reservoirs.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

USGS stream gage 01382500 – Pequannock River at Macopin Intake Dam, NJ is the gage immediately downstream of the Charlotteburg Reservoir and the Newark diversion. The stream gage flow was reported as average monthly flow in MGD. The passing flow utilized in the 1984 study was 0.362 MGD and is currently listed as 7.95 MGD (12.3 CFS) per the Water Supply Allocation Permit Rules. (N.J.A.C. 7:19-4, 2005)

During the 1962-1967 time period, only six months would have met the required 7.95 MGD passing flow, if that passing flow had been required at that time, and twenty-nine months did not meet the 0.362 MGD passing flow of the 1960's drought with twenty-two of those months reporting no flow through the gage.

In the 2000-2004 time period, twenty-six months fell below the 7.95 passing flow threshold with the lowest flow being reported as 0.38 MGD average monthly flow. Figures 4.5 and 4.6 chart the reported stream flows at gage 01382500 with the passing flow of 7.95 MGD as a baseline. During the two time periods low flows are recorded, but the 1960's drought had a greater impact on the flows at this gage. New Jersey can relax passing flows during drought conditions, but the passing flow of 7.95 was applied to calculate the theoretical available storage during both time periods.

The drainage area above gage 01382500 has one diversion (Newark) and one discharge. The discharge does not exceed 0.2 MGD for any month and would have negligible effect on the reconstructed flow.

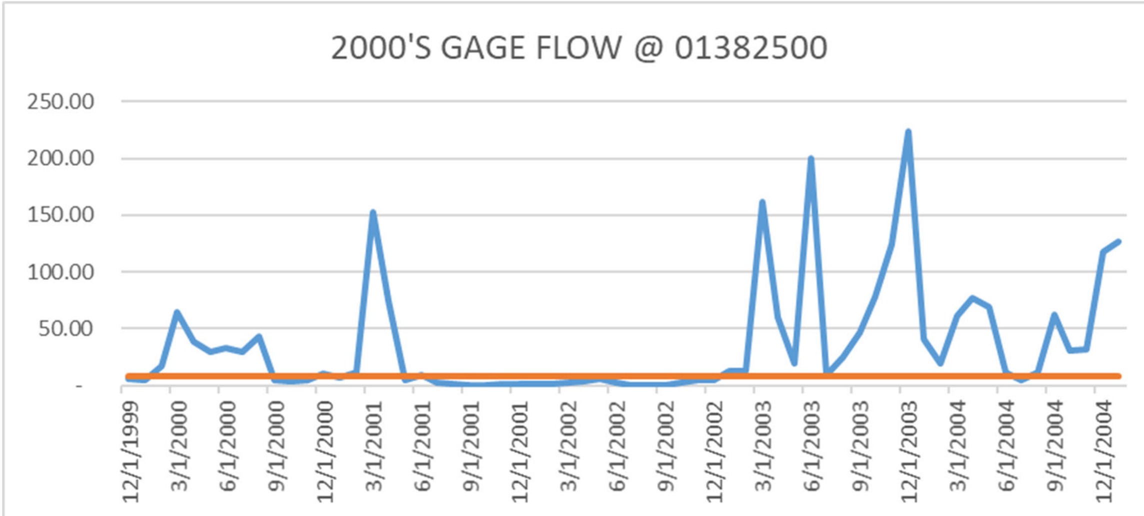

Figure 4.5 Reported gage flow at USGS gage 01382500 plotted against the passing flow of 7.95 MGD for the time period 2000-2004.
Source: Graph generated utilizing data from (USGS)

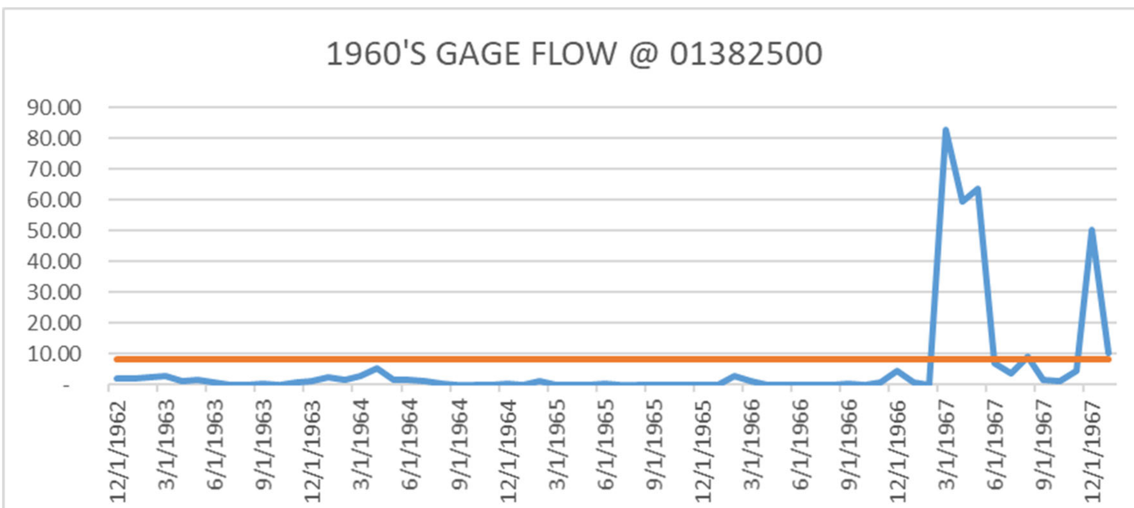

Figure 4.6 Reported gage flow at USGS gage 01382500 plotted against the passing flow of 7.95 MGD for the time period 1963-1967.
Source: Graph generated utilizing data from (USGS)

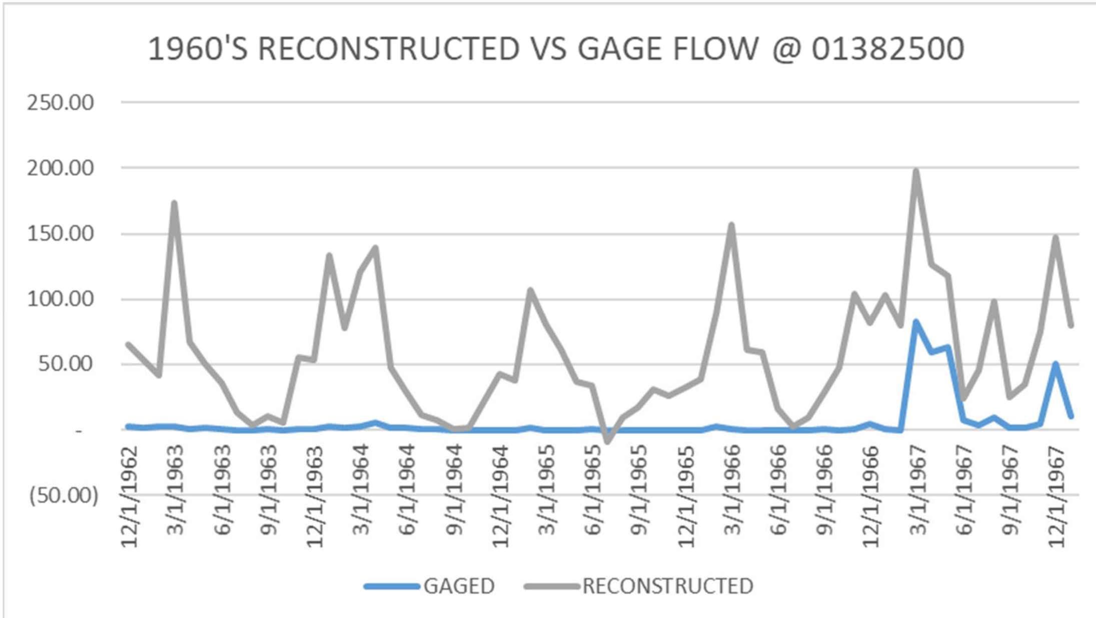

Figure 4.7 Reconstructed and gaged flows (MGD) shown for the USGS stream gage 01382500 for the 1960's time period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

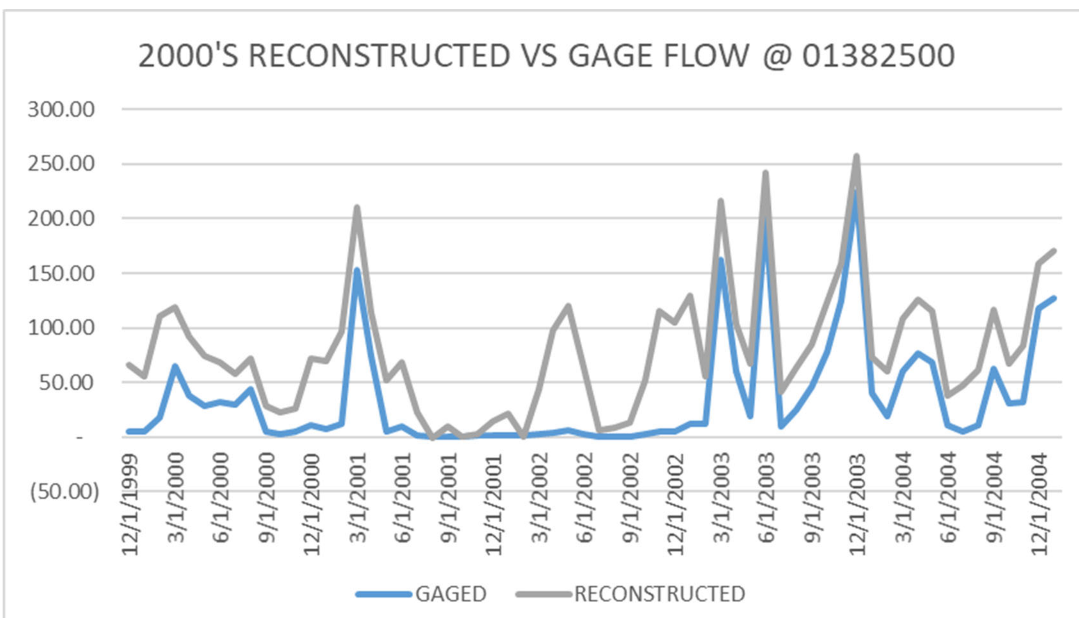

Figure 4.8 Reconstructed and gaged flows (MGD) shown for the USGS stream gage 01382500 for the 2000's time period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

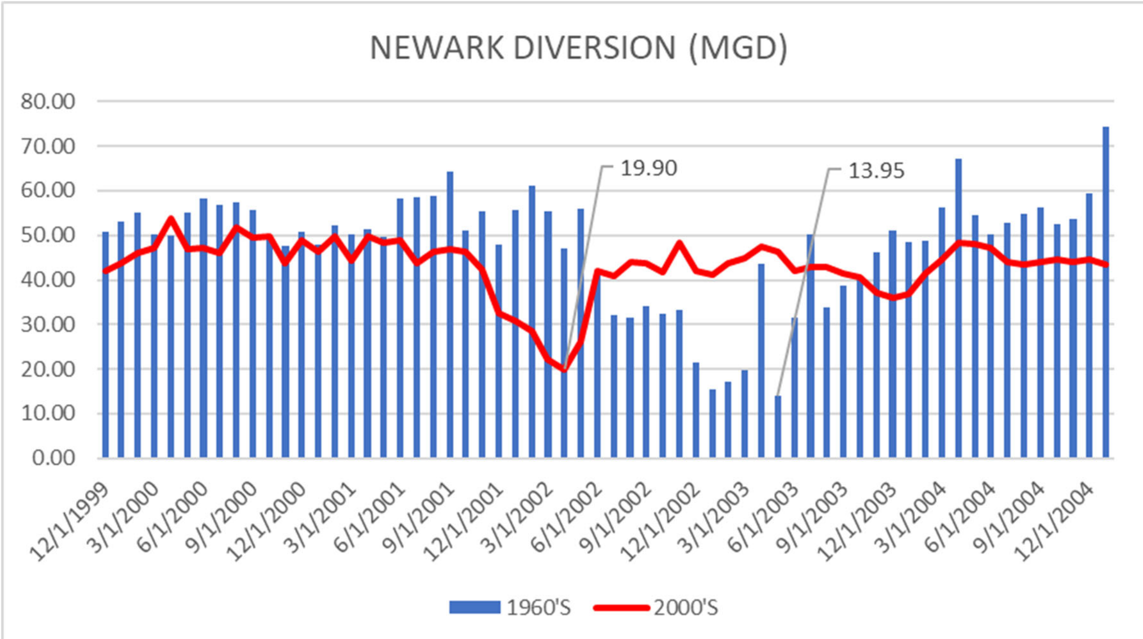

Figure 4.9 Reported monthly diversions for Newark plotted for the time periods 1963-1967 and 2000-2004 with the lowest diversion shown in MGD. The 2000's was shown to have diverted more water during the drought periods.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

The Newark System also receives 49.4 MGD of water from NJDWSC. During the drought periods the monthly diversions reported were reduced to about half of the average monthly MGD. The typical diversions ranged typically from 40-50 MGD; however, in the drought periods they were reported as low as 14 MGD in the 1960's and 20 MGD in the 2000's (Figure 4.9). The purveyor is responsible for managing the water supply and based on these reported values, it is presumed that Newark attempted to preserve the reservoir storage during this critical time.

Starting with a full storage of 14,456 MG, adding in the reconstructed inflow, subtracting the safe yield of 49.1 MGD and passing flow of 7.95 MGD, the system would have reached a theoretical low storage of approximately 7,800 MG in October 2002. For the 1960's period the storage began in May 1964 with a bit over 11,500 MG which is not full for the combined storage of the Newark System, however Charlotteburg had just been completed in 1962 and had not yet been filled completely; therefore, May 1964 represents the most full the system was during that time period when the drought occurred.

Utilizing that start point and a passing flow of 7.95 MGD, the theoretical storage would have over drafted in August 1965. However, the passing flow for the 1984 safe yield study was 0.362 MGD which would have maintained more water in the reservoirs. Utilizing that passing flow and a starting storage of 11,500 MG, the reservoir would have reached its lowest point of less than 10 MG in January 1966.

In either scenario of utilizing the two passing flows, the drought conditions would have affected the Newark system more severely in the 1960's drought in comparison with the 2000's time period. Some contributing factors could include the fact that Charlotteburg was not completely filled when the drought period began in the 1960's but also that less water was diverted in the 1960's during the critical time periods.

4.3 The Jersey City System

The Jersey City System consists of two on-stream surface water reservoirs that are filled by gravity within the Rockaway River watershed. The system is modeled as one reservoir with a total storage capacity of 10.676 BG from the following reservoirs as reported by DGS 09-1:

- Boonton – 7.366 BG
- Splitrock – 3,310 BG

Table 4.3 depicts the five months with the lowest reported available storage during the drought periods. The reservoir storage was similar during both time periods however, the 1960's had lower overall monthly volumes.

Table 4.3 1960's vs 2000's Drought Jersey City Combined Reservoir Low Storage

End of Month 1960's	Reported Storage (MG) Full – 10,676	End of Month 2000's	Reported Storage (MG) Full – 10,676
11/30/1964	4,471	11/30/2001	6,493
12/31/1964	5,064	12/31/2001	5,761
1/31/1965	5,036	1/31/2002	4,873
9/30/1965	4,704	2/28/2002	4,481
10/31/1965	4,843	3/31/2002	5,942

Source: Table generated utilizing data from: (DGS 09-1, 2013)

Splitrock has a total storage of 3,310 MG and was at approximately 50% full in 1965 but was maintained more full in 2002. Table 4.4 provides information on the minimum storage volumes for both reservoirs.

Table 4.4 1960's vs 2000's Boonton and Splitrock Minimum Storage

Reservoir Name	Boonton (MG)	Date	Splitrock (MG)	Date
1960's Lowest Storage	2,225	(11/30/64)	1,532	(1/31/1965)
2000's Lowest Storage	2,072	(2/28/2002)	2,409	(2/28/2002)

Source: Table generated utilizing data from: (DGS 09-1, 2013)

Figures 4.10 and 4.11 illustrate the storage volumes for Boonton and Splitrock Reservoirs. Boonton Reservoir storage fluctuated more in the 1960's than in in the 2000's, but the total reported storage was similar. The Jersey City System preserved upstream storage in Splitrock Reservoir in the 2000's drought and allowed Boonton to get drawn down more than in the 1960's.

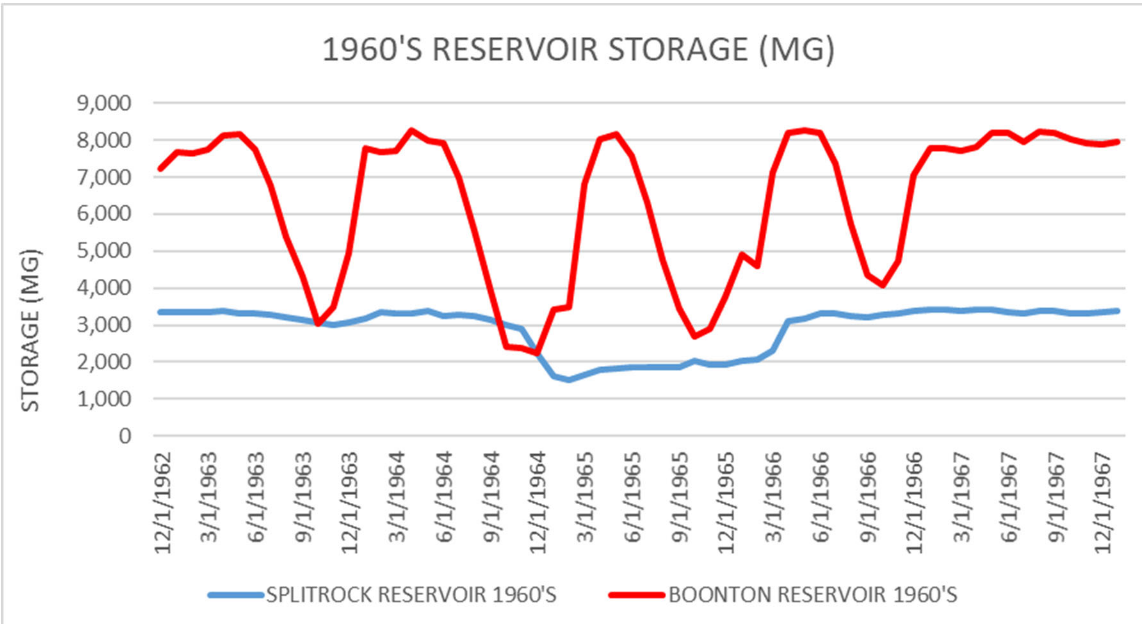

Figure 4.10 Jersey City storage for the 1960's drought for the two system reservoirs.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

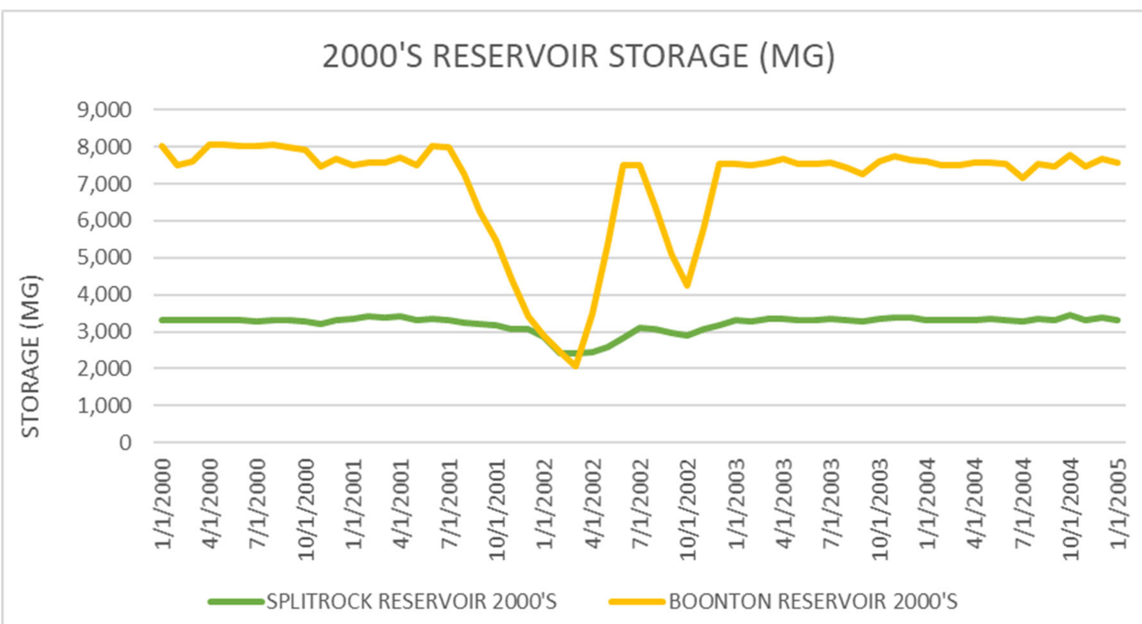

Figure 4.11 Jersey City storage for the 2000's drought for the two system reservoirs.
Source: (Graph generated utilizing data from (DGS 09-1, 2013)

At USGS stream gage 01381000 – Rockaway River below Reservoir at Boonton NJ a passing flow of 7 MGD is required on the Rockaway River. During the 2000-2004 time period, the passing flow was not met for six of the gaged monthly averages but only fell to 5.69 MGD. During drought conditions, the State has the authority to reduce passing flows which was done through executive order reducing the passing flow to 5 MGD. The reduction was not applied to the model and the passing flow was modeled for the 7 MGD (Hoffman and Domber, 2013).

The passing flow was not established until 1969 and therefore was not in effect during the 1960's drought; however, if it were required, only about half of the months reported during that period would have met the passing flow. The passing flow was imposed because Rockaway Valley Regional Sewerage Authority is located directly below the Boonton gage and the flow released from Boonton was needed to dilute treated effluent that was creating water quality issues in the Rockaway River (Hoffman and Domber, 2013).

The Jersey City System model included the diversion to Jersey City, the storage changes in two reservoirs (modeled as one), two discharges, and nine withdrawal sites above gage 01381000.

No withdrawals or discharges were included in the 1960's calculation as these were not included in the 1984 safe yield study. The model also evaluated the 2000's period by removing the discharges and withdrawals and did not change the overall outcome. The theoretical storage in October 1965 was approximately 3,900 MG and 4,200 MG in February 2002 at the lowest points. Figures 4.10 and 4.11 both indicate that during the drought period the reservoir storages refilled and were drawn down.

Figure 4.13 plots the five years of available Jersey City diversion records for the period of 1963-1967 and 2000-2004. This graph would indicate that less water was drawn from the Jersey City in the 2000's period. The reported storage for the two periods was very similar. The reconstructed flow for both time periods plotted for the five-year durations also shows similar general patterns.

Based on these observations with the storage and reconstructed flow having similar trends, it would appear the change in operating practices by lowering the amount of water being diverted played a role in the system. As mentioned previously, it is the purveyor's responsibility to regulate the water within the system, but it is not known what those operational procedures were that could have resulted in the change in diversion during these two drought periods.

For the 2000's period, if start storage on June 2001 of 11,370 MG was utilized then this would have created the most severe condition in the Jersey City System. The lowest theoretical storage would have been approximately 3,770 MG. For the 1960's period, the volume of reservoir storage oscillated and created a few different possible start points for the storage drawdown to begin. In the worst case, starting with a full storage of 11,580 in April 1964, the available storage was approximately 5,550 MG.

The system having very similar observed patterns of storage data makes the Jersey City System more difficult to determine which time period was more severe. However, based on the available storage calculated, the 2000's drought would have been more critical.

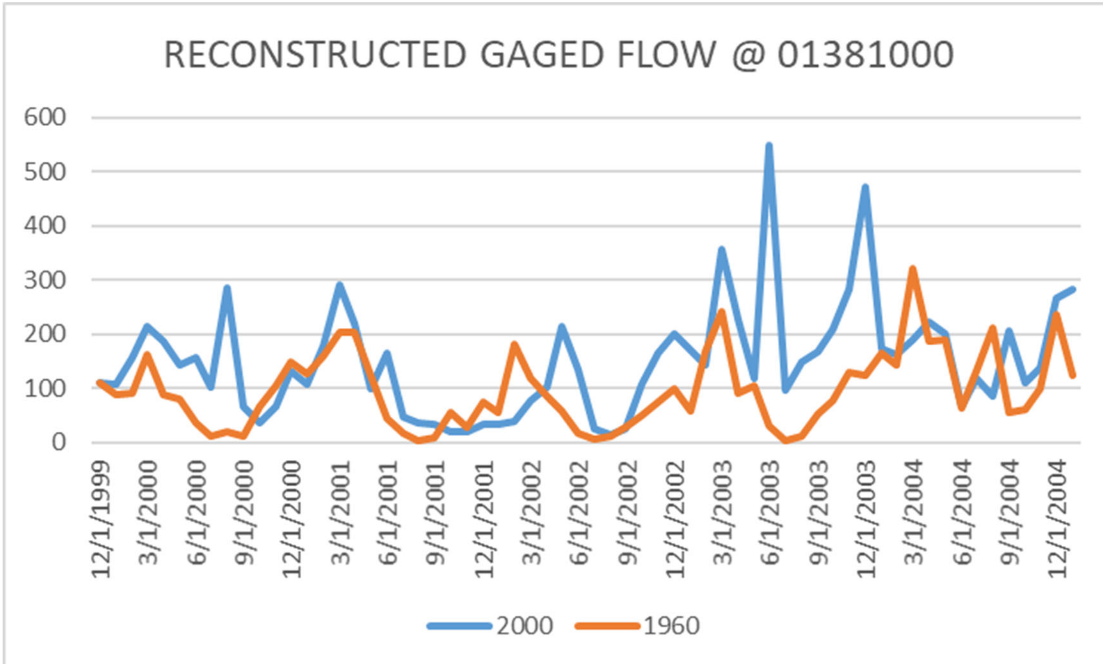

Figure 4.12 Reconstructed flows (MGD) for the USGS stream gage 01381000 for the 1960's and 2000's five-year period.

Source: (Graph generated utilizing data from: (USGS) and (DGS 09-1, 2013)

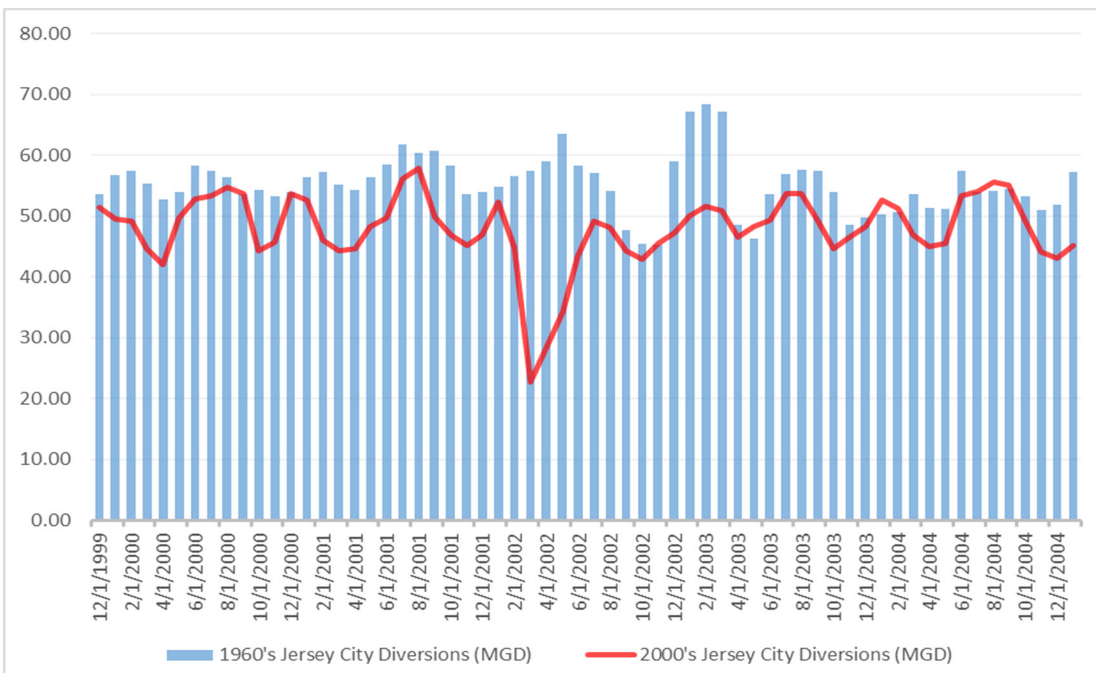

Figure 4.13 Five years of monthly diversions (MGD) to Jersey City plotted for 1960's and 2000's.

Source: Graph generated utilizing data from (DGS 09-1, 2013)

4.4 New Jersey American Water Company

The New Jersey American Water Company (NJAWC) diverts water from the Passaic River and Canoe Brook. NJAWC operates three small off-stream reservoirs with a total storage capacity of 2.84 BG. No pumping is allowed on the Passaic River pump station from June 1st – September 30th. Reservoir storage was not available; therefore, the analysis for this system had a different approach. The NJAWC is the smallest of the five purveyors in the model with a current safe yield of 10.8 MGD.

The diversion for the NJAWC is located downstream of USGS gage 01379500 and has a passing flow requirement of 75 MGD. There are thirteen discharges and three withdrawals above this gage.

Upstream of this gage, there are eleven wastewater discharges with three being located immediately upstream of the gage. The passing flow is essential for dilution of the wastewater discharges to maintain an acceptable water quality at the diversion of NJAWC.

Figures 4.14 and 4.15 illustrate the average monthly stream flow for the 1960's gaged and the 2000's flows with the 75 MGD passing flow plotted. There are several periods of gaged flow that is less than the required passing flow, however these typically occurred during the "no pump" months and therefore NJAWC would not be diverting water from the Passaic River.

Data for the 1960's pertaining to discharges and withdrawals was not available; therefore, no flow reconstruction occurred. Additionally, the reconstruction for the 1960's did not consider the diversion for NJAWC at Passaic River as those diversions were not reported for the 1960's period. Figure 4.16 is a combination chart which illustrates the passing flow requirement in orange, the reconstructed streamflow with the withdrawals and discharges, excluding NJAWC diversion, in green, and a comparison reconstruction with NJAWC added into the flow in blue. The chart was also limited to show only two years of stream flows as this was the most critical time period from 2001 to 2002. During the "no pump" months, the stream flows are identical as no water was diverted for NJAWC on the Passaic River.

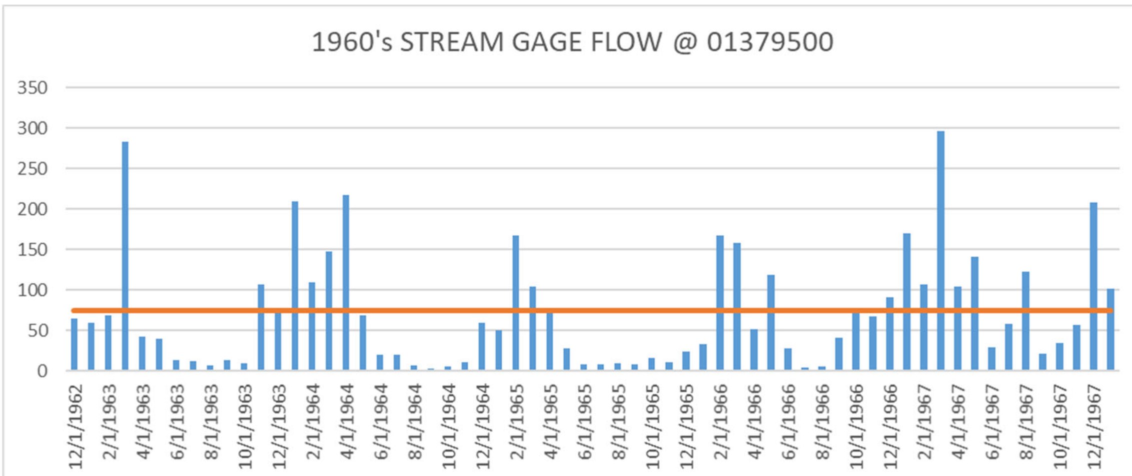

Figure 4.14 Gaged stream flows in the 1960's period with the passing flow of 75 MGD plotted at 01379500.
Source: Graph generated utilizing data from (DGS 09-1, 2013) and (USGS)

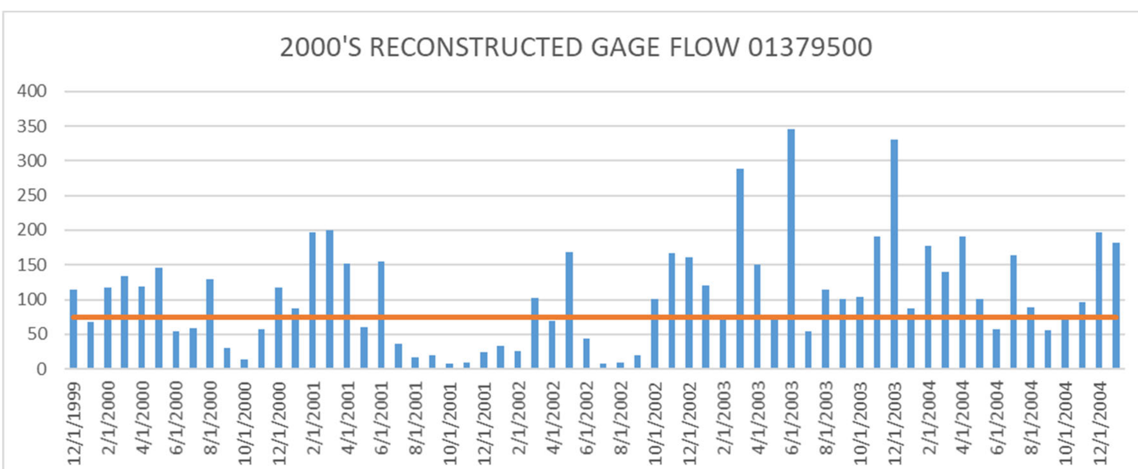

Figure 4.15 Gaged stream flows in the 2000's period with the passing flow of 75 MGD plotted at 01379500.
Source: Graph generated utilizing data from (DGS 09-1, 2013) and (USGS)

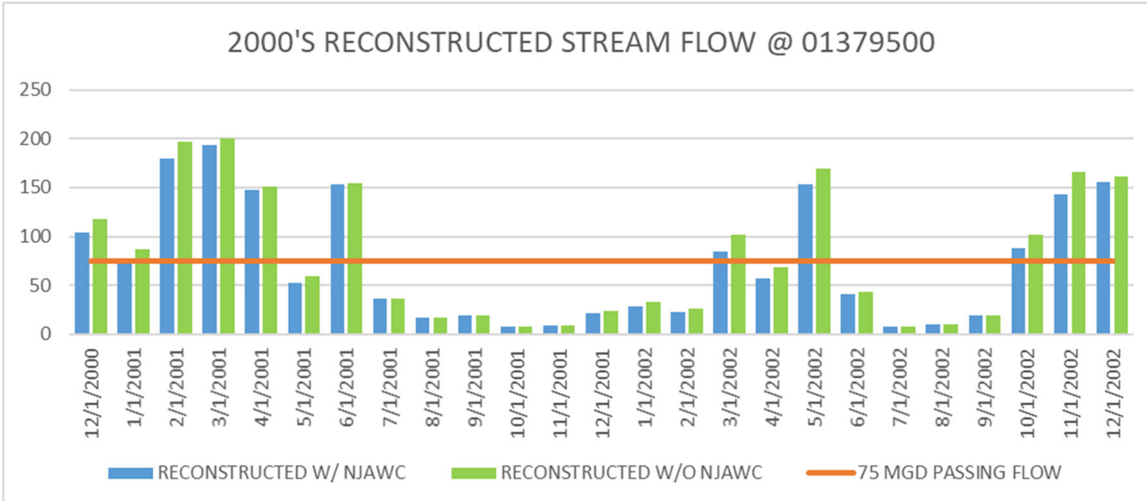

Figure 4.16 Reconstructed stream flows in the 2000's period with the passing flow of 75 MGD.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

The wastewater discharges have an overall average value of almost 8 MGD for the five years of record, 2000 to 2004. This is significant because the discharges almost equal the safe yield for the NJAWC system which is 10.8 MGD.

During the 2000's period there were no months that had less than 10.8 MGD in the gaged stream flow at 01379500. There were twelve months that reported less than 10.8 MGD in the gage; however, nine of those occurred during the "no pump" months and would not have impacted the NJAWC diversion. Absent storage data for the three reservoirs operated by NJAWC, the conclusion is made through the available data of stream gage flows. Based on stream gage data alone, it would appear that the 1960's drought was more critical for the NJAWC system.

4.5 North Jersey District Water Supply Commission

The North Jersey District Water Supply Commission is a complex system. The NJDWSC operates the Wanaque and Monksville Reservoirs which are both on-steam and filled by gravity within the Wanaque River watershed. The Wanaque Reservoir can also be filled from two pumping stations. The Ramapo Pump Station is located on the Ramapo River and the Two Bridges Pump Station provides water from the Pompton River near the confluence of the Passaic River. The Two Bridges Pump Station can be used to divert water to Wanaque Reservoir, to Passaic Valley Water Commission at Little Falls, or through a partnership with United Water New Jersey to the Oradell Aqueduct.

Greenwood Lake is not owned by NJDWSC; however, can benefit from releases from the reservoir as the dam is operated by the NJDEP and would discharge directly to the Wanaque River and flow into Monksville Reservoir. This release was not considered in this study but should be noted.

The NJDWSC underwent several changes between the time of the 1984 safe yield study report and the 2000's drought. The 1984 report established a safe yield of 95.1 MGD. At that time, two major system characteristics were not included. The addition of the Monksville Reservoir and the Two Bridges Pump Station, both completed in 1987, were constructed to provide additional water into the NJDWSC system and ultimately increased the current safe yield to 190 MGD. This includes 49.4 MGD that is allocated to Newark, and also 10.34 MGD to PVWC.

In July 1984 Dr. Robert Dresnack, Dr. Eugene Golub, and Dr. Franklin Salek prepared a reported title "Safe Yield Study of the Proposed Projects to Provide Additional Water for Northeast New Jersey". This report detailed the impacts to the safe yield previously established in the March 1984 study with the possible addition of the Monksville Reservoir, and additional pumping station transfers into NJDWSC. The maximum pumping described in Table 4.5 was a feasibility study of how these changes would augment the safe yields in the Passaic River Basin.

The partnership between NJDWSC and SUEZ (UWNJ) is such that the 250 MGD available at the Two Bridges Pump Station would be equally shared 125/125 MGD and the Ramapo River Pump Station, which involved upgrading the system, increased the pumping capacity from 100 to 150 MGD and the additional capacity was equally divided 125/25 MGD. These changes in pumping were not included in the original 1984 study but were studied as a way to increase the safe yield of NJDWSC. Through the addition of the pumps and the additional storage of Monksville Reservoir, the July 1984 study estimated an increase in safe yield from 95 to 177 MGD. The safe yield was also estimated to be 177 MGD with Monksville and 152 MGD without Monksville, meaning that the addition of the reservoir would increase the safe yield by 25 MGD (Dresnack et al., July 1984).

Table 4.5 Maximum Pumping for NJDWSC

Operator	Pump Station	Maximum Allowed Pumping (MGM)
NJDWSC	Two Bridges	3,875
SUEZ*	Two Bridges	3,875
NJDWSC	Ramapo River	3,875
SUEZ*	Ramapo River	775

* Formerly the Hackensack Water Co. or United Water NJ
Source: Table generated from (Dresnack et al., July 1984)

According to the New Jersey Water Supply Planning Activities in 2012 report, NJDWSC requested and were denied an increase in the safe yield from 173 to 208 MGD in 2005. A settlement was reached that would increase the safe yield in the system to the currently accepted 190 MGD which was dependent on additional pumping from the two pump stations downstream (Hoffman, 2013).

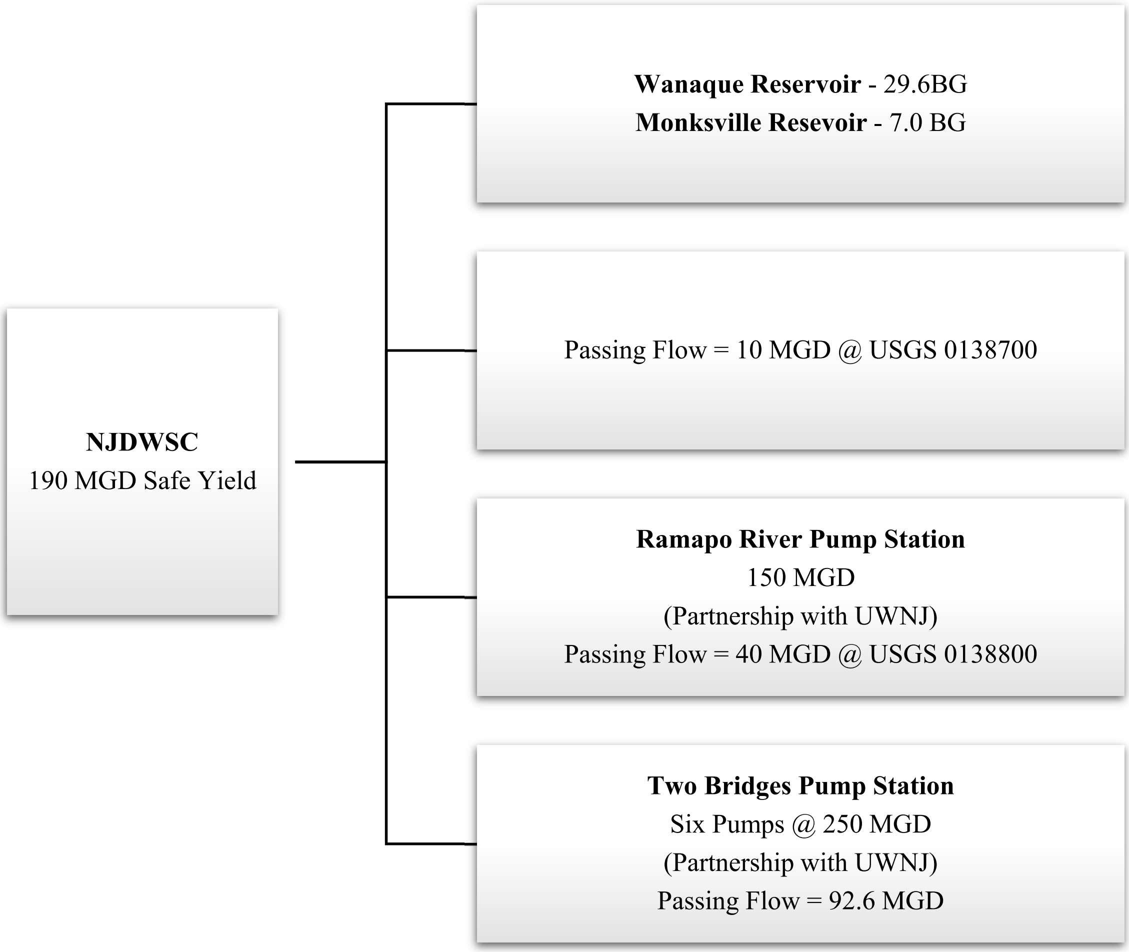

Figure 4.17 Figure represents the operational characteristics of the North Jersey District Water Supply Commission including information on the pumping, passing flow requirements, and diversions.
Source: Figure generated utilizing data from: (NJ Water Supply Plan, 2017-Appendix C)

Figures 4.18 and 4.19 illustrate the reported storage in the Wanaque Reservoirs in the 1960's and 2000's respectively with the full line plotted. Figure 4.20 includes Wanaque and Monksville Reservoir storage in only the 2000's period as Monksville was not constructed during the 1960's drought period. Monksville increases the available storage by 7,000 MG for the NJDWSC. During the 2000's drought it appears that Monksville was not used to divert water into Wanaque as the lowest storage reported was 5,740 MG in

2002. As with the other purveyors, the upstream storage was preserved during the 2000's drought as the preferred operating procedure.

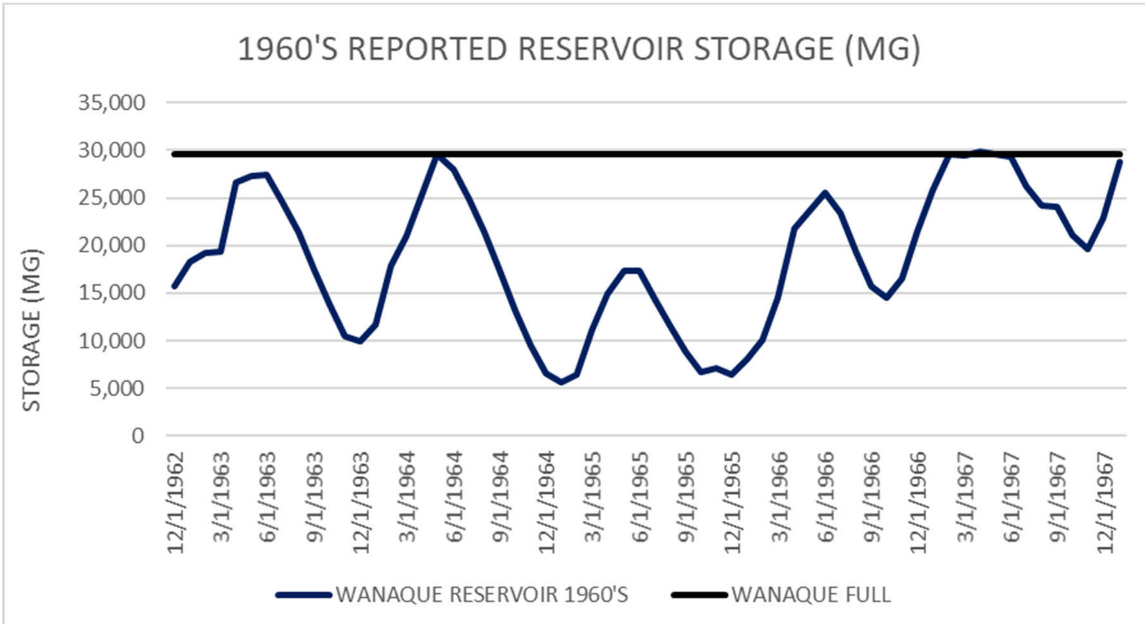

Figure 4.18 Wanaque reservoir storage in the 1960's drought period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

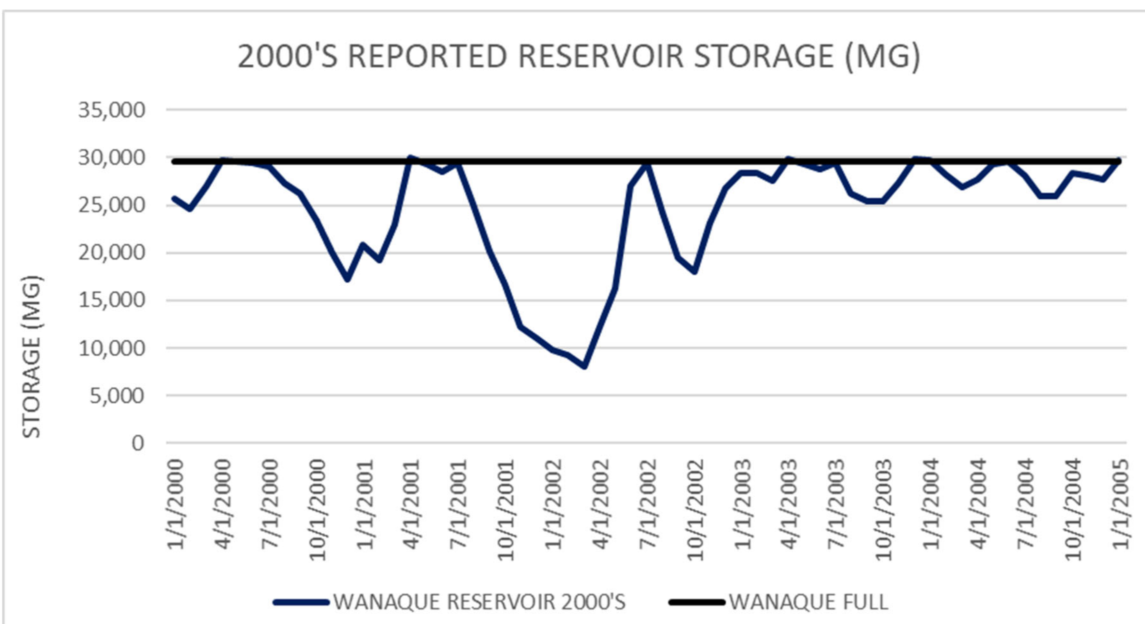

Figure 4.19 Wanaque reservoir storage in the 2000's drought period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

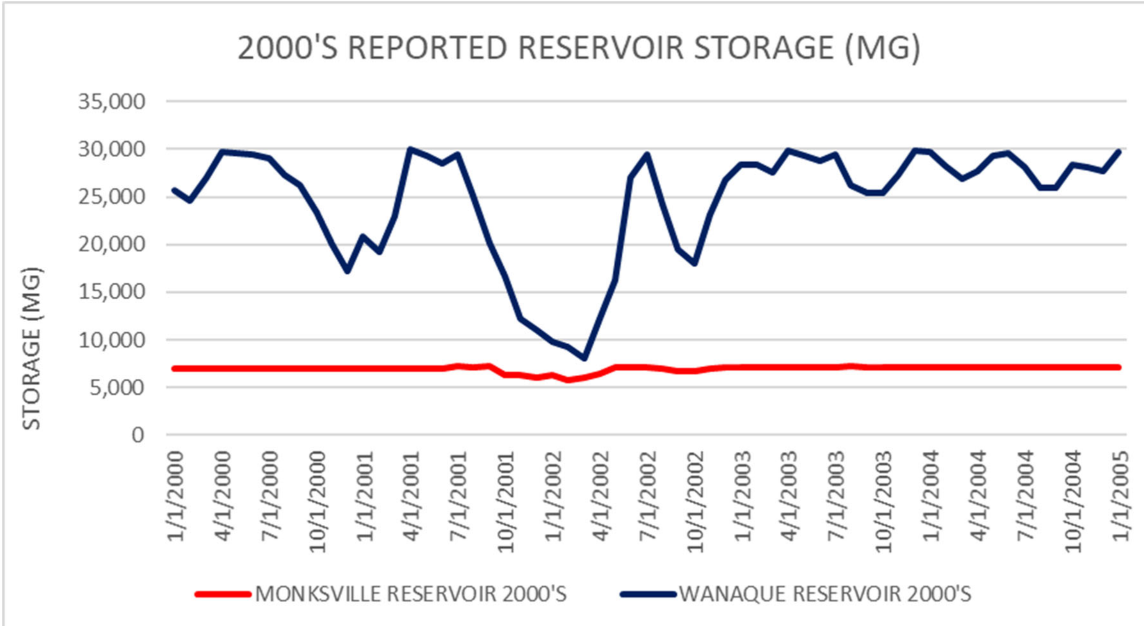

Figure 4.20 NJDWSC reservoir storage in the 2000's drought period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013)

Upstream of gage 01387000 there were eight surface water discharges and no reported withdrawals. In the 2000's period, the Wanaque Reservoir storage was augmented with pumping from Ramapo River Pump Station and more continuously from the Two Bridges Pump Station. In the 1960's only the Ramapo River Pump Station was included for the reconstruction of flow at gage 01387000.

The reconstructed flow fell below zero ten months during the 2000's drought period, but there was only one month with a negative value in the 1960's. This is where pumping is necessary to augment the system to offset the negative reconstructed inflows.

The safe yields were 95.1 MGD and 173 MGD in the 1960's and 2000's respectively. For the model development and to compare theoretical available storage, pumping into the system was eliminated to calculate the volumes based on an alternate safe yield. As pumping is sporadic and not a constant input, it was determined that to evaluate both time periods with a more equal comparison, the pumping operations would be eliminated.

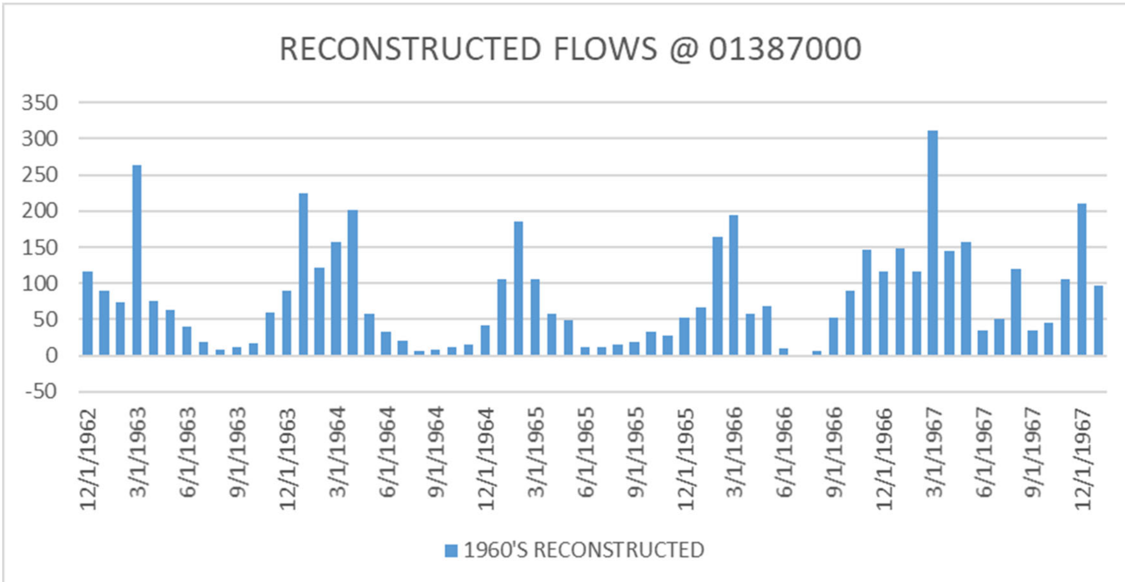

Figure 4.21 Reconstructed flows at gage 0138700 for the 1960's period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

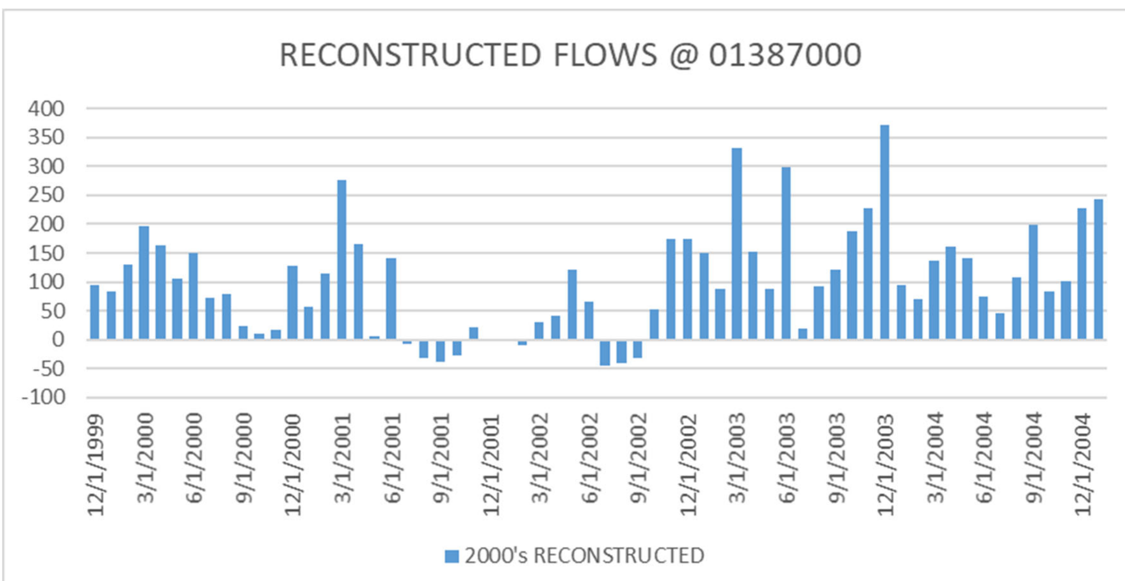

Figure 4.22 Reconstructed flows at gage 0138700 for the 2000's period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

The following assumptions were made to estimate a safe yield without the effects of pumping (Dresnack et al., March 1984 and July 1984):

- 95.1 MGD safe yield in March 1984 study includes 25 MGD of pumping, so the safe yield for just the Wanaque Reservoir is assumed to be 70.1 MGD
- 177 MGD is the estimated safe yield in the July 1984 study which includes the effect of increasing pumping from Ramapo River Pump Station and the addition of Two Bridges Pump Station with Monksville Reservoir
- 152 MGD is the estimated safe yield in the July 1984 study without Monksville Reservoir but including the additional pumping
- Monksville provides an additional 25 MGD of safe yield (177 – 152 MGD)
- 152 – 70.1 MGD is assumed to be the effect of both pump stations with 81.9 MGD
- 81.9 MGD – 25 MGD is the original pumping input of the 100 MGD Ramapo Pump Station to establish the safe yield of 95.1 MGD (70.1 + 25 MGD). 56.9 MGD would account for the increase in pumping capacity in Ramapo River Pump Station from 100 to 150 MGD and the addition of Two Bridges Pump Station's 250 MGD. Only 125 MGD from each pump station is for NJDWSC through the partnership with UWNJ

Through these assumptions, the safe yield used for the 1960's drought was 95.1 (70.1 Wanaque + 25 Monksville) MGD and 95.1 MGD for the 2000's time period to simulate the system without the effects of pumping. The physical components in the NJDWSC reflect the largest change in infrastructure between the two drought periods. Therefore, to evaluate the system with a reasonable comparison, the safe yield was estimated with only the Wanaque and Monksville Reservoirs. When calculating the theoretical storage in the 1960's the reservoir storage that began the drawdown added the volume of Monksville Reservoir (7,000 MG).

Table 4.6 Theoretical Storage Calculations for NJDWSC in the 1960's Drought

MONTH	RECON FLOW @ 01387000	SAFE YIELD (95.1 MGD)	PASSING FLOW (10 MGD)	THEORETICAL STORAGE
	A (MG)	B (MG)	C (MG)	D = START STORAGE + A – B -C
MAY 1964	1,774.87	2948.1	310	36,622 **LAST FULL (29,622 + 7,000)**
JUN 1964	980.57	2853	300	34,449.57
JUL 1964	641.59	2948.1	310	31,833.06
AUG 1964	181.73	2948.1	310	28,756.69
SEP 1964	243.17	2853	300	25,846.86
OCT 1964	336.45	2948.1	310	22,925.22
NOV 1964	453.90	2853	300	20,226.11
DEC 1964	1,315.17	2948.1	310	18,283.18
JAN 1965	3,254.05	2948.1	310	18,279.13
FEB 1965	5,170.52	2662.8	280	20,506.85
MAR 1965	3,294.27	2948.1	310	20,543.02
APR 1965	1,733.09	2853	300	19,123.11
MAY 1965	1,498.05	2948.1	310	17,363.05
JUN 1965	331.27	2853	300	14,541.33
JUL 1965	356.66	2948.1	310	11,639.88
AUG 1965	476.41	2948.1	310	8,858.19
SEP 1965	572.48	2853	300	6,277.68
OCT 1965	997.26	2948.1	310	4,016.84
NOV 1965	825.17	2853	300	1,689.00
DEC 1965	1,644.93	2948.1	310	75.83
JAN 1966	2,040.62	2948.1	310	(1,141.65) **OVERDRAFT**
FEB 1966	4,611.86	2662.8	280	527.41
MAR 1966	6,006.57	2948.1	310	3,275.89
APR 1966	1,747.36	2853	300	1,870.25
MAY 1966	2,144.89	2948.1	310	757.04
JUN 1966	304.68	2853	300	(2,091.28)
JUL 1966	(94.10)	2948.1	310	(5,443.48)
AUG 1966	173.80	2948.1	310	(8,527.78)
SEP 1966	1,564.79	2853	300	(10,115.99)
OCT 1966	2,800.16	2948.1	310	(10,573.93)
NOV 1966	4,398.63	2853	300	(9,328.29)
DEC 1966	3,629.86	2948.1	310	(8,956.54)
JAN 1967	4,605.29	2948.1	310	(7,609.35)
FEB 1967	3,248.34	2662.8	280	(7,303.81)
MAR 1967	9,678.49	2948.1	310	(883.41)
APR 1967	4,363.32	2853	300	326.91
MAY 1967	4,872.30	2948.1	310	1,941.11

Source: Table generated from data collected from (DGS 09-1, 2013) and (USGS)

Table 4.7 Theoretical Storage Calculations for NJDWSC in the 2000's Drought

MONTH	RECON FLOW @ 01387000	SAFE YIELD (95.1 MGD)	PASSING FLOW (10 MGD)	THEORETICAL STORAGE
	A (MG)	B (MG)	C (MG)	D = START STORAGE + A – B -C
MAY 2000	3,284.92	2948.1	310	36,650 **LAST FULL**
JUN 2000	4,502.27	2853	300	36,677
JUL 2000	2,213.26	2948.1	310	38,026
AUG 2000	2,456.49	2948.1	310	36,981
SEP 2000	733.07	2853	300	36,180
OCT 2000	325.15	2948.1	310	33,760
NOV 2000	535.32	2853	300	30,827
DEC 2000	3,946.46	2948.1	310	28,209
JAN 2001	1,755.98	2948.1	310	28,897
FEB 2001	3,196.41	2662.8	280	27,395
MAR 2001	8,588.11	2948.1	310	27,649
APR 2001	4,998.35	2853	300	32,979
MAY 2001	176.19	2948.1	310	34,824
JUN 2001	4,242.01	2853	300	31,742
JUL 2001	(248.92)	2948.1	310	32,831
AUG 2001	(961.75)	2948.1	310	29,324
SEP 2001	(1,153.48)	2853	300	25,105
OCT 2001	(839.59)	2948.1	310	20,798
NOV 2001	622.77	2853	300	16,700
DEC 2001	(68.22)	2948.1	310	14,170
JAN 2002	(94.97)	2948.1	310	10,844
FEB 2002	(242.84)	2662.8	280	7,491
MAR 2002	940.57	2948.1	310	4,305
APR 2002	1,258.28	2853	300	1,988
MAY 2002	3,740.11	2948.1	310	93
JUN 2002	1,942.43	2853	300	575
JUL 2002	(1,403.21)	2948.1	310	(636) **OVERDRAFT**
AUG 2002	(1,279.68)	2948.1	310	(5,297)
SEP 2002	(949.21)	2853	300	(9,835)
OCT 2002	1,615.37	2948.1	310	(13,937)
NOV 2002	5,248.13	2853	300	(15,580)
DEC 2002	5,436.72	2948.1	310	(13,485)
JAN 2003	4,626.03	2948.1	310	(11,306)
FEB 2003	2,444.66	2662.8	280	(9,938)
MAR 2003	10,285.83	2948.1	310	(10,436)
APR 2003	4,565.86	2853	300	(3,408)
MAY 2003	2,744.50	2948.1	310	(1,996)
JUN 2003	8,988.66	2853	300	(2,509)
JUL 2003	584.48	2948.1	310	3,326
AUG 2003	2,848.37	2948.1	310	653

Source: Table generated from data collected from (DGS 09-1, 2013) and (USGS)

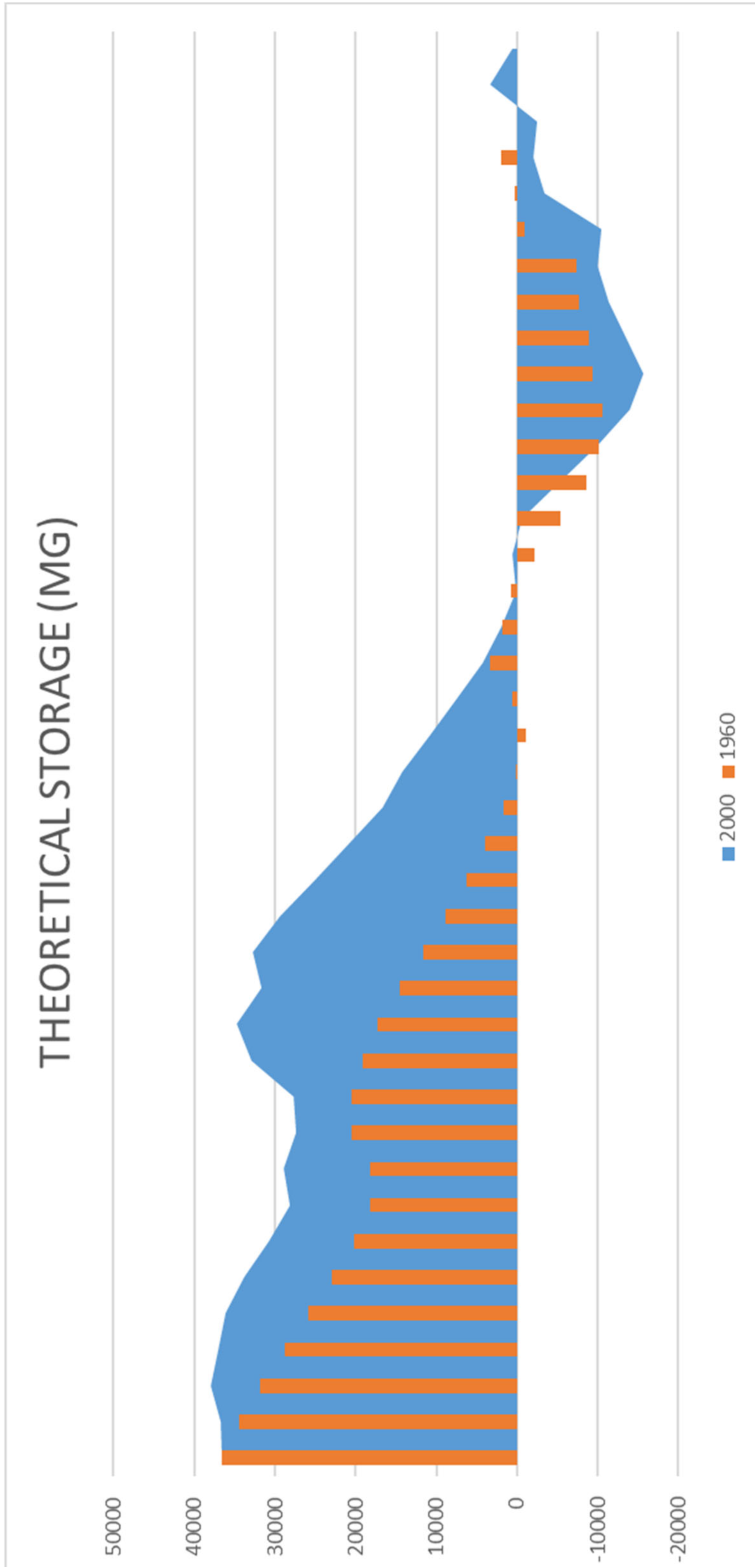

Figure 4.23 Theoretical storage for both the 1960's and 2000's are graphed from the start point where the storage was full.
Source: Graph generated data from (DGS 09-1, 2013) and (USGS)

Figure 4.23 illustrates the theoretical storage drawdown from Tables 4.6 and 4.7. Pumping will augment this system significantly, but those operations are at the discretion of the purveyor on how and when they will pump into the reservoir and from which location. Evaluating the NJDWSC as a reservoir storage only system is an attempt to analyze the two drought periods with a common baseline. Based on the assumptions stated for the NJDWSC System model, the 2000's drought may have been more severe and caused a greater deficit in available storage than in the 1960's.

4.6 Passaic Valley Water Commission

The Passaic Valley Water Commission is the most downstream purveyor of the Passaic River Basin. PVWC operates an intake on the Passaic River at Little Falls to a water treatment plant. PVWC also has the capability to pump water from the Two Bridges Pump Station on the Pompton River at the confluence of the Passaic River to divert water to the treatment plant at Little Falls. Point View is an off-stream storage reservoir that is filled by the Jackson Avenue Pump Station on the Pompton River. The Point View Reservoir is used to ensure that PVWC can maintain a safe yield of 75 MGD by releasing water as needed into the Pompton River.

A governing factor for PVWC is the assumption that the other upstream purveyors are operating within their allowable safe yield limits. The model was constructed using worst case scenario operations and assuming that each purveyor is operating at their safe yield limits, a total of 306.7 MGD is subtracted from the reconstructed flow. This is the sum of Newark - 49.1, Jersey City -56.8, NJDWSC - 190, and NJAWC - 10.8 MGD.

Safe yield is a term used to describe the amount of water available within a water system including storage reservoirs. Although PVWC does have reservoir storage in Point View, this purveyor operates differently than the other systems. PVWC operates under a passing flow agreement where the amount of water that needs to be available for diversion is 75 MGD in the Passaic River.

There are eighteen withdrawals and twenty-four discharges above the gage at Little Falls that were used for the reconstruction of gage 01389500. Pumping from Two Bridges for both PVWC and NJDWSC and the Jackson Avenue Pump Station were included in the reconstruction. During the 2000's drought, five months reported activity with Point View Reservoir. As storage data was not available for this model, the releases and pumping were considered for the reconstruction, but the storage volume was not. Lastly the average monthly diversion at PVWC was included to determine, if upon removal of all the outside influences, whether the natural streamflow would have been sufficient to satisfy the 75 MGD required.

Figure 4.25 is the reconstructed gage flow at 01389500 for both the 2000 and 1960 five-year period. The negative flows would indicate that there is not sufficient water in the Passaic River, however the assumptions made do not account for any of the storage available at Point View Reservoir.

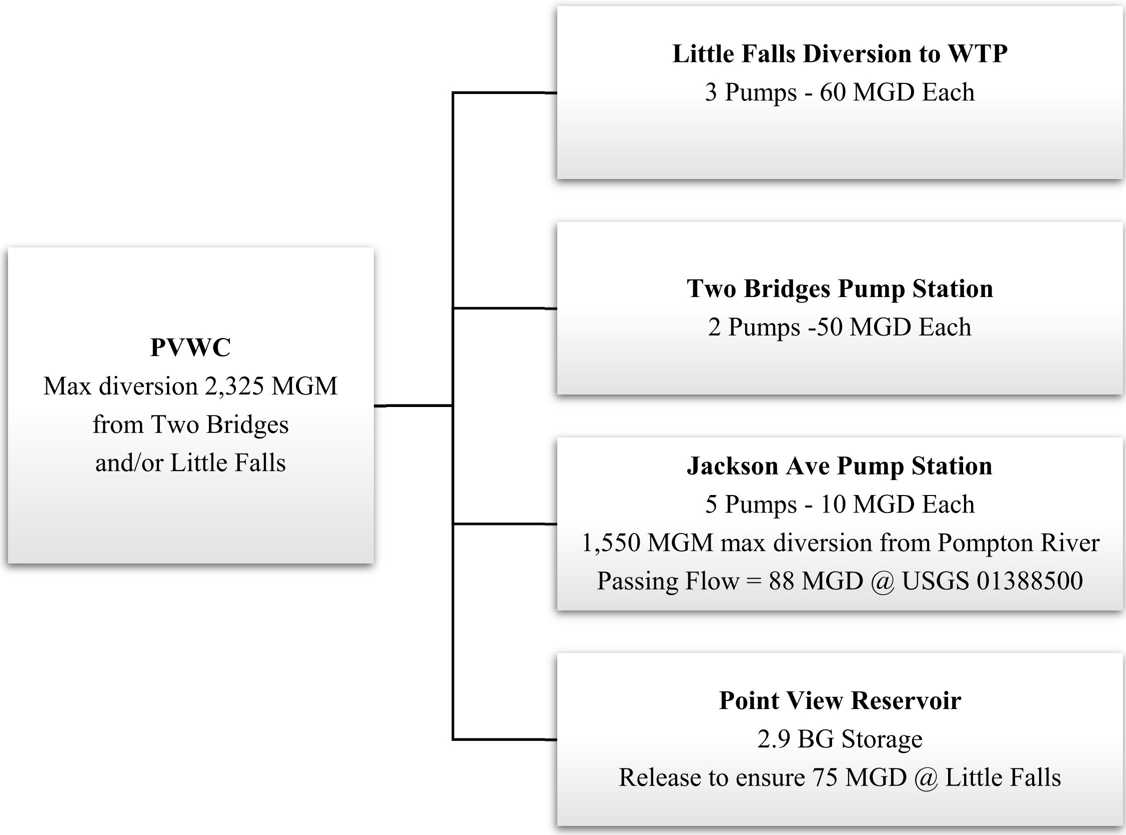

Figure 4.24 Figure represents the operational characteristics of the Passaic Valley Water Commission including information on the pumping, passing flow requirements, and diversions.
Source: Generated utilizing data from (NJ Water Supply Plan, 2017-Appendix C)

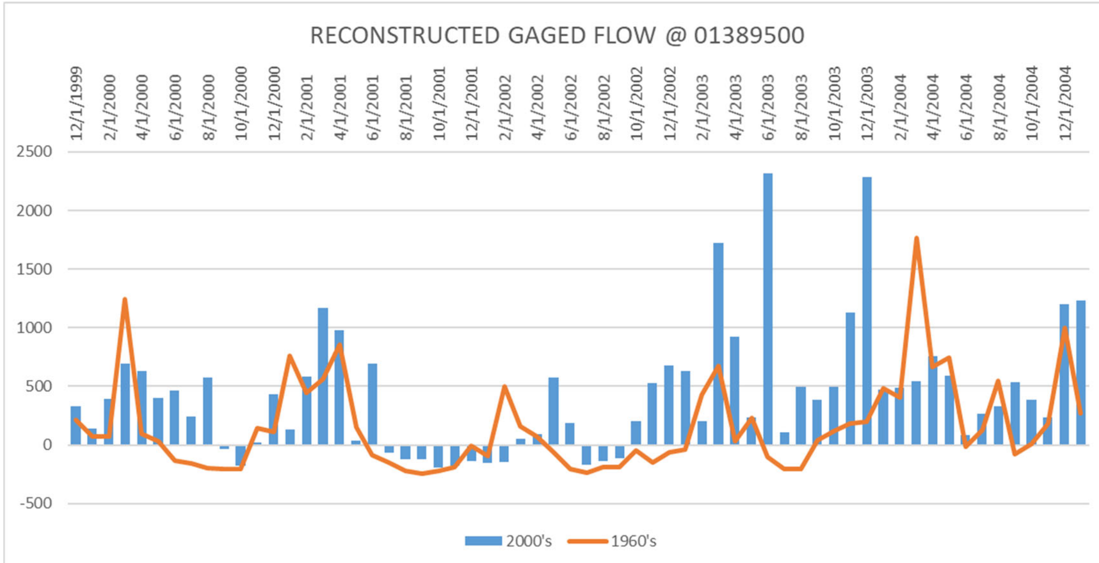

Figure 4.25 Reconstructed flows for the USGS stream gage 01381000 for the 1960's and 2000's five-year period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

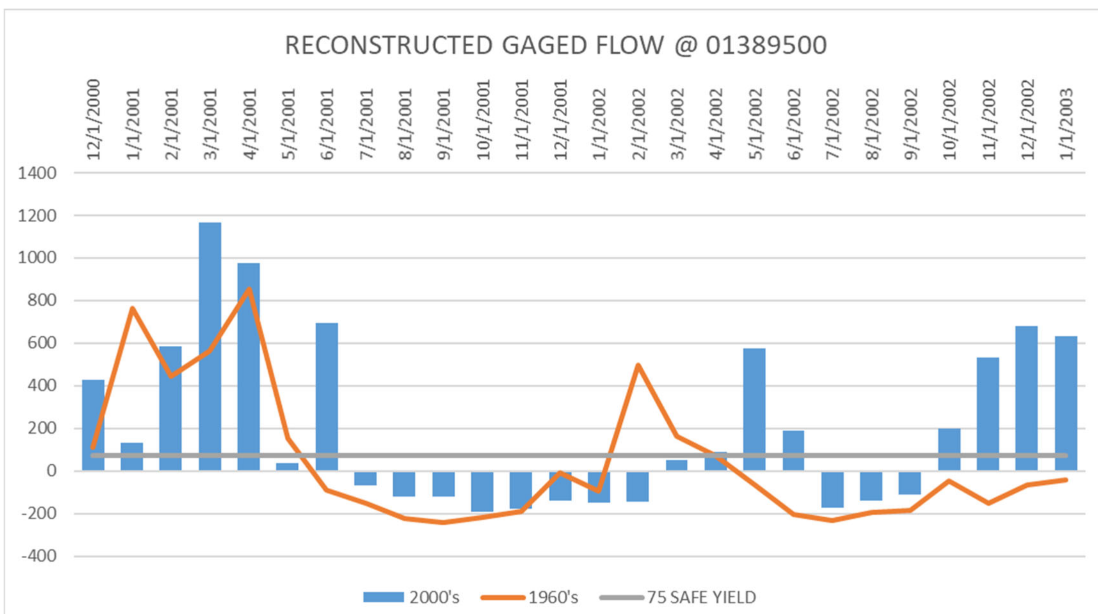

Figure 4.26 Reconstructed flows for the USGS stream gage 01381000 for the 1960's and 2000's five-year period close up of the 2001-2002 period.
Source: Graph generated utilizing data from: (DGS 09-1, 2013) and (USGS)

For the Passaic Valley Water Commission, the reconstructed flow would indicate that there is less available water in the 1960's. The assumptions made were to try to create worst case scenario conditions where the safe yield was consistently being pulled out of the river by the four upstream purveyors. In the 2000's the lowest flow in the Passaic River was -191.5 MGD and – 243.7 MGD in the 1960's time period as an average monthly flow. For the PVWC the indication is that the 1960's was a more severe drought for this system.

CHAPTER 5

CONCLUSION

5.1 Summary of Results and Conclusion

The summary of results would indicate that through the model analysis of evaluating changes in reservoir storage, gaged stream flows, diversions, withdrawals, and discharges within the Passaic River Basin was affected differently for the two drought periods. The 1960's drought appeared to be more severe for Newark, New Jersey American Water Company, and Passaic Valley Water Commission, while Jersey City and North Jersey District Water Commission may have been more critical in the 2000's drought period.

This conclusion is limited by assumptions made for the model, accuracy of the data used, and the overall complexity of the system. Additionally, the use of monthly versus daily data could account for some variation in how the system operates and responds during drought conditions.

The Interconnection Study Mitigation of Water Supply Emergencies (Public Version) prepared by the NJDEP contains rule curves created to help operators make informed decisions about pumping and interconnection transfers. Documentation, including memorandum from Mr. Paul Schorr, located within Appendix 2 – Water Emergency and Drought Plan of the study, provides information related to the operational considerations made and trigger events to manage the water supplies in the State. Drought conditions may affect purveyors differently and the surplus of some may be vitally important to the deficit of other systems during these conditions (NJDEP Interconnection Report, 2007).

Table 5.1 provides information on the various interconnections within the Passaic River Basin. The purveyors within the basin can either be purchasers and or suppliers so water is moving through the interconnections to balance inequities in water availability in the systems. Water can also be transferred inter-basin as the State may experience differing levels of drought conditions, the water demand can be supplied from sources outside of the limits of the Passaic River Basin drainage area.

Table 5.1 Contract Interconnection of Water Suppliers and Purchasers

Supplier	Purchaser	Contract Capacity MGD
NJAWC-Short Hills	Livingston	0.1
NJAWC-Short Hills	Southeast Morris County	2.9
Newark	Belleville	3.5
Newark	East Orange	1.4
Jersey City	Lyndhurst	2.7
Jersey City	UWNJ	5.7
Jersey City	Hoboken	4.1
Morris County	NJAWC-Short Hills	0.8
PVWC	Elmwood	2.0
PVWC	Garfield	1.9
PVWC	Cedar Grove	0.4
PVWC	NJAWC-Short Hills	8.0
PVWC	Harrison	1.1
NJDWSC	Cedar Grove	1.4
NJDWSC	Montclair	4.2
NJDWSC	Newark	35.8
NJDWSC	Bayonne	8.8
NJDWSC	Kearny	6.6
NJDWSC	PVWC	40.8
NJDWSC	Wayne	7.6
NJAWC-Elizabethtown	NJAWC-Short Hills	13.0

Source: Table generated utilizing data from: (NJDEP Interconnection Report, 2007)

The need of purveyor transfers and inter-basin transfers further confirms the complexity of analyzing the Passaic River Basin. The conclusions were reached based on publicly available data and are limited both by the monthly reported values and operational knowledge of each purveyor. The model attempted to create conditions that could compare two time periods with relative commonality. To the greatest extent practicable the model was able to make generalized conclusions to better understand the Passaic River Basin safe yields.

5.2 Contribution and Future Work

This dissertation is a continuation of work by Dr. Robert Dresnack, Dr. Eugene Golub, and Dr. Franklin Salek to study the safe yields within the Passaic River Basin. The study of water availability is continuous and ongoing to help plan for and manage this natural resource in the future. The concept of establishing a safe yield is multifaceted and labor intensive.

Per the New Jersey Water Supply Plan 2017-2022, the NJDEP continues to study the Hackensack, Passaic, and Raritan River Basins by developing computer models to simulate water availability. Previous models and future models are necessary to manage the water supply needs of the residents in the State of New Jersey. Optimization is key to managing the water supply needs within the region. The NJWSP discusses the interconnection between NJAW Passaic and NJAW Raritan systems and how utilizing this interconnection more has the potential of freeing up water supply for other areas of the Passaic River Basin (NJ Water Supply Plan, 2017).

Although the per capita water use has decreased in recent years due to the adoption of the Energy Policy Act of 1992 and using high efficiency appliances, the overall trend of potable water supply has increased (NJ Water Supply Plan, 2017).

The American Water Works Association launched the "No Water" campaign to bring awareness to the importance of water through a variety of slogans like No Water No Coffee, No Water No Nature, and No Water No Smile. (AWWA) The message is simple, but it highlights a much larger call to action to understand and manage this natural resource. This dissertation was focused on researching and understanding the Passaic River Basin and the purveyors that supply the water in the northeast region of the State. Developing this model served to evaluate the Passaic River Basin to draw conclusions about the events of the 1960's versus the 2000's drought.

The development of safe yield models is time consuming due to the amount of data that must be collected to understand the operations of the system. The systems will continue to grow in complexity with the introduction of new infrastructure. As the safe yield study is typically conducted for a long historic period of record, the more data available, the longer the model development will take.

In the future, perhaps work can be done to approach the safe yield modeling in a different way. As storm water and flooding calculations are predicted using probabilities such as 2-, 10-, and 100-year storm events, it would be interesting to explore the possibility of incorporating that strategy into safe yield development. Instead of safe yield being a single unit number, it could be adjusted as droughts reach certain intensities.

APPENDIX A

1984 SAFE YIELD STUDY PURVEYOR DESCRIPTIONS

Source: (Dresnack, R., Golub, E., and Salek, F. (1984), Safe Yield Study of the Passaic River Basin. New Jersey Institute of Technology. NJDEP Contract WR 9-2-0)

As was indicated in Chapter 2 of this dissertation, this appendix includes the full purveyor descriptions used in the 1984 model including reservoir storages, pumping capacities, passing flows, and safe yields.

Passaic Valley Water Commission (PVWC)

<u>Physical Characteristics</u>

Storage:	2.8 BG of usable storage in Point View Reservoir
Pump Station:	50 MGD capacity pump station of the Pompton River at the 355 square mile drainage area location.
Diversions:	Taken at Little Falls on the Passaic River at the 762 square mile drainage area.

<u>Restrictions</u>

Passing Flow:	88.5 MGD on the Pompton River at the Point Pump Station.

<u>Simulation:</u>

The flow at Little Falls is simulated by Gage 3895. The flow at the pump station is simulated by Gage 3885. Releases are made from Point view Reservoir to make up for deficits at Little Falls.

Gage 3895 is reconstructed from 1/1/59 – present (present means 1981)

Gage 3895 is simulated by multiple linear regression from flows at Gages 3815, 3810, 3795, 3825, 3870, 3880 from 10/1/21-12/31/58)

Gage 3895 is reconstructed from 10/1/41 – present (present means 1981)

Gage 3885 is simulated by multiple linear regression from flows at Gages 3825, 3870, 3880, from 10/1/21 – 9/30/42.

Safe Yield:

The safe yield at the PVWC is dependent upon the operation of the other four purveyors since their facilities are upstream of the PVWC intake. The safe yield presented assumes that Jersey City, Newark, Commonwealth, and Wanaque are operating at their respective safe yields within their legal constraints as described herein.

Safe Yield = 105 MGD fully utilizing Point View Reservoir

Safe Yield = 75 MGD authorized limit

Jersey City System

Physical Characteristics

Storage:	8.1 BG of usable storage in Boonton Reservoir
	3.36 BG of usable storage in Split Rock Reservoir
Drainage Area:	119 square miles at Boonton Reservoir
	5 square miles at Split Rock (release from Split Rock flow to Boonton)
Diversions:	Taken at Boonton Reservoir

Restrictions

Passing Flow:	7 MGD from Boonton Reservoir
Maximum Release:	From Split Rock Reservoir is 25 MGD

Simulation:

The flow into Boonton Reservoir is simulated by Gage 3810. The flow into Split Rock Reservoir is simulated as 0.462 x flow at Gage 3810 where 0.462 represents the ratio of the drainage areas to Split Rock and Boonton Reservoirs.

Gage 3810 is reconstructed from 10/1-25 – present (present means 1981)

Gage 3810 is simulated by multiple linear regression from the flows at Gages 3870, 3795, and 3815.

Safe Yield:

Safe Yield = 56.8 MGD

Pequannock Reservoir System

Physical Characteristics

Storage:	14.36 BG usable storage in five reservoirs (Canistear, Clinton, Oak Ridge, Charlotteburg, Echo Lake.)
Drainage Area:	60.8 square miles at the lowest reservoir
Diversions:	Taken at Charlotteburg Reservoir

Restrictions

Passing Flow:	0.362 MGD from Charlotteburg Reservoir

Simulation:

The system is simulated as one reservoir of 14.36 BG capacity located at the Charlotteburg Reservoir. The flows into the reservoir are taken as 60.8/63.7 x flow at the Macopin Gage (3825). The ratio of 60.8/63.7 represents the ratio of the drainage areas at the reservoir and the Macopin Gage.

Gage 3825 is reconstructed from 10/1/42 – present (present means 1981)

Safe Yield:

Safe Yield = 49.1 MGD

Wanaque Reservoir

Physical Characteristics

Storage:	29.518 BG usable storage
Drainage Area:	90.4 square miles at the reservoir
Pump Station:	100 MGD capacity pump station on the Ramapo River at the 160 square mile drainage area location
Diversions:	Taken at Wanaque Reservoir

Restrictions

Passing Flow:	10 MGD release from the reservoir. (7 MGD when Greenwood Lake is not releasing)
	40 MGD on the Ramapo River at the pump station
No Pumping:	From June 1 to September 30 inclusive at the Ramapo Pump Station
Maximum Pumping:	100 MGD average for any month is the maximum allowed at the Ramapo Pump Station
	The maximum withdrawal from the reservoir of Ramapo River water is 25 MGD average for the year

Simulation:

The flow into Wanaque Reservoir is simulated by Gage 3870 and the flow at Ramapo Pump Station by Gage 3880.

Gage 3870 is reconstructed from 10/1/21 – present (present means 1981)

Gage 3880 is reconstructed from 10/1/21 – present (present means 1981)

Safe Yield:

The safe yield at the Wanaque System is limited by the allowed withdrawal of 25 MGD average of Ramapo River water on an annualized basis. The safe yield of the Wanaque System is obtained by assuming that the Ramapo Pump Station is not operating and then adding 25 MGD to the resulting yield. This gives a result as follows:

Safe Yield = 95.1 MGD

Commonwealth Water Company

Physical Characteristics

Storage:	3.05 BG usable storage in three small reservoirs
Pump Station:	80 MGD capacity pump station on the Passaic River at the 115 square mile drainage area location
	40 MGD capacity pump station on Canoe Brook at the 11 square mile drainage area location

Diversions: Taken at Reservoir #1

Restrictions

Passing Flow:	75 MGD in the Passaic River at the pump station.
	1.375 MGD in Canoe Brook at the pump station. The flow in Canoe Brook must exceed 3.5 MGD before pumping can be initiated.
No Pumping:	From June 1 to September 30 inclusive at the Passaic River Pump Station. (Due to a transfer of diversion rights, 2.12 MGD can be pumped at Passaic Pump Station regardless of passing flow or time of year)
Maximum Pumping:	13.2 MGD average for the year and 80 MGD average for the month at the Passaic River Pump Station. 3.5 MGD for the year at the Canoe Brook Pump Station.

Simulation:

The system is simulated as one reservoir of 3.05 BG capacity fed by pump stations on the Passaic River and Canoe Brook. The flows at the Passaic River Pump Station are taken as 115/110 x flow at Gage 3795. The ratio 115/110 is the ratio of the drainage areas at the pump station to the gage.

The flows at the Canoe Brook Pump Station are taken as 11/115 x flow at the Passaic River Pump Station. The ratio 11/115 is the ratio of drainage areas at the two pump stations.

Gage 3795 reconstructed from 10/1/37 – present (present means 1981)

Gage 3795 simulated from gage 3790 from 10/1/21 – 9/30/37

Safe Yield:

Safe Yield = 10.8 MGD

APPENDIX B

RESERVOIR STORAGE GRAPHS

Sources used to generate the graphs in Appendix B (DGS 09-1, 2013) and (USGS)

The following figures represent the individual storage graphs of the reservoirs in the Passaic River Basin.

Newark System

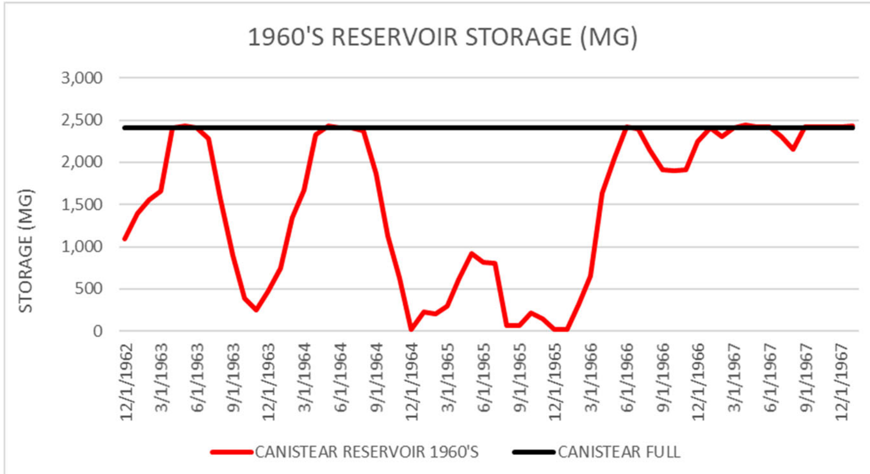

Figure B.1 Canistear Reservoir 1960's storage.

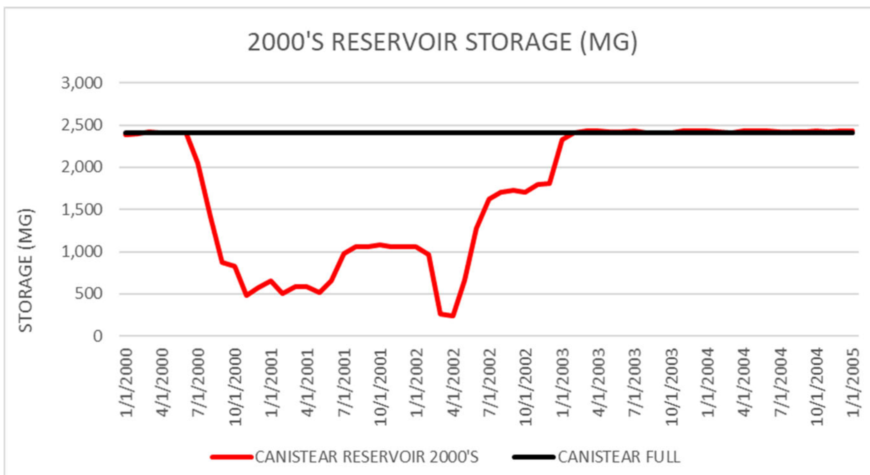

Figure B.2 Canistear Reservoir 2000's storage.

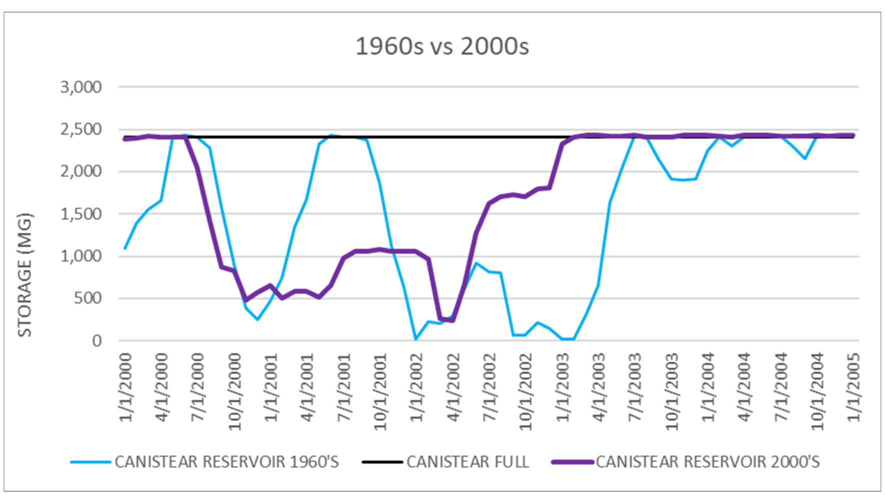

Figure B.3 Canistear Reservoir storage comparison.

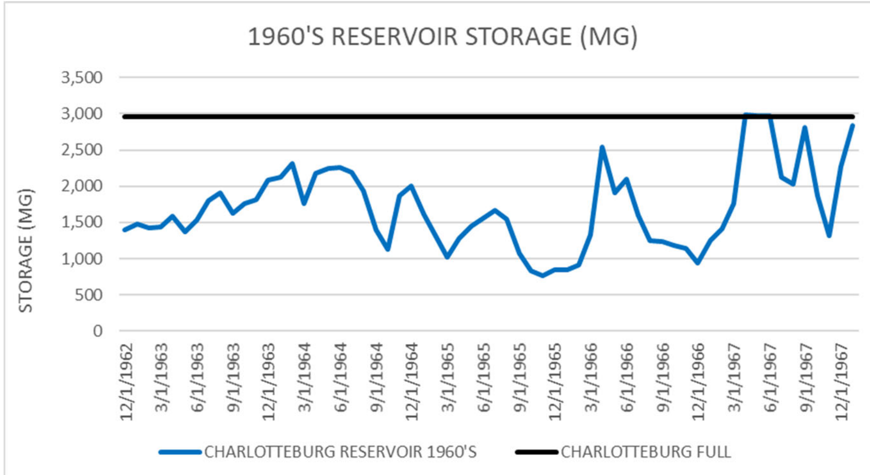

Figure B.4 Charlotteburg Reservoir 1960's storage.

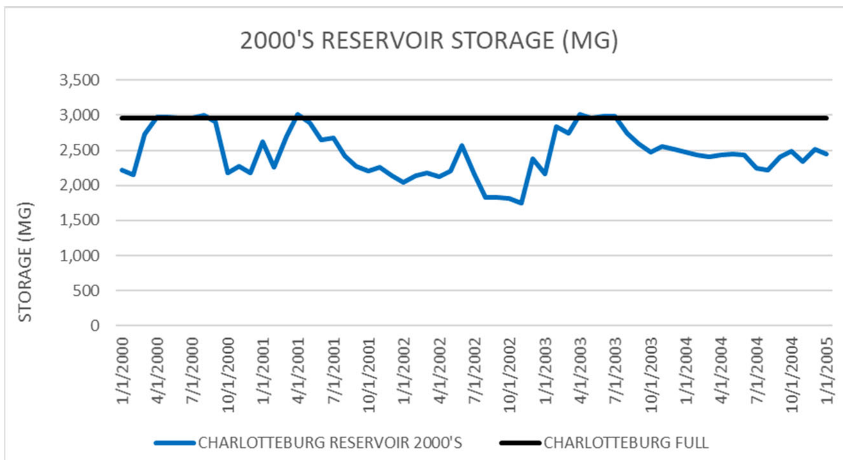

Figure B.5 Charlotteburg Reservoir 2000's storage.

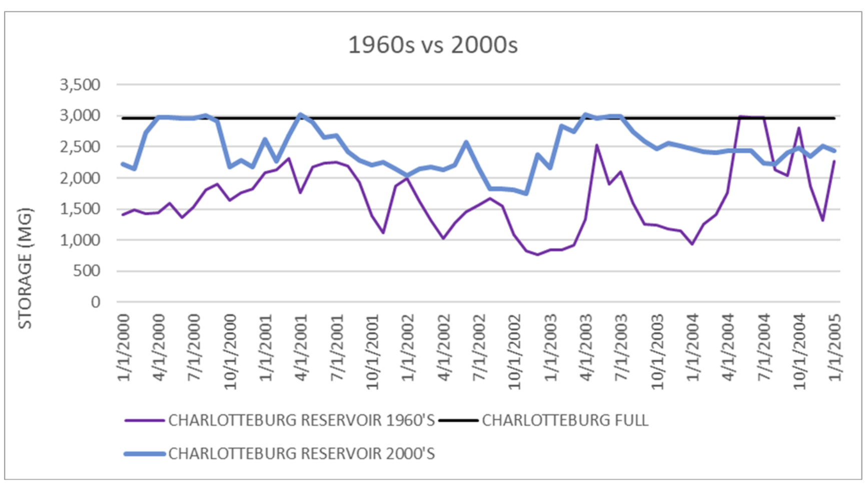

Figure B.6 Charlotteburg Reservoir storage comparison.

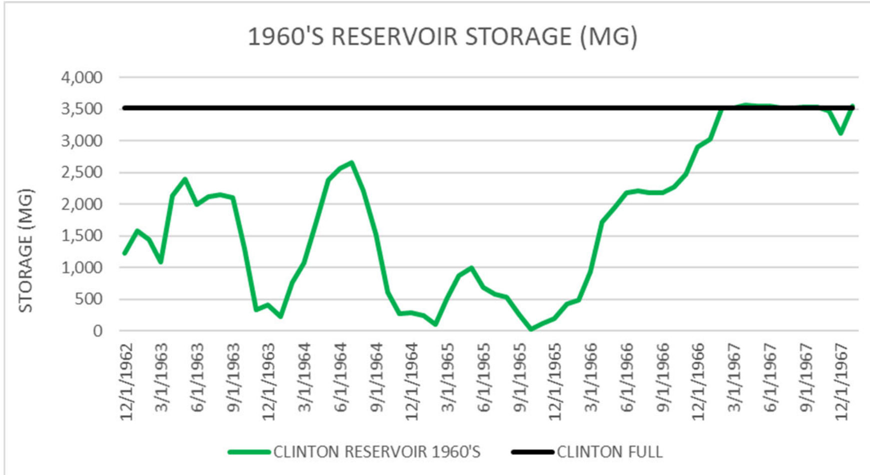

Figure B.7 Clinton Reservoir 1960's storage.

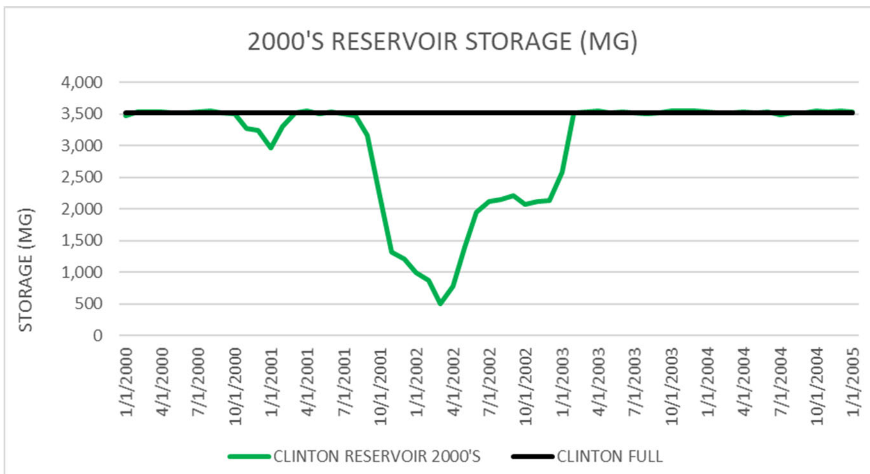

Figure B.8 Clinton Reservoir 2000's storage.

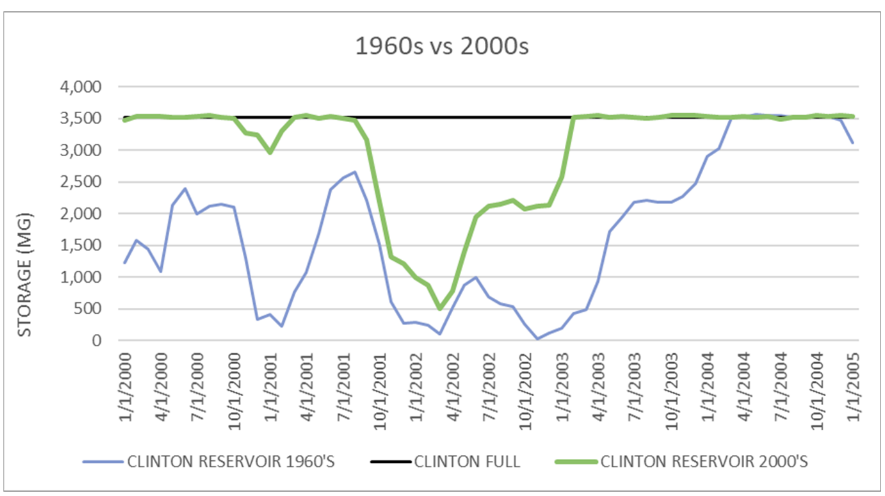

Figure B.9 Clinton Reservoir storage comparison.

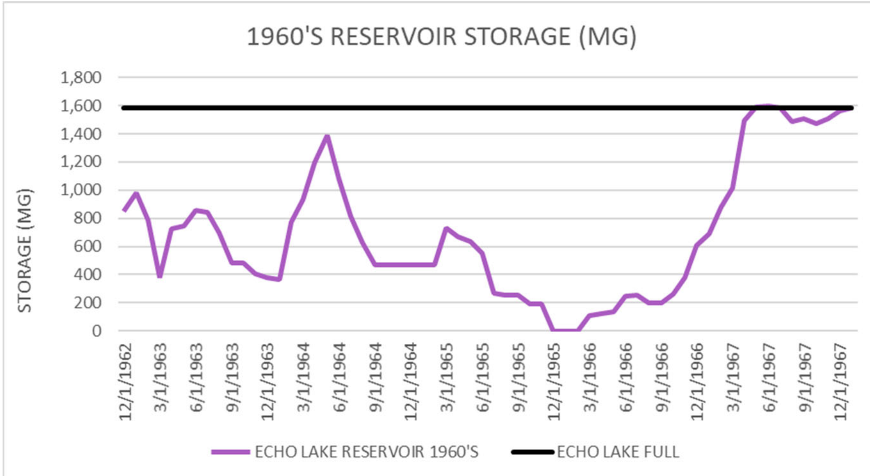

Figure B.10 Echo Lake Reservoir 1960's storage.

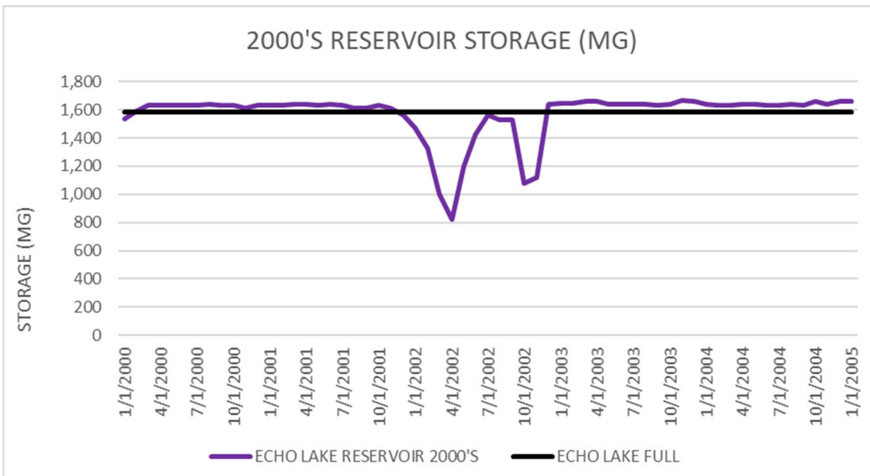

Figure B.11 Echo Lake Reservoir 2000's storage.

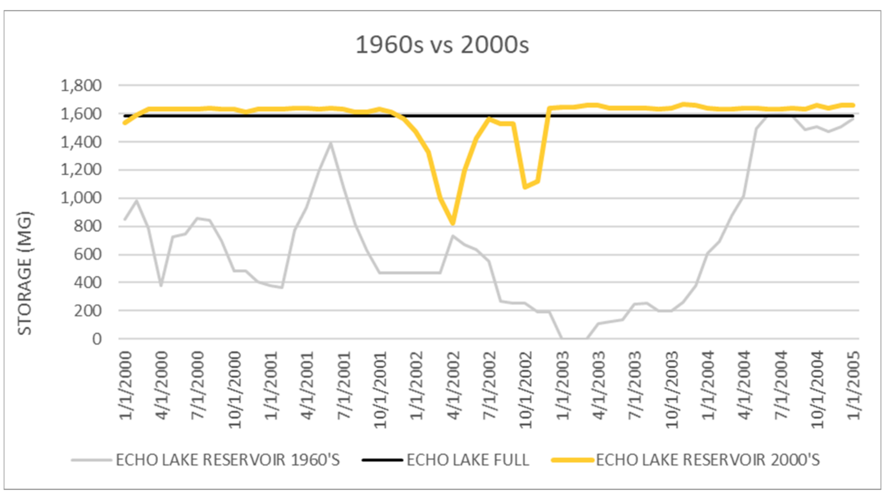

Figure B.12 Echo Lake Reservoir storage comparison.

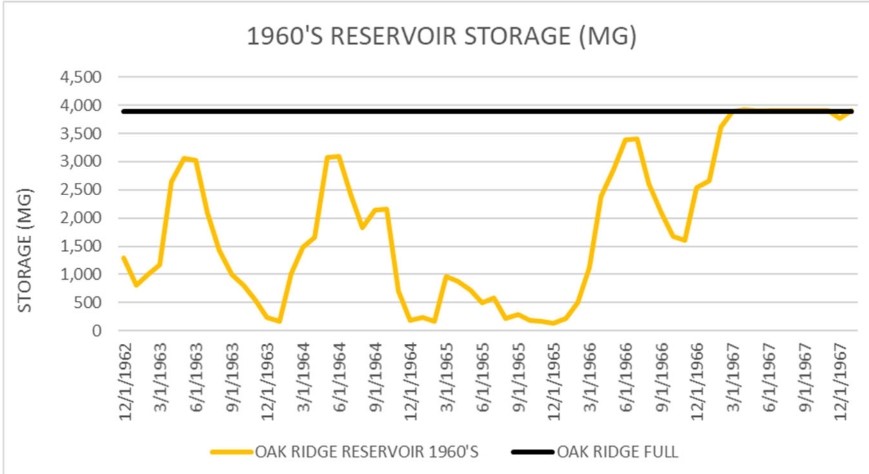

Figure B.13 Oak Ridge Reservoir 1960's storage.

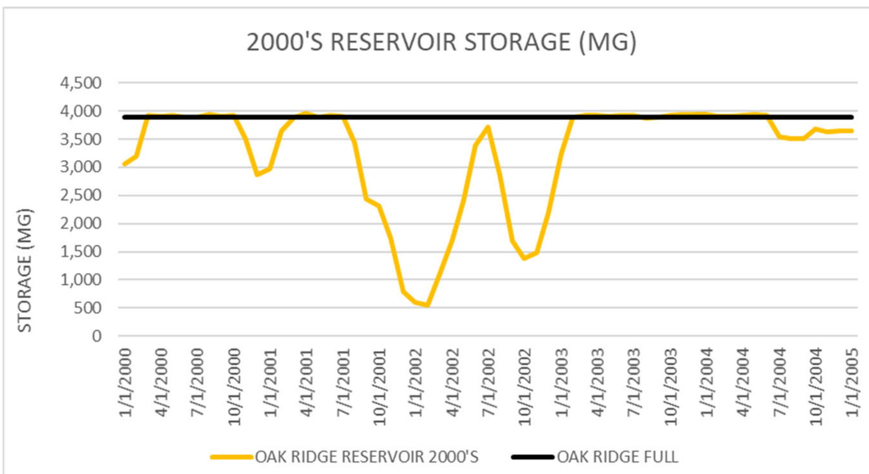

Figure B.14 Oak Ridge Reservoir 2000's storage.

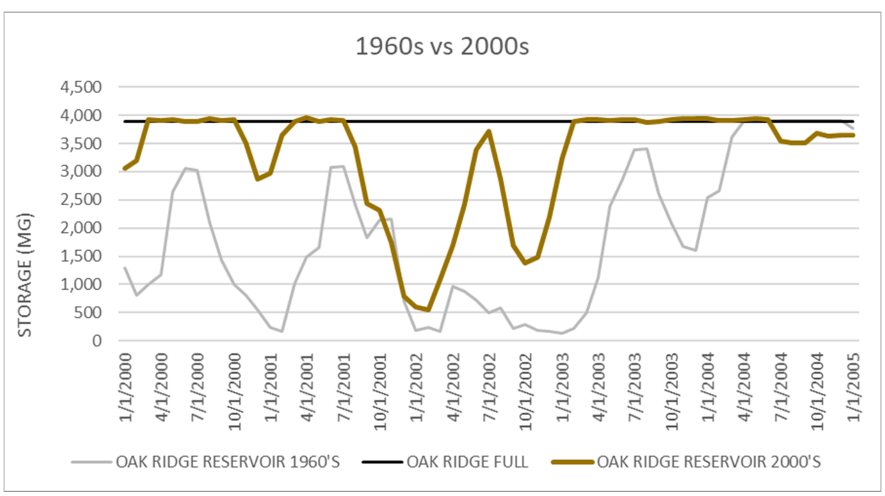

Figure B.15 Oak Ridge Reservoir storage comparison.

Jersey City System

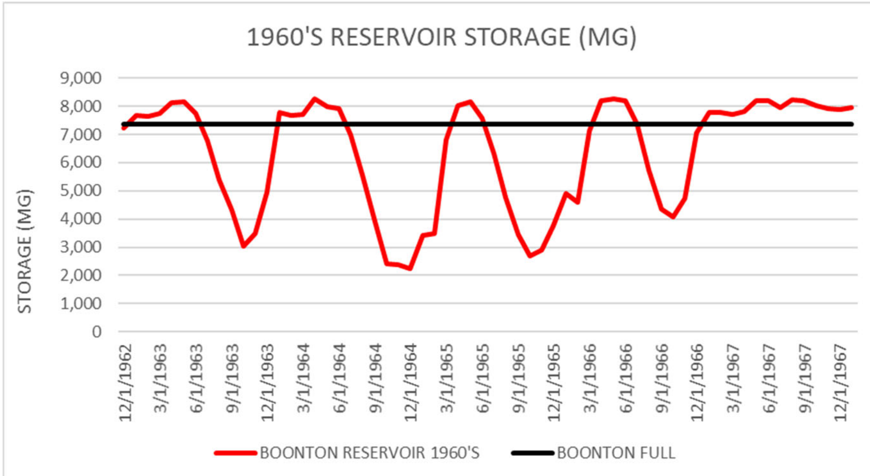

Figure B.16 Boonton Reservoir 1960's storage.

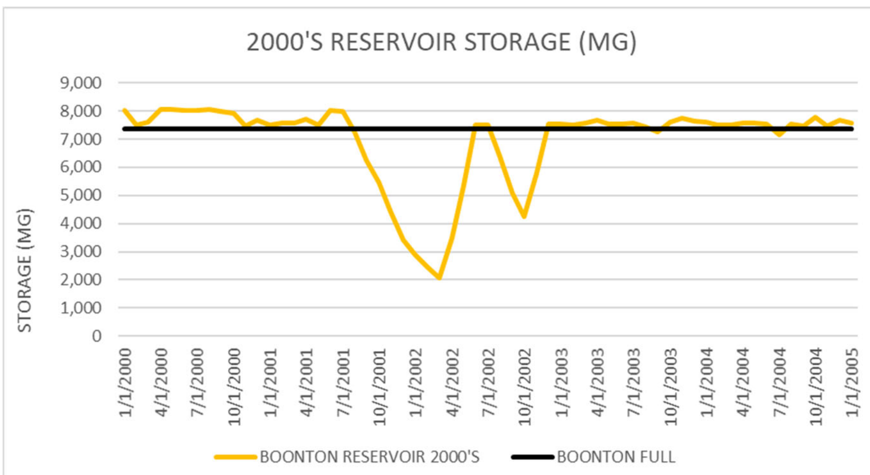

Figure B.17 Boonton Reservoir 2000's storage.

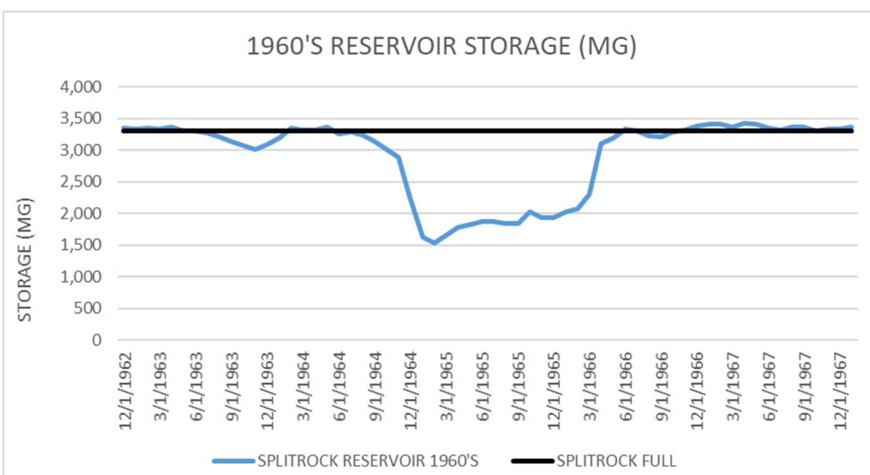

Figure B.18 Splitrock Reservoir 1960's storage.

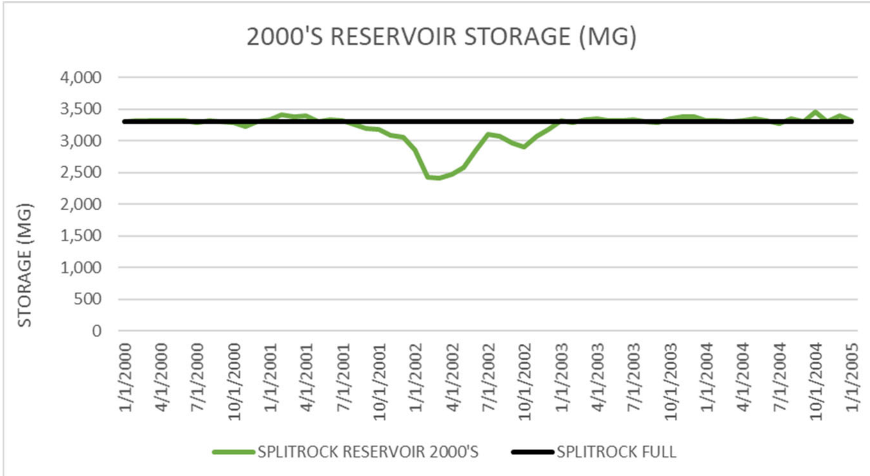

Figure B.19 Splitrock Reservoir 2000's storage.

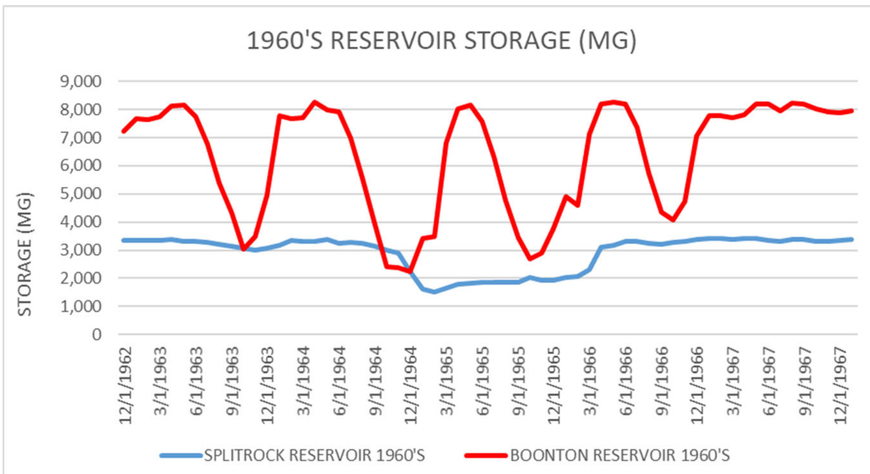

Figure B.20 Boonton and Splitrock Reservoirs 1960's storage.

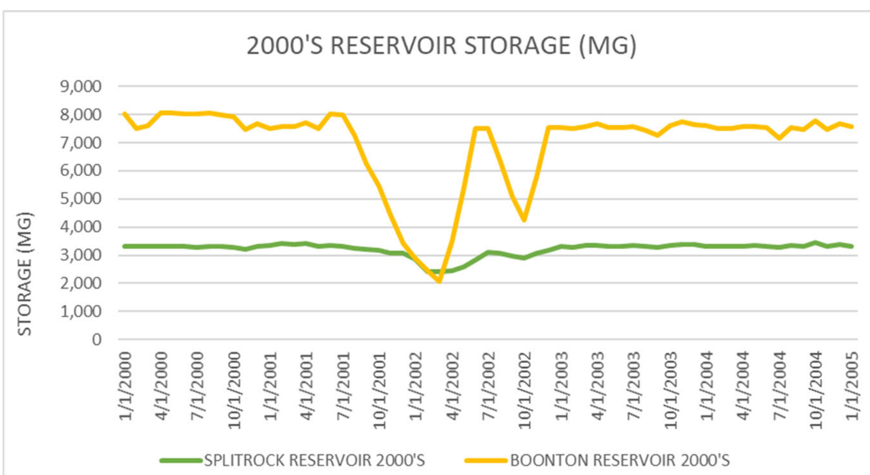

Figure B.21 Boonton and Splitrock Reservoirs 2000's storage.

North Jersey District Water Supply Commission System

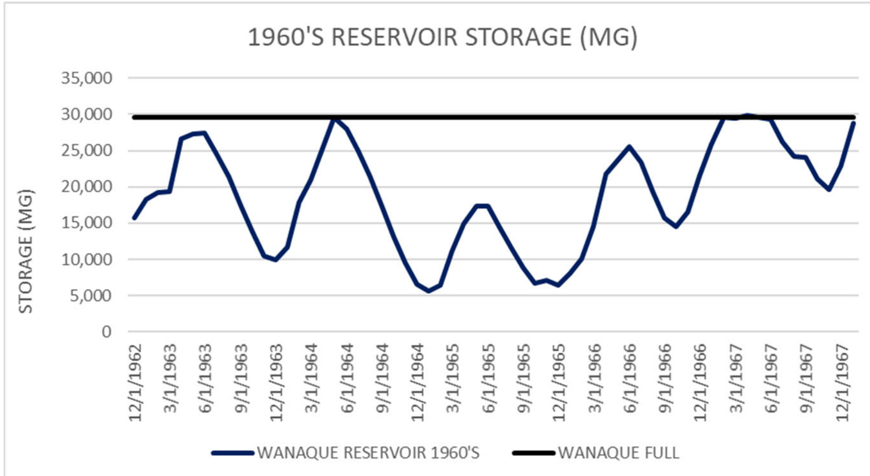

Figure B.22 Wanaque Reservoir 1960's storage.

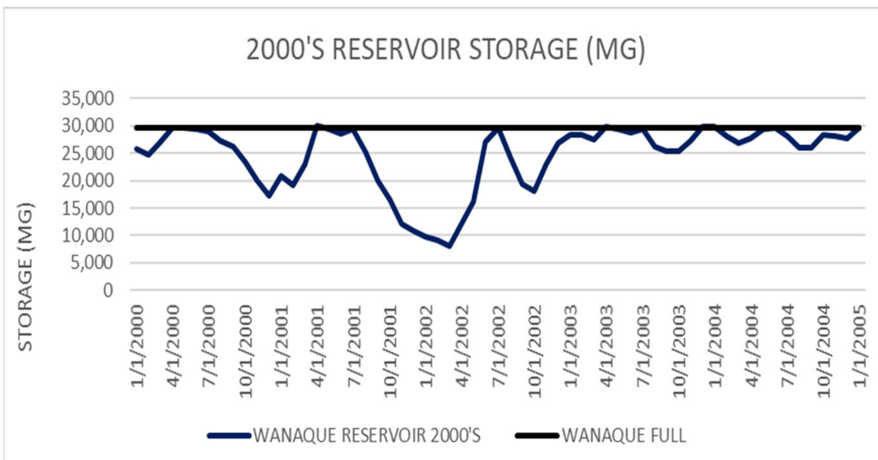

Figure B.23 Wanaque Reservoir 2000's storage.

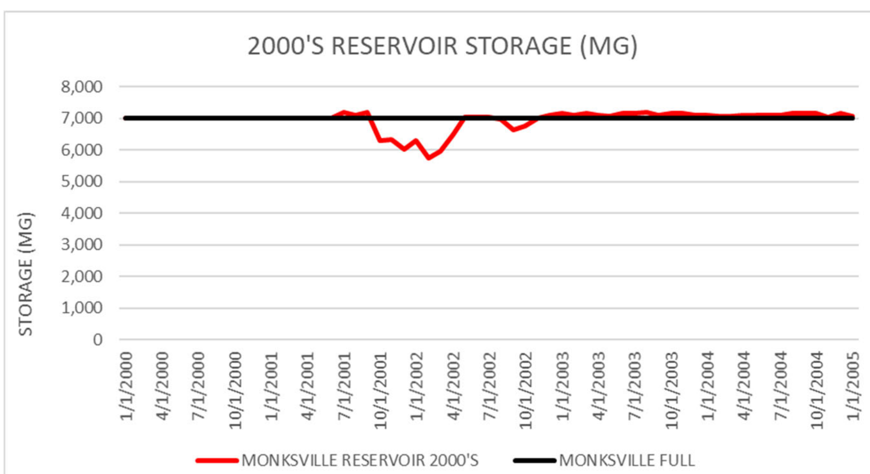

Figure B.24 Monksville Reservoir 2000's storage.

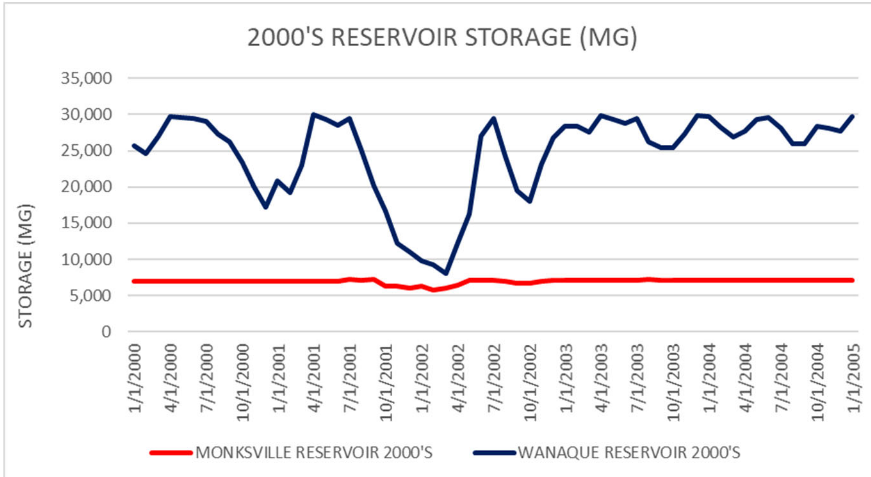

Figure B.25 Monksville and Wanaque Reservoirs 2000’s storage.

APPENDIX C

RECONSTRUCTION EQUATIONS

Appendix C contains schematic figures and explanations to describe how the flows were reconstructed for the five systems. All figures are adapted and modified from the 1984 Safe Yield Study.
Source: Adapted from (Dresnack et al., March 1984)

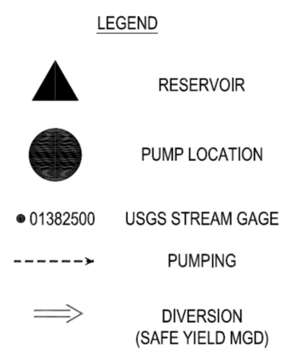

Figure C.1 Legend for schematic figures in Appendix C

Descriptions:

Change in Storage = End of month – beginning of month storage

Observed Flow = USGS gaged flow

Diversions = Reported purveyor diversion from the Passaic River Basin

Pumping = Transferring water from a river to a different location

Withdrawals = Permitted withdrawals from the drainage area

Discharges = Permitted returns of water into the drainage area

Withdrawals and Discharges values were only used in the reconstruction flows for the 2000-2004 time period. The general impact of these values was insignificant, with the exception of PVWC which is the most downstream purveyor of the Passaic River Basin System.

Newark System

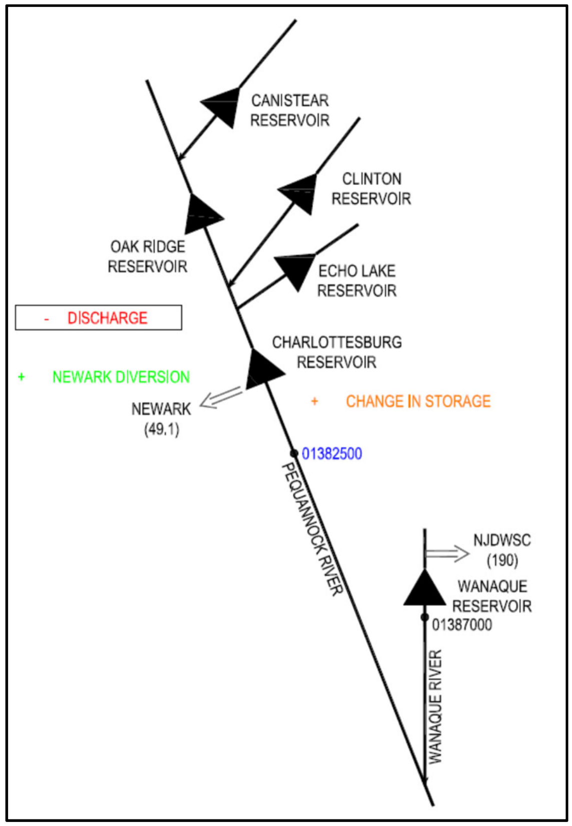

Figure C.2 Schematic of the Newark System

USGS Gage 01382500 was reconstructed by using the observed gaged flow and including the change in storage of the reservoirs (total) with the reported monthly Newark Diversion.

1960

Reconstructed Newark Inflow =
Observed Gaged Flow + Change in Storage + Newark Diversion

2000

Reconstructed Newark Inflow =
Observed Gaged Flow + Change in Storage + Newark Diversion – Discharge (1)

Jersey City System

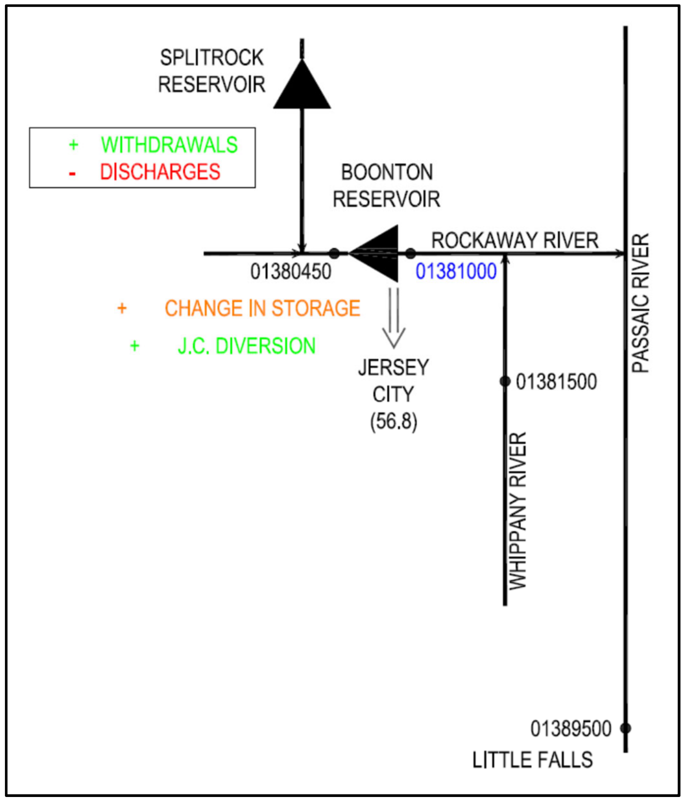

Figure C.3 Schematic of the Jersey City System

USGS Gage 01381000 was reconstructed by using the observed gaged flow and including the change in storage of the reservoirs (total) with the reported monthly Jersey City Diversion.

1960

Reconstructed Jersey City Inflow =
Observed Gaged Flow + Change in Storage + J.C. Diversion

2000

Reconstructed Jersey City Inflow =
Observed Gaged Flow + Change in Storage + J.C. Diversion + Withdrawals (9) – Discharges (2)

NJAWC

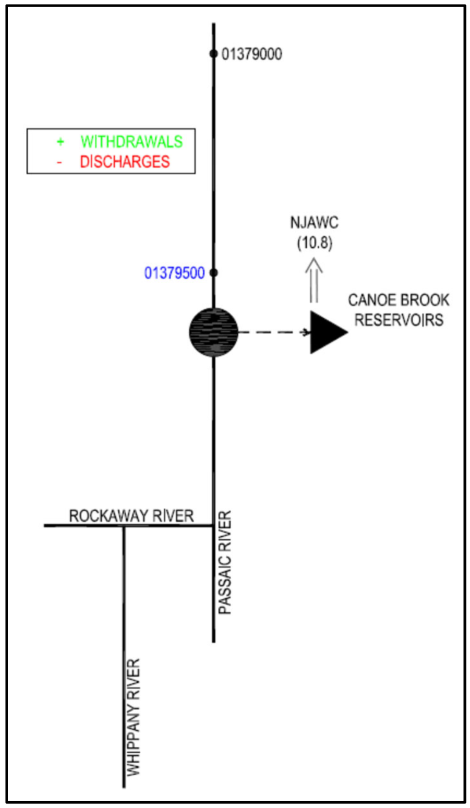

Figure C.4 Schematic of the New Jersey American Water Co. System

USGS Gage 01379500 was reconstructed by using the observed gaged flow the upstream discharges and withdrawals. The diversion for NJAWC was not included as it occurs downstream of the gage.

1960

Reconstructed Gaged Flow =
Observed Gaged Flow

2000

Reconstructed Gaged Flow =
Observed Gaged Flow + Withdrawals (3) – Discharges (13)

NJDWSC

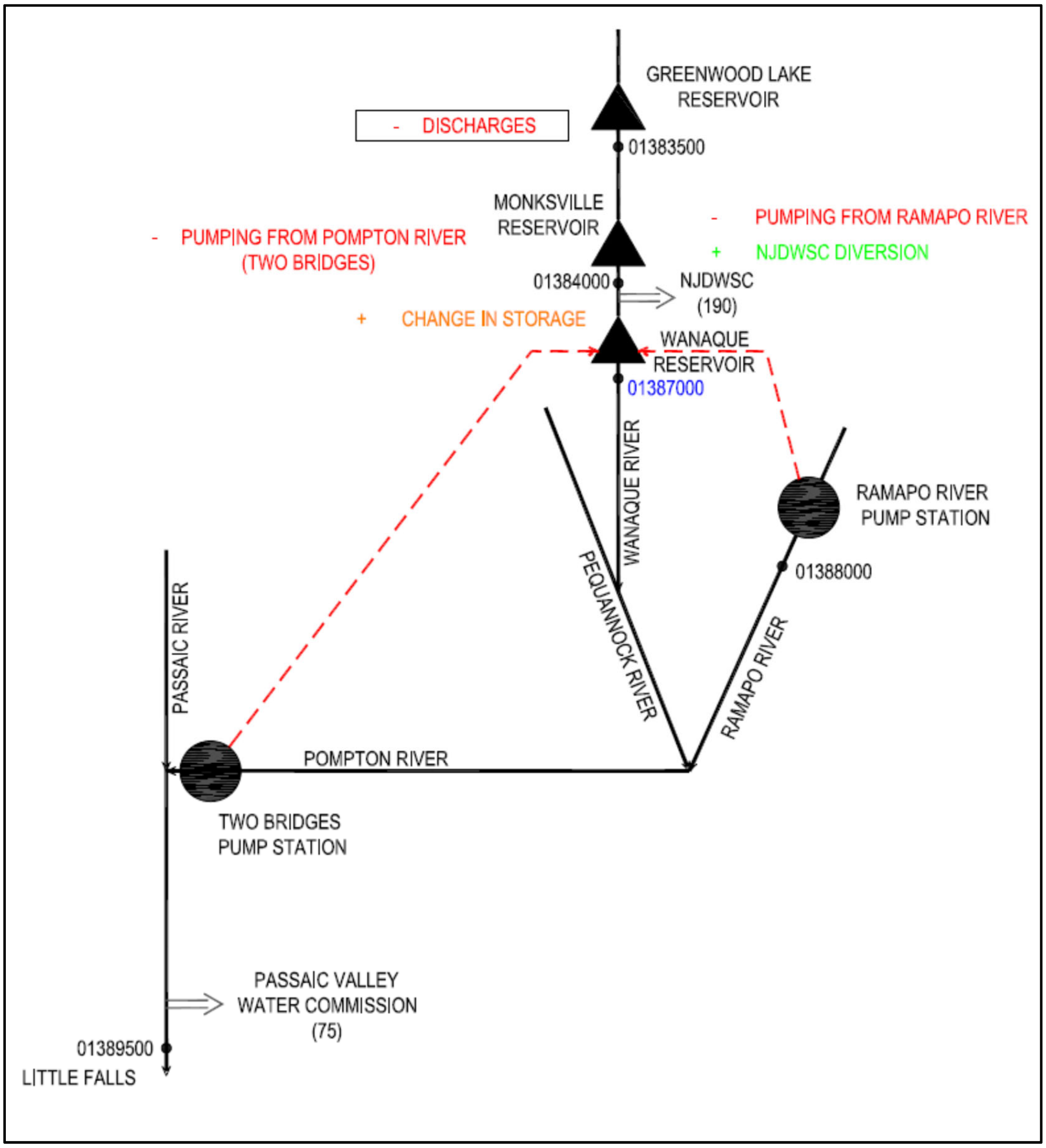

Figure C.5 Schematic of the North Jersey District Water Supply Commission

USGS Gage 01387000 was reconstructed by using the observed gaged flow and including the change in storage (total) with the reported monthly NJDWSC diversion. The pumping from the pump stations on the Pompton River and Ramapo River were removed from the reconstruction calculation.

1960

Reconstructed Inflow =
Observed Gaged Flow + Change in Storage + NJDWSC Diversion – Pumping from Ramapo River P.S.

2000

Reconstructed Inflow =
Observed Gaged Flow + Change in Storage + NJDWSC Diversion – Pumping from Ramapo River P.S. – Pumping from Pompton River P.S. (Two Bridges) – Discharges (8)

PVWC

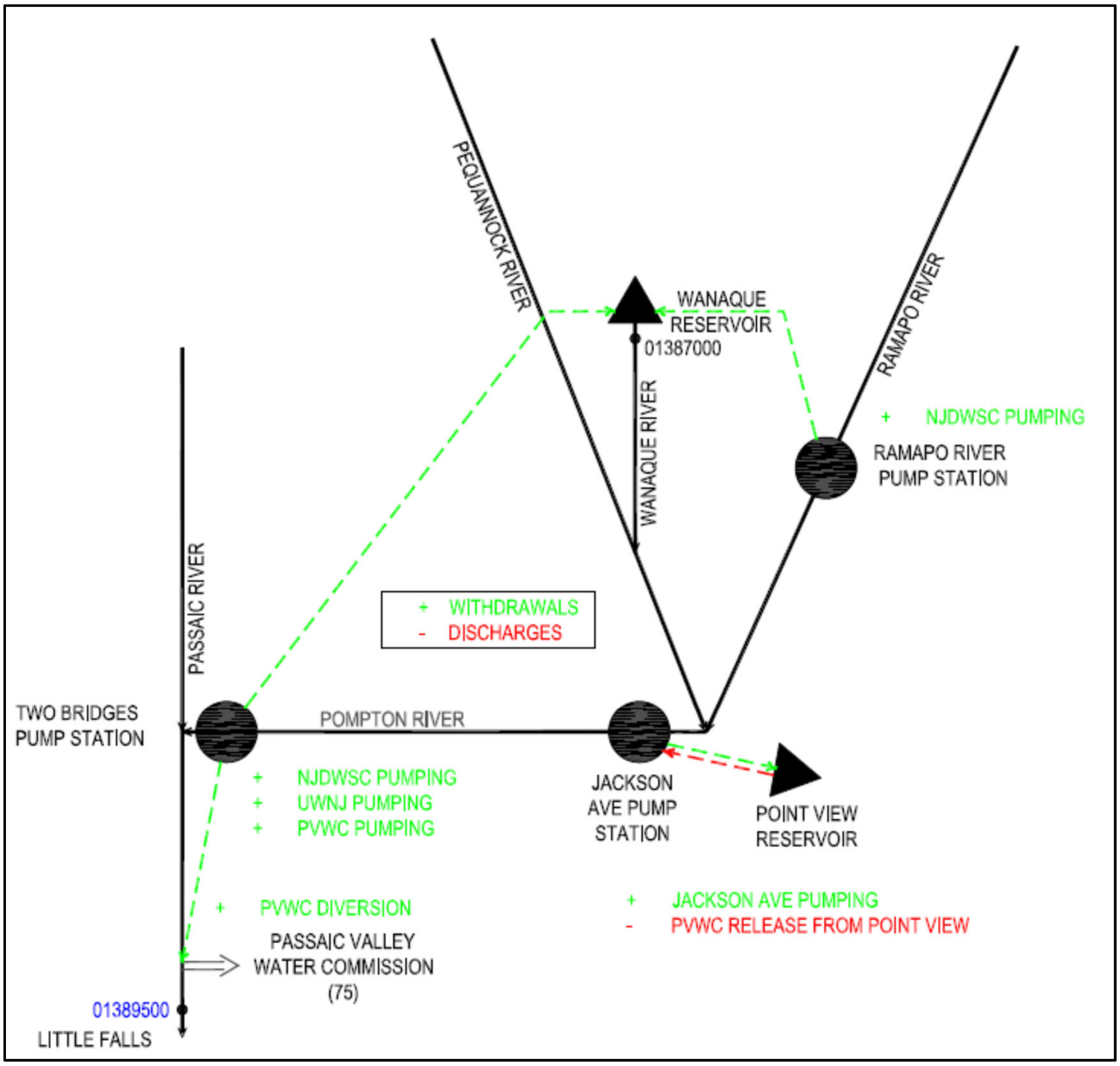

Figure C.6 Schematic of the Passaic Valley Water Commission

USGS Gage 01389500 was reconstructed by using the observed gaged flow and adding the reported monthly PVWC diversion. The pumping from the pump stations on the Pompton River and Ramapo River were added as they would have naturally flowed to PVWC if not for the pumping operations. Upstream permitted withdrawals and discharges were included in the 2000-2004 reconstruction calculation which included the diversion for NJAWC on the Passaic River.

1960

Reconstructed Gaged Flow =
Observed Gaged Flow + PVWC Diversion @ Little Falls + NJDWSC Pumping Ramapo River P.S.

2000

Reconstructed Gaged Flow =
Observed Gaged Flow + PVWC Diversion @ Little Falls + PVWC Diversion Pumping from Pompton River (Two Bridges) + NJDWSC Pumping Ramapo River P.S. + NJDWSC Pumping Pompton River P.S. (Two Bridges) + PVWC Pumping Pompton to Point View (Jackson Ave) + UWNJ Pumping Pompton and Ramapo P.S. + Withdrawals (24) – PVWC Diversion Point View to Little Falls – Discharges (18)

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