New York City Department of Environmental Protection

Water System Safe Yield Calculation - 2011

Environmental Protection

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1. Executive Summary

This report provides a summary of the computation of the safe yield of the New York City Reservoir System. This analysis has been undertaken by agreement of the Parties to the 1954 Supreme Court Decree (Decree),[i] the states of New York, New Jersey, Delaware, the Commonwealth of Pennsylvania and the City of New York, for the purpose of reevaluating the Excess Release Quantity as defined in the Decree as specified in the Flexible Flow Management Program (FFMP) that went into effect on June 1, 2008. The calculation of safe yield assumes that severe hydrologic conditions will occur at some point in the future and that these conditions can be approximated by a theoretical repeat of the drought of the 1960's. Prior computations of safe yield relied on the hydrologic record of the 1930's drought, an event less severe than the 1960's drought. In addition, this new computation of the System safe yield takes advantage of modern computational methods and data processing capabilities not previously available. This allows for an analysis of the conjunctive operations of all components of the System using daily time steps. Prior computations generally used less precise monthly time steps and did not fully assess the aggregate capabilities and limitations of the real-world System.

The calculation of safe yield prepared in support of the 1954 Supreme Court Decree estimated the safe yield at 1,665 Million Gallons per Day (MGD). More recent calculations, which took account of the more severe drought of the 1960's and additional release and operating rule requirements, estimated the safe yield in the range of 1,225 MGD to 1,370 MGD.

Figure 1: Neversink Reservoir

For the current calculation of the New York City water supply system safe yield, the Operations Support Tool (OST) driven by OASIS Software was employed. OASIS is a software program that models the operations of a water resource system. It simulates the routing of water through a system of nodes and arcs by solving a linear program. The routing accounts for both human control and physical constraints on the system. The model is able to incorporate all of NYC's operating rules and constraints that apply to its entire water supply system. It also reflects water supply priorities and operating policies imposed on the operation of the system.

The model is constructed to capture not only the rules and regulations that the City must abide by, but also the realistic way the system is operated on a day-to-day basis. Operating rules in the model consist of regulatory release requirements, reservoir balancing routines, and operating preference (e.g. drawdown priority, water quality, etc.).

The City calculates safe yield as the maximum continuous demand that can be met by the City water supply system during a repetition of the drought of record while maintaining a 25% storage reserve in the collection reservoirs of the Catskill and Croton Systems and in Rondout Reservoir. This is necessary to maintain potable water quality and to provide adequate flow and pressure in the water distribution system. This reserve requirement has been included in all prior calculation of safe yield for the system since the Decree.

In order to determine the NYC reservoir system safe yield, a series of trial and error runs were performed for each scenario by gradually increasing average total annual demand until a supply shortage occurred. The runs were conducted at 10 MGD demand increments and produced the following results.

Scenario	**Estimated Safe Yield**
Present With Pumping	**1,140 MGD**
Present Without Pumping	**1,080 MGD**
Future With Pumping	**1,310 MGD**
Future Without Pumping	**1,180 MGD**

The four separate model runs determine the estimated safe yield of the system under present system conditions and under anticipated conditions when certain modifications to the system have been completed. The present conditions are analyzed with and without pumping from the Croton System. The future conditions are also analyzed with and without pumping from the Croton system.

The safe yield estimated for the system under present conditions without pumping is less than the average water demand for the past five years by a margin of 8.4%. With pumping from the Croton system, the safe yield estimate is 1,140 MGD, an amount that is less than the recent average demands by 3.3%.

Under future system conditions, treatment will allow the Croton System to be used to a greater extent. Without pumping, the safe yield will match recent water demands and with pumping, the safe yield will exceed recent demands by 11%.

2. Overview of New York City's Water Supply Operations

2.1. Water Supply Operations

The New York City reservoir system is among the most complex water supply systems in the world. On average, more than 1.1 billion gallons (BG) of water flows each day by gravity from upstate New York to meet the water supply needs of more than 9 million residents of the City and the surrounding communities. The City must manage the system in a way that protects water supply reliability and balances multiple objectives including water quantity and quality, as well as environmental, and economic objectives.

The City's water supply system, depicted on Figure 1, is made up of the Delaware, Catskill, and Croton Systems. The Delaware System includes four reservoirs, the Delaware River Basin Reservoirs; Pepacton, Cannonsville, and Neversink, from which water is diverted to the fourth reservoir, Rondout Reservoir. From Rondout Reservoir, water is diverted to West Branch and Kensico Reservoirs via the Delaware Aqueduct. The Catskill System includes the Schoharie and Ashokan Reservoirs, which divert water to Kensico Reservoir. From Kensico, water is diverted to Hillview Reservoir and subsequently conveyed to the City via City Tunnel Nos. 1, 2, and 3. The City's Croton System, which is currently not in service pending completion of the Croton Water Treatment Plant, includes 12 reservoirs and 3 controlled lakes that can deliver water to the Jerome Park Reservoir in the Bronx for distribution.

The Delaware River Basin reservoirs have provided 50% of the water delivered to meet the City's needs.[ii] In addition, Delaware System water is historically the highest quality water in the system and there is often a need to divert more from the Delaware System. Conditions like high turbidity events in Ashokan Reservoir, droughts, or when a critical piece of infrastructure is offline for repairs or inspection are examples of circumstances that require increased diversion from the Delaware System.

It is in this context that the City manages the water system to maximize overall system reliability, maintain high quality drinking water for those dependent on the City's system for their water supply needs, address environmental concerns, and meet regulatory and other legal obligations. While the system is fundamentally and foremost a drinking water supply system essential to the City of New York and surrounding communities, the assets of the system are used to support other important environmental and economic needs.

Bureau of Water Supply's Mission Statement

The mission of the Bureau of Water Supply is to reliably deliver a sufficient quantity of high quality drinking water and to ensure the long-term sustainability of the delivery of this most valuable resource in order to promote public health, economic development, and quality of life of the City of New York.

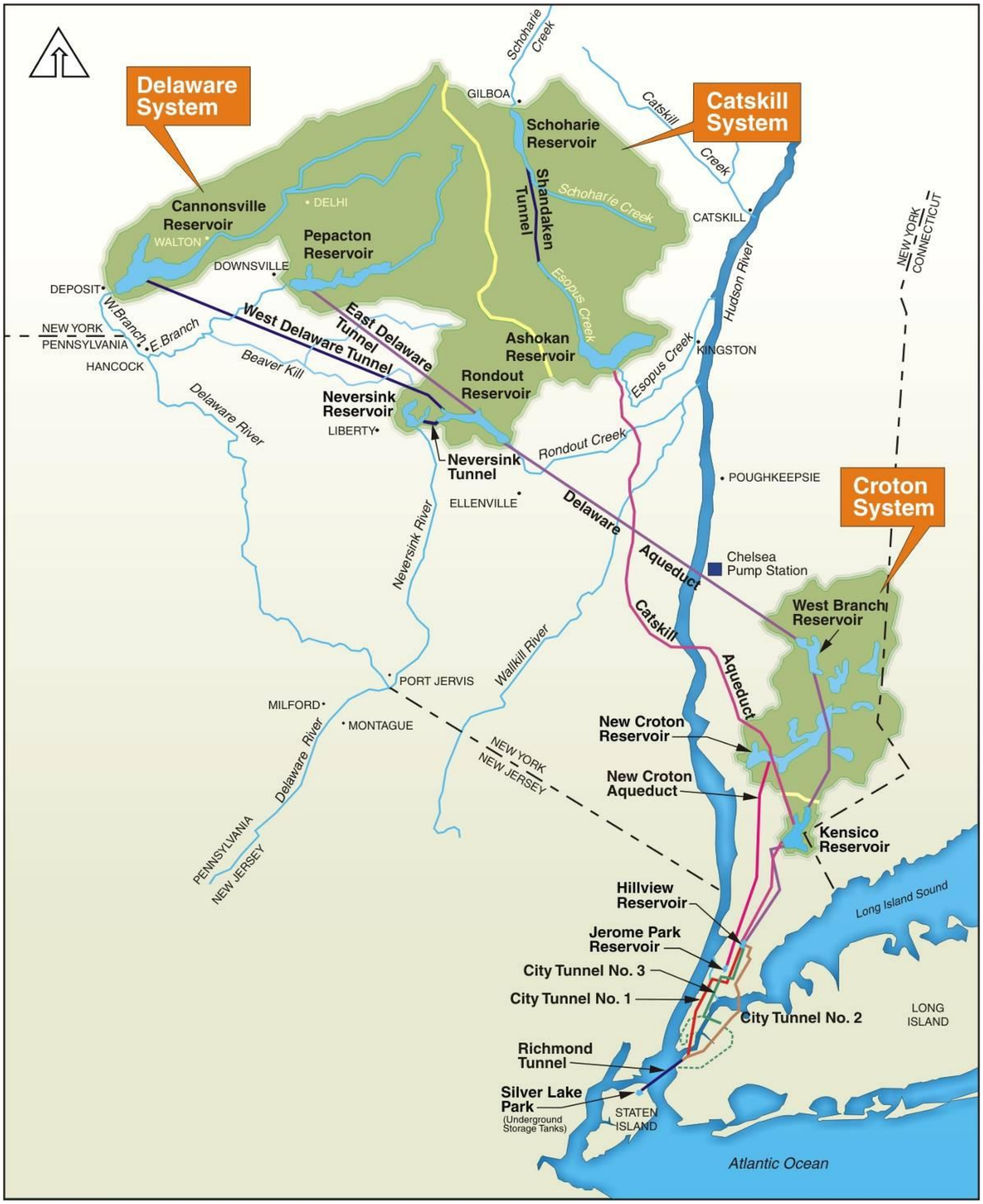

Figure 2: New York City Water Supply System

The following sections describe in more detail the major objectives for which the City's water supply system is operated.

2.2. Water Supply Reliability

The City's main priority is to meet the water supply needs of the City and upstate users. Accordingly, overall system reliability is the most important objective. The City consistently operates the system in a proactive manner to be prepared for unplanned events that could impair its ability to deliver high-quality water. As the highest quality and most reliable year-round water supply within the New York City System, the Delaware reservoirs are critical for maintaining this overall supply reliability.

The City is faced with the constant need to maintain the hydrologic reliability of the water supply and protect against potential drought or infrastructure failure conditions. To this end, operators endeavor to manage the system so that reservoirs are full by the beginning of the drawdown period, on or around June 1st of each year. Operators and managers then balance reservoir drawdown, taking account of refill probability, water quality, reservoir release requirements and economics. To do this, operators must forecast the range of inflow to each reservoir and estimate the probability of drawing the reservoirs down to undesirably low levels during the drawdown period and of refilling the system by the beginning of the next drawdown period. Doing this analysis in a robust fashion is a very difficult task, particularly in a system as extensive and complex as New York City's. The new system modeling software, known as the Operations Support Tool (OST), which is being used by the City while under further development, is greatly assisting in this effort.

Theoretical calculations of the "safe yield" of any water system presume that all water in the system can be allocated to some purpose. This would include diversions for drinking water use, conservation releases from reservoirs, and natural losses like evaporation or the allocation of storage volumes to dead-storage or operational minimum reserves.

The theoretical calculated value of "safe yield" is derived by assuming that the system would be operated to complete depletion of the operational storage volume at some critical point during the design drought. This point would be followed by a refill period that would allow full diversions to be maintained throughout the design drought. However, in practice, operators should not and do not operate the system in a way that would result in emptying all reservoirs at the worst point in the drought of record. The limited record of hydrologic data available demonstrates that worse conditions than the "drought of record" can occur. The traditional value of safe yield for the New York City System was based on the 1930's drought while the calculations described in this report are based on the more severe 1960's drought. Other analyses, such as tree-ring studies,[iii] suggest that even more severe events than the 1960's drought have occurred in the past outside of the period of recorded hydrologic data. The consequences of emptying all reservoirs would be catastrophic, and in actual operations, there is no assurance that the historical drought-ending rainfall will come at precisely the right moment to "save the day."

Although there are various definitions, the American Water Works Association ("AWWA") defines safe yield as "[t]he maximum rate at which water can be withdrawn continuously over a long period of time including very dry periods."[iv] The City calculates safe yield as the maximum continuous demand that can be met by the City water supply system during a repetition of the drought of record while maintaining a 25% storage reserve in the collection reservoirs of the Catskill and Croton Systems and in Rondout Reservoir.

Figure 3: Rainbow Over Shaft 18

Like numerous other municipalities that maintain such reserve for various reasons, the City maintains this reserve capacity based on the following rationale:

- To have reserve storage should a period occur that is drier than that experienced in the past (i.e., a new drought of record);
- To limit water quality impacts caused by reservoir drawdown;
- To allow for the effect of silting, which most likely has reduced reservoir storage volume;
- To provide adequate hydraulic head to deliver water at full aqueduct capacities; and
- To provide reservoir storage in the event a dry period occurs while spring runoff is frozen.

2.3. Water Quality Reliability

The City must maintain a safe, reliable, high quality water supply for its consumers. As with water supply reliability, the system must be ready to respond to a water quality event when it occurs. Water quality events include but are not limited to high turbidity resulting from storm runoff, elevated levels of phytoplankton or coliform bacteria, or an increase in concentrations of disinfection by-product (DBP) precursors, which are naturally occurring organic matter compounds that can react with chlorine to produce DBPs.

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An integral part of maintaining water quality reliability includes management of the reservoir system such that delivered water quality is maximized. In the event that contaminants in drinking water could rise to unacceptable levels, appropriate physical and/or chemical treatment must be undertaken.

The City's comprehensive water quality monitoring plan (New York City Department of Environmental Protection, 2009) is designed to ensure compliance with all federal, state, and local regulations; protect the water supply for public health; protect and improve the watersheds to meet the terms of the Filtration Avoidance Determination, described below, (US Environmental Protection Agency Region 2, 2007); meet the needs for current and future predictions of watershed conditions and reservoir water quality; support operational decisions and policies; and provide surveillance to ensure delivery of the best quality water to consumers.

In 2002, New York City was granted a five-year Filtration Avoidance Determination (FAD) by the United States Environmental Protection Agency (USEPA) for the Catskill and Delaware water supply systems (US Environmental Protection Agency Region 2, 2002). The FAD waived the requirements for unfiltered water systems to provide filtration, as promulgated by the Surface Water Treatment Rule, contingent on several conditions including: construction of a UV Disinfection Facility to treat the Catskill and Delaware water supplies; implementation of a Catskill Turbidity Control Program (CTCP); and continued implementation of a broad suite of watershed protection programs by the City. The Catskill Turbidity Control Program was originally proposed by the City in Section 6.4.9 of New York City's 2001 Watershed Protection Program Summary, and updated and refined in Section 2.3.11 of New York City's 2006 Long-term Watershed Protection Program (New York City Department of Environmental Protection, 2001; New York City Department of Environmental Protection, 2006). Catskill turbidity control remained a priority concern in the 2007 FAD, which required implementation of OST for controlling turbidity export from Schoharie, as described in the CTCP Phase II Implementation Plan (US Environmental Protection Agency Region 2, 2007). Further, the 2007 FAD required the City to continue to study turbidity control options for the Ashokan Reservoir and implement any selected options.

2.4. Environmental Objectives

In addition to providing a high quality, reliable supply of drinking water to its water supply users, the City operates pursuant to rules that serve to protect downstream users, fish habitat and stream ecosystems. Reservoir releases are made in accordance with the New York State Environmental Conservation Law 6 NYCRR Parts 670 and 672 to maintain flows from Rondout Reservoir and in the Croton and Catskill Systems. Minimum releases to tributaries of the Delaware River are defined by the terms of the 1954 Supreme Court Decree (Decree), agreements among the Parties of the Decree, DRBC dockets, and the current Flexible Flow Management Program (FFMP). The release rate requirements for the tributaries to the Delaware River outlined by 6 NYCRR

671 have been superseded by the various Decree Parties agreements and DRBC dockets. The Shandaken Tunnel, which diverts water from Schoharie Reservoir to Ashokan Reservoir, is also operated pursuant to New York State Department of Environmental Conservation SPDES Permit NY-0268151 (New York State Department of Environmental Conservation, 2006).

2.5. Economic Considerations

Fortunately, conditions that approximate the design drought and challenge the safe yield of the system are infrequent. During normal conditions, the operation of the reservoir system can be tailored to address important economic objectives. These economic objectives include:

- Minimizing the cost of operations and maintenance to customers of the water system;
- Minimizing energy consumption;
- Providing assistance in flood mitigation for downstream users; and
- Maintaining flows to meet various cold-water fishery and recreational needs.

Under normal conditions, the water supply system should be operated in a manner designed to satisfy the aforementioned water resource needs. However, as drought conditions develop, the operation of the system will shift toward supply preservation objectives set to maintain the reliability of the system. During normal conditions, the system should not be operated in a prescriptive manner based on the theoretical safe yield. The safe yield of the system is one important planning measure for reliability during drought conditions but it is not an operational formula. Conventional principals of water supply management dictate that when there is other high quality water available in normal and wet periods, the cost to pump and treat Croton or Catskill water can and should be minimized. This would also minimize additional unnecessary envi-ronmental impacts associated with increased energy use. The Decree also notes that sources of water that require pumping are specifically excluded from the City's calculation of safe yield for the

Figure 4: Pepacton Reservoir

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purposes of determining the Excess Release Quantity.

3. Prior Estimates of System Safe Yield

The traditional technique previously used to determine the official "Safe Yield" of the New York City water supply system employed the "Mass Curve" method. The details of this method can be found in many excellent texts and will not be expounded upon in this document. Suffice it to say that in previous studies, this technique was applied separately to each of the City's three reservoir subsystems, and to Rondout reservoir. The sum of these four yield numbers became the official NYC water supply system "Safe Yield."

It should be noted that there are several disadvantages to the "Mass Curve" method. Important constraints on individual reservoirs, both of a physical and operational nature, are substantially ignored by simply adding the calculated values of safe yield determined individually for each of the reservoirs. With the advent of additional and more complex operating constraints (e.g., the "Good Faith" agreement and NYSDEC's reservoir release regulations), the importance of individual reservoir operations to meet these added constraints became even more paramount in accurately determining the "Safe Yield".

A second and very important disadvantage of the "Mass Curve" method is its disregard of integrated system operation. In using the "Mass Curve" method, the distinct elements of the New York City water supply system were isolated and their individual safe yields determined. The result of this procedure was to determine four "Safe Yields" based on somewhat different critical drawdown periods, thereby foregoing the ability to optimize subsystem operations. By integrating all the reservoir elements in a system model, a higher system "Safe Yield" can be realized.

This is because, at any given time, reservoirs in the system with higher inflows relative to the others in a given period can assume a larger portion of the total system demand. The net result of this type of operation is a flexible shifting of the demand burden to different parts of the system over time, thus extending the system-wide critical drawdown period, and producing a greater "Safe Yield" relative to the one computed by the "Mass Curve" technique.

While the real-world synergy of operating the entire reservoir system as a whole increases the theoretical safe yield of the system, prior computations of safe yield relied on monthly rather than daily time steps. By viewing changes in the system by monthly time steps, shorter-term changes to the system are effectively averaged out of the computation. The result is a tendency toward over-estimating the safe yield of the system.

A third disadvantage of the "Mass Curve" method is its inability to perform Delaware River routing and directed release targeting, which are accommodated in an integrated system model. In the "Mass Curve" method, only approximations could be made for daily target releases.

A fourth disadvantage of the "Mass Curve" method is its inability to model non-NYC reservoirs, which have an effect on NYC reservoir operations. This is clearly the case in modeling the Lake Wallenpaupack operations plan which results in a reduction in NYC directed releases to the Delaware River. This is a task that can easily be performed by an integrated system model.

3.1. The 1954 Decree Calculation

The stated value of safe yield for the New York City reservoir system was developed in support of the 1954 Supreme Court Decree. This calculation relied on a mass curve analysis using monthly inflow and withdrawal time steps. The system inflow pattern was based on what was then known to be the worst drought of record, the 1930's drought. The impact of the apportionment of water from sources located in the Delaware Basin was considered in the computation. A minimum storage reserve equal to 25% of the volume of the Croton and Catskill Reservoir Systems and the Rondout Reservoir was part of this computation. In addition, the calculation excluded pumping from the Croton System. **The resulting safe yield for the system was estimated to be 1,665 Million Gallons per Day (MGD).**[v]

3.2. The 1974 Calculation

In response to conditions that actually occurred in the 1960's, the New York City Department of Water Resources prepared an updated calculation of the system safe yield in 1974 (the Mekenian and Rosen calculation).[vi] This computation was also done using a mass curve analysis that estimated the safe yield of each independent reservoir system. As in the case of the 1954 Decree calculation, this analysis also maintained a 25% reserve in the Catskill, Croton and Rondout Reservoirs. The release requirements of the 1954 Decree were accounted for in the estimate. Monthly time steps were used in the computation and the analysis excluded pumping from the Croton system. The inflow pattern replicated the actual flow record complied in the 1960's drought. **The resulting safe yield for the system was estimated to be 1,225 (MGD).**

3.3. The 1993 System Analysis

In 1993, R. A. Mayer performed an integrated analysis of all New York City reservoir system components using a digital computer model.[vii] As in the case of the prior computations, a monthly time step was used in this simulation. A 25% reserve volume was maintained in the Croton, Catskill and Rondout Reservoirs as in prior computations. The reservoir system operating rules were updated to include the goals of the Good Faith Negotiations and the release requirements of New York State Environmental Conservation Regulations, 6 NYCRR Part 670, 671 and 672 were also accounted for in the computation. However, unlike past computations, pumping from the Croton system was factored into the estimate of safe yield rather than excluded. **The resulting safe yield for the system was estimated to be 1,370 (MGD).**

4. Safe Yield Calculation – 2011

4.1. Model Background

For the current calculation of the New York City water supply system safe yield, the OASIS component of the Operations Support Tool (OST), a forecast-driven simulation and analysis tool, was employed. OASIS is a computer program that models the operations of a water resource system. It simulates the routing of water through a system of nodes and arcs by solving a linear program. The routing accounts for both human control and physical constraints on the system. The OASIS model is able to incorporate operating rules and constraints that apply to the entire NYC water supply system and reflects realistic water supply operations and priorities.

A critical component of the NYC OASIS model is a proprietary programming language named Operations Control Language ("OCL"). OCL consists of thousands of lines of code that represent NYC's complex water supply operations. The City operates its reservoir system pursuant to rules that serve to protect downstream users, fish habitat and stream ecosystems. Reservoir releases are made in accordance with the New York State Environmental Conservation Regulations, 6 NYCRR Parts 670 and 672 to maintain flows from Rondout Reservoir and in the Croton and Catskill

Figure 5: Ashokan Reservoir

Systems. Minimum releases to tributaries of the Delaware River and the flow target on the Delaware River at Montague, New Jersey are defined by the following: the terms of the 1954 Supreme Court Decree, The "Good Faith" Agreement among the Parties to the Decree, DRBC reservoir release dockets, NYSDEC 6 NYCRR Part 671 and the current OST-based Flexible Flow Management Program. In addition, the Shandaken Tunnel, which diverts water from Schoharie Reservoir to Ashokan Reservoir, is operated pursuant to New York State Department of Environmental Conservation SPDES Permit NY-0268151. All of these rules are embedded in the NYC OASIS model OCL. It is this complex coding that drives the model.

The City manages the water system to maximize overall system reliability, maintain high quality water for those dependent on the City's system for their water supply needs, address environmental concerns, and meet regulatory and other legal obligations. The model captures not only the rules and regulations that the City must abide by, but also the realistic way the system is operated on a day-to-day basis. Operating rules in the model consists of the aforementioned regulatory release requirements, reservoir balancing routines, and operating preferences (e.g., drawdown priority, water quality, etc.).

OASIS expresses system objectives by a series of linear relationships that comprise the "objective function." OASIS consists of goals and constraints. While OASIS attempts to meet goals to the extent possible, it must always meet constraints. Each goal is assigned a weight, a relative numerical value to establish priorities among competing objectives. Weights determine the number of points the model receives for meeting various objectives. OASIS creates a linear programming problem (LP) based on all goals and constraints in the model for each simulation day. The linear program is solved in such a way as to maximize the number of points while complying with all model constraints. Figures 6 through 8 show the magnitude of many of the weights in the model. Weights shown in these Figures for the Delaware, Catskill and New Croton Aqueducts serve to enforce diversion targets that drive the overall system balancing in the model. Diversions are set to the flows needed to meet expected demands over the following seven days, maintain target elevations at West Branch and Kensico Reservoirs, and generally keep the systems balanced. In addition, aqueduct targets are modified to reflect occurrence of exceptional events (e.g. Catskill turbidity events, infrastructure outages) as well as physical infrastructure limitations (e.g. Rondout gate settings).

Major components of the OASIS model include reservoir inflows, consumptive demands, system physical data, and operating rules. In OASIS, inflow to a reservoir represents the net local inflow to that reservoir, not including flows from upstream reservoirs. Net inflows are derived from historical gauge and operations data and serve to represent the range of possible future hydrologic conditions. Flows between reservoirs are based on release and diversion decisions made by the model. Demands are modeled as recurring annual patterns throughout the simulation period. Demand in a given month is calculated as the product of the annual average

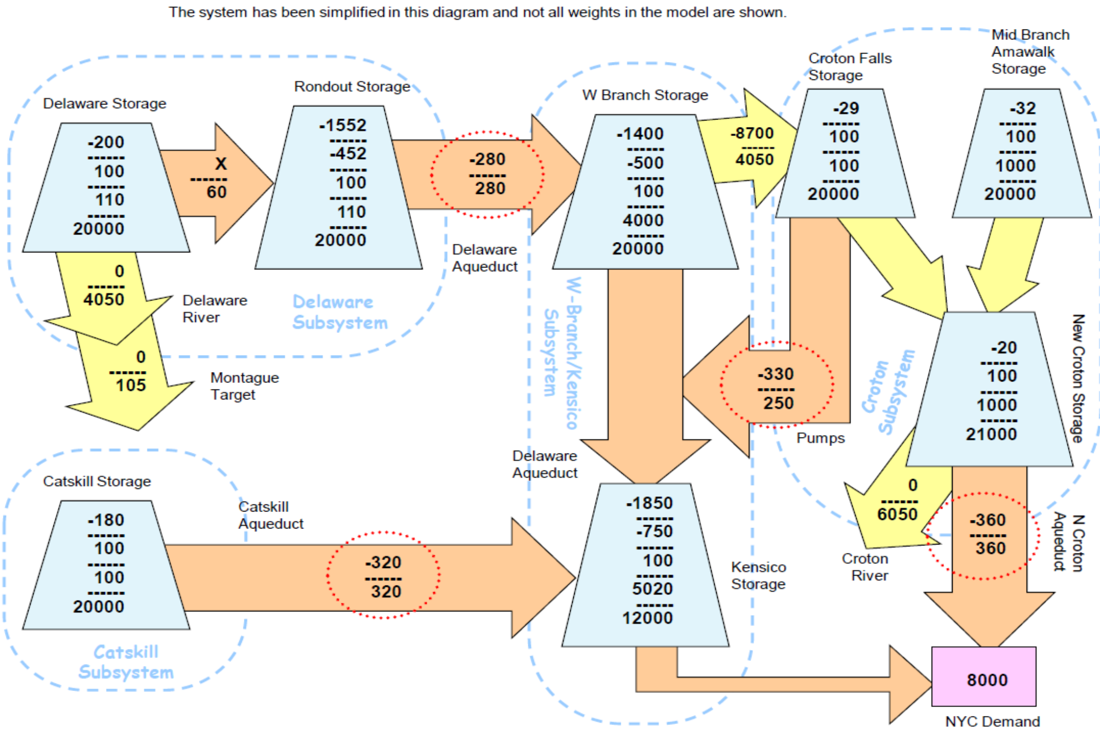


Figure 6: Simplified System Link Diagram

demand level and a monthly peaking factor. The OASIS model includes data that represent physical constraints on the flow and storage of water (e.g., spillway rating curves, maximum capacities of aqueducts and release works, elevations of structures, reservoir storage-elevation curves).

Balancing the system is another key factor in the model. Catskill, Delaware, and Croton diversions are balanced based on storage levels and season. Adjustments to this balance are made in case more or less water is needed to meet demands or to keep West Branch and Kensico Reservoirs at specific elevations. Individual reservoirs within each system are balanced such that drawdown occurs roughly simultaneously within a sub-system. These sub-system balancing rules are associated with the lowest weighs in the model such that all other operating rules will over-ride the sub-system balancing The model will choose to make the required reservoir releases before attempting to bring the system into balance.

The first step for overall system balancing is to determine the total diversion needed to meet demands over the next 7 days and maintain Kensico and West Branch Reservoir target elevations. Next, the system operations mode is determined, based on user inputs, current usable storage, and probability of refill on or around June 1st. A flow chart showing the balancing routine is presented in Figure 9.

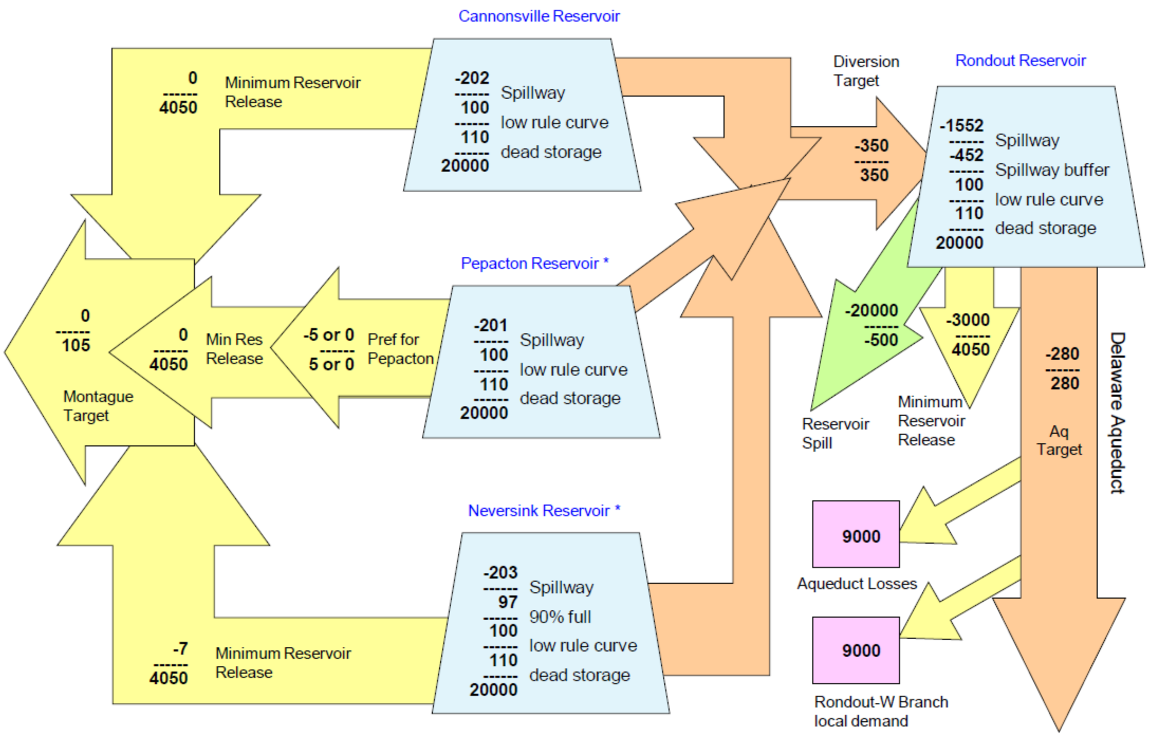


Figure 7: Delaware Subsystem

The current model includes a daily inflow database that includes data from 1927 through 2010. It should be noted that the OASIS model can inform reservoir system operators about the impacts of different operating rules or scenarios, but does not optimize operating rules or scenarios for the user. In order to determine the NYC reservoir system safe yield, a series of trial and error runs were performed gradually increasing average total annual demand until a shortage occurred.

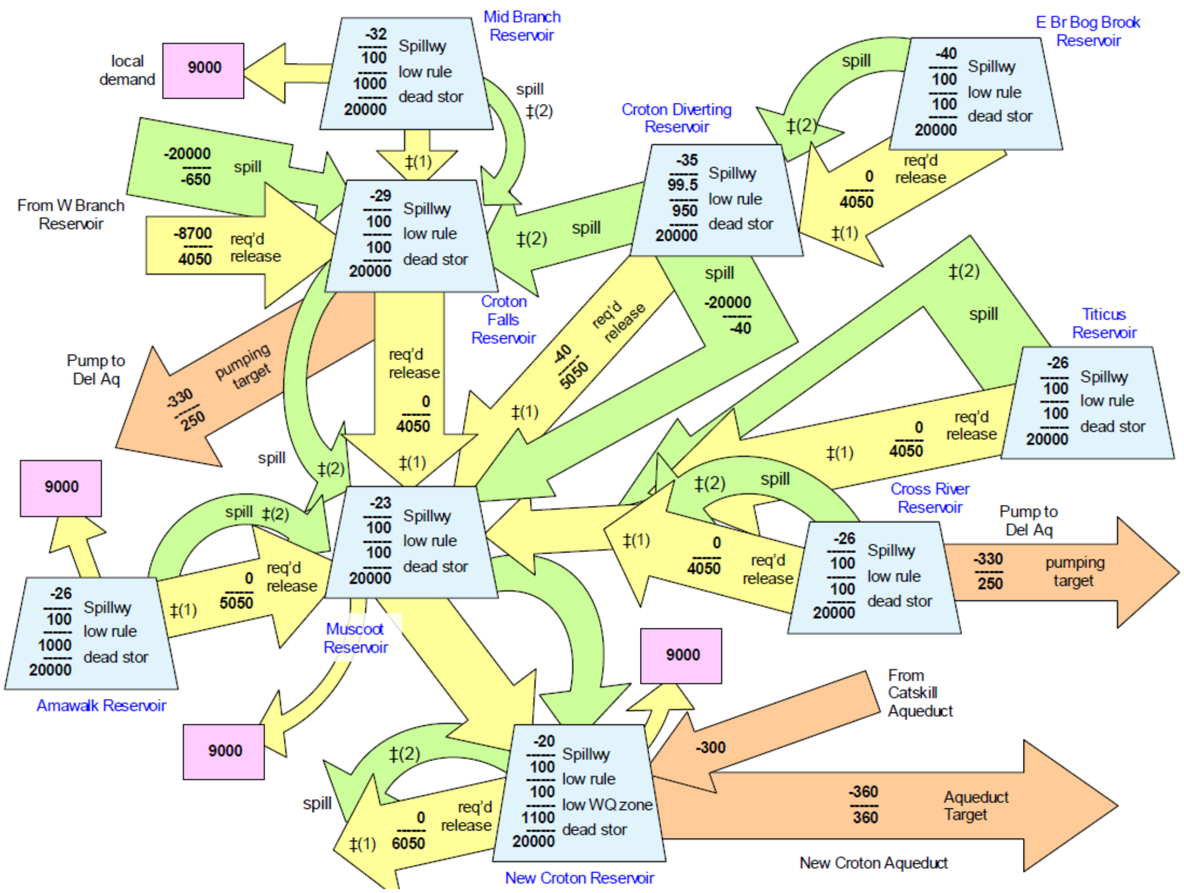
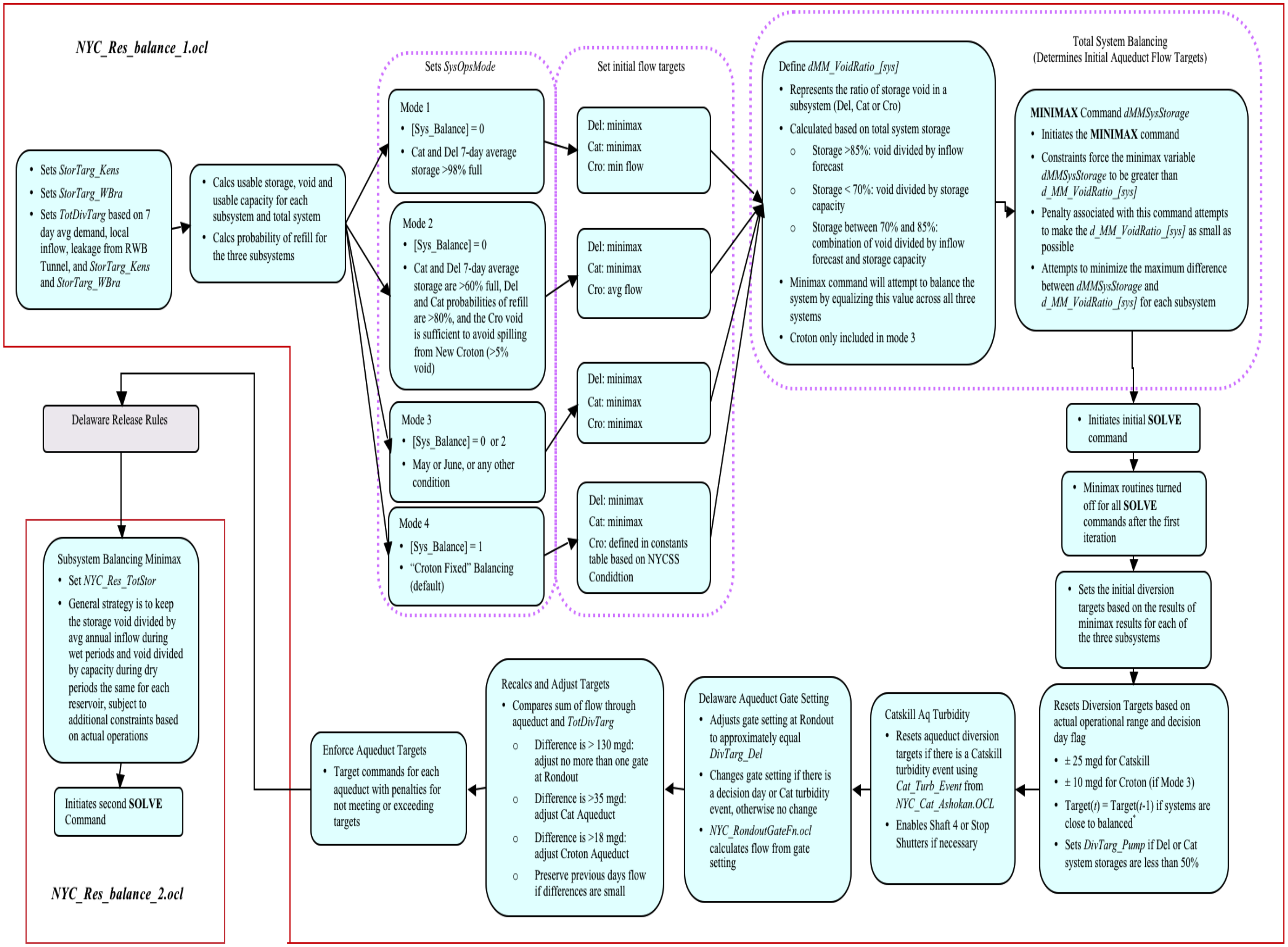


Figure 8: Croton Subsystem



*System is "close to balanced" if minimax void ratios for the systems are within 0.07 of each other and the total diversion target is within 80 mgd of yesterday's value.

Figure 9: System Balancing Routine

4.2. Safe Yield Model Run Details

The OST simulation mode was used for the safe yield model runs. The simulation mode is designed for the purpose of long-term planning and consists of a single extended simulation period over which operating rules are applied consistently. In this case, the 1960's drought of record was simulated, beginning on June 1, 1960 and ending on June 1, 1967. This driest period of record was used to determine the safe yield, which is the maximum annual average demand that could be met by the system.

Figure 10: New Croton Spillway

Twenty-five percent of the gross reservoir storage was held in reserve for the Catskill and Croton reservoir systems and Rondout Reservoir, consistent with past safe yield calculations. In addition, minimum operating level requirements were specified for Kensico Reservoir (351.5 ft) and West Branch Reservoir (478 ft). These reservoirs are the terminal supply reservoirs for the system. Water surface elevations must be maintained at or above these levels to provide adequate flow and pressure within the City's water distribution network and to allow adjacent communities to draft water from the system (e.g., from Kensico Reservoir). In addition, these elevations also allow the City to maintain an operational storage reserve in the event that actual drought conditions are worse than the historic drought of record. While beyond the scope of this report, experience has also demonstrated the need to maintain these reservoir levels to ensure that safe drinking water objectives can be met.[viii]

For this study, four scenarios were selected. The operating rules (e.g., regulatory release requirements, reservoir balancing routines, and operating preference) for all scenarios are the same. The scenarios differed in terms of the planning horizon (i.e., present or future) and whether or not pumping was allowed from the Croton System. The four separate model runs determine the estimated safe yield of the system under present system conditions and under anticipated conditions when certain modifications of the system have been completed. The present conditions are analyzed with and without pumping from the Croton System. The future conditions are also analyzed with and without pumping from the Croton system. A detailed summary of each model condition follows.

Scenario 1 *"SY_PR_SF_P"*
Safe Yield Run 1
Present operating conditions
Croton pumping

Model Assumptions for Scenario 1

- Catskill Aqueduct maximum capacity (Ashokan to Kensico): 595 MGD
- Catskill Aqueduct minimum capacity (Ashokan to Kensico): 275 MGD
- New Croton Aqueduct Capacity (with pumping): 42 MGD
- Croton Falls hydraulic pumping: 30 MGD
- Cross River electrical pumping: 60 MGD
- Rondout – West Branch Tunnel (RWBT) maximum capacity (Delaware Aqueduct): 850 MGD
- RWBT Leak: Function of the tunnel flow ranging from 20-35 MGD
- NYC Delaware Basin diversions: FFMP 6/1/2011
- Shandaken Tunnel: Part 671 regulations and SPDES permit
- Croton System Reservoirs & Rondout Reservoir: Part 672 regulations
- Ashokan Reservoir Community releases: Implemented
- Ashokan Waste Channel: On
- Kensico minimum operating level: 351.5 ft
- West Branch minimum operating level: 478 ft (due to 25% storage reserve)
- Water supply demand: Outside community demand implicit in total water supply demand
- Demand: Seasonal monthly demand factors applied (Figure 11)

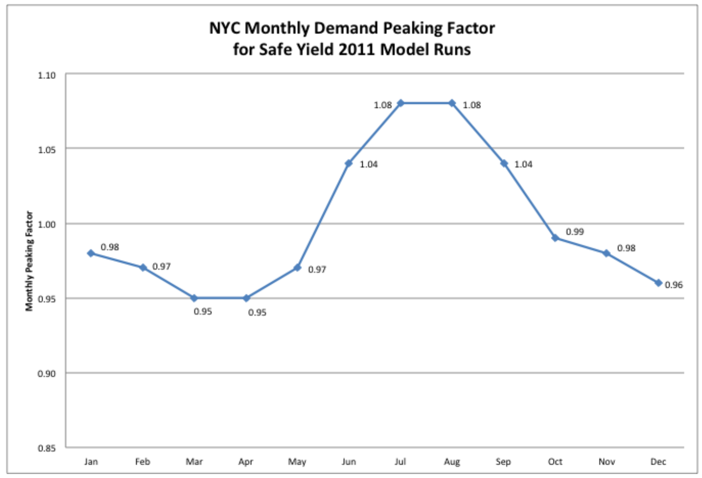


Figure 11: Seasonal Demand Factors

Under present conditions, the losses in the Rondout-West Branch Tunnel vary with flow through the tunnel. For tunnel flow rates less than 800 MGD, these losses are estimated at 20 MGD. For tunnel flow rates in excess of 800 MGD, the losses are estimated at 35 MGD.

Scenario 2 *"SY_PR_SF_NP"*
Safe Yield Run 2
Present operating conditions
No Croton pumping

Model Assumptions for Scenario 2

- Catskill Aqueduct maximum capacity (Ashokan to Kensico): 595 MGD
- Catskill Aqueduct minimum capacity (Ashokan to Kensico): 275 MGD
- New Croton Aqueduct Capacity (with pumping): 0 MGD
- Croton Falls hydraulic pumping: 0 MGD
- Cross River electrical pumping: 0 MGD
- Rondout – West Branch Tunnel maximum capacity (Delaware Aqueduct): 850 MGD
- RWBT Leak: Function of the tunnel flow ranging from 20-35 MGD
- NYC Delaware Basin diversions: FFMP 6/1/2011
- Shandaken Tunnel: Part 671 regulations and SPDES permit
- Croton System Reservoirs & Rondout Reservoir: Part 672 regulations
- Ashokan Reservoir Community releases: Implemented
- Ashokan Waste Channel: On
- Kensico minimum operating level: 351.5 ft
- West Branch minimum operating level: 478 ft (due to 25% storage reserve)
- Water supply demand: Outside community demand implicit in total water supply demand
- Demand: Seasonal monthly demand factors applied

Under future model conditions, the leak in the Rondout-West Branch Tunnel has been eliminated. In addition, the Catskill Aqueduct capacity has been increased from 595 MGD to 600 MGD. Finally, treatment for the Croton system is in place allowing this system to be considered in the future "with pumping" scenario. The 25% storage reserve is maintained for the Croton, Catskill and Rondout Reservoirs as in all prior calculations.

Scenario 3 *"SY_F_SF_P"*
Safe Yield Run 3
Future operating conditions
Croton pumping

Model Assumptions for Scenario 3

- Catskill Aqueduct maximum capacity (Ashokan to Kensico): 600 MGD
- Catskill Aqueduct minimum capacity (Ashokan to Kensico): 275 MGD
- New Croton Aqueduct Capacity (with pumping): 290 MGD
- Croton Falls hydraulic pumping: 180 MGD
- Cross River electrical pumping: 60 MGD
- Rondout – West Branch Tunnel maximum capacity (Delaware Aqueduct): 850 MGD
- RWBT Leak: No leak
- NYC Delaware Basin diversions: FFMP 6/1/2011
- Shandaken Tunnel: Part 671 regulations and SPDES permit
- Croton System Reservoirs & Rondout Reservoir: Part 672 regulations

- Ashokan Reservoir Community releases: Implemented
- Ashokan Waste Channel: On
- Kensico minimum operating level: 351.5 ft
- West Branch minimum operating level: 478 ft (due to 25% storage reserve)
- Water supply demand: Outside community demand implicit in total water supply demand
- Demand: Seasonal monthly demand factors applied

Scenario 4 *"SY_F_SF_NP"*
Safe Yield Run 4
Future operating conditions
No Croton pumping

Model Assumptions for Scenario 4

- Catskill Aqueduct maximum capacity (Ashokan to Kensico): 600 MGD
- Catskill Aqueduct minimum capacity (Ashokan to Kensico): 275 MGD
- New Croton Aqueduct Capacity (no pumping[ix]): 70 MGD
- Croton Falls hydraulic pumping: 0 MGD
- Cross River electrical pumping: 0 MGD
- Rondout – West Branch Tunnel maximum capacity (Delaware Aqueduct): 850 MGD
- RWBT Leak: No leak
- NYC Delaware Basin diversions: FFMP 6/1/2011
- Shandaken Tunnel: Part 671 regulations and SPDES permit
- Croton System Reservoirs & Rondout Reservoir: Part 672 regulations
- Ashokan Reservoir Community releases: Implemented
- Ashokan Waste Channel: On
- Kensico minimum operating level: 351.5 ft
- West Branch minimum operating level: 478 ft (due to 25% storage reserve)
- Water supply demand: Outside community demand implicit in total water supply demand
- Demand: Seasonal monthly demand factors applied

In order to determine the NYC reservoir system safe yield, a series of runs were performed for each scenario by gradually increasing average total annual demand until a supply shortage occurred. The runs were conducted at 10 MGD demand increments. The final results show the maximum annual average water supply demand that can be met by NYC's water supply system without a resulting shortage for the simulation period. The following table summarizes the results of this analysis.

Scenario	Estimated Safe Yield
Present With Pumping	**1,140 MGD**
Present Without Pumping	**1,080 MGD**
Future With Pumping	**1,310 MGD**
Future Without Pumping	**1,180 MGD**

The results for Scenario 1, Present Conditions With Pumping, are presented graphically in the following Figures 12 and 13. Under a repeat of the hydrologic conditions that existed during the 1960's drought, total system storage would be drawn down to critical levels.

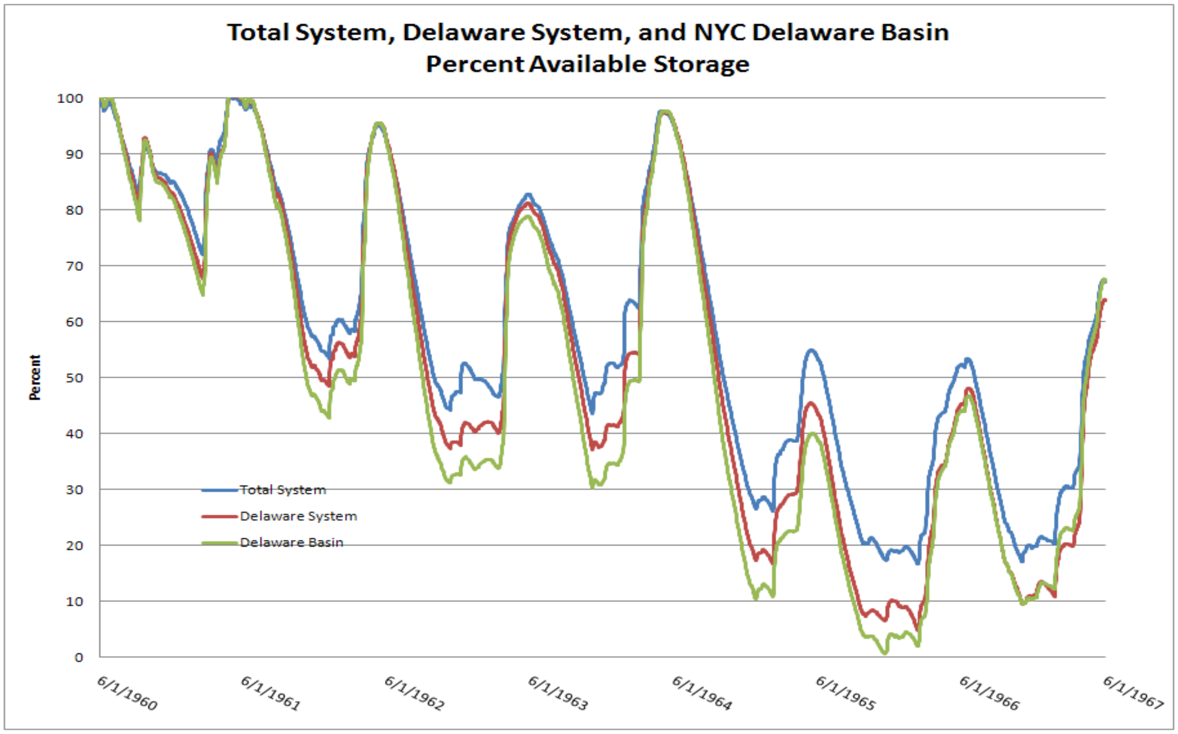


Figure 12: Estimated Storage Total and Delaware Systems (%)

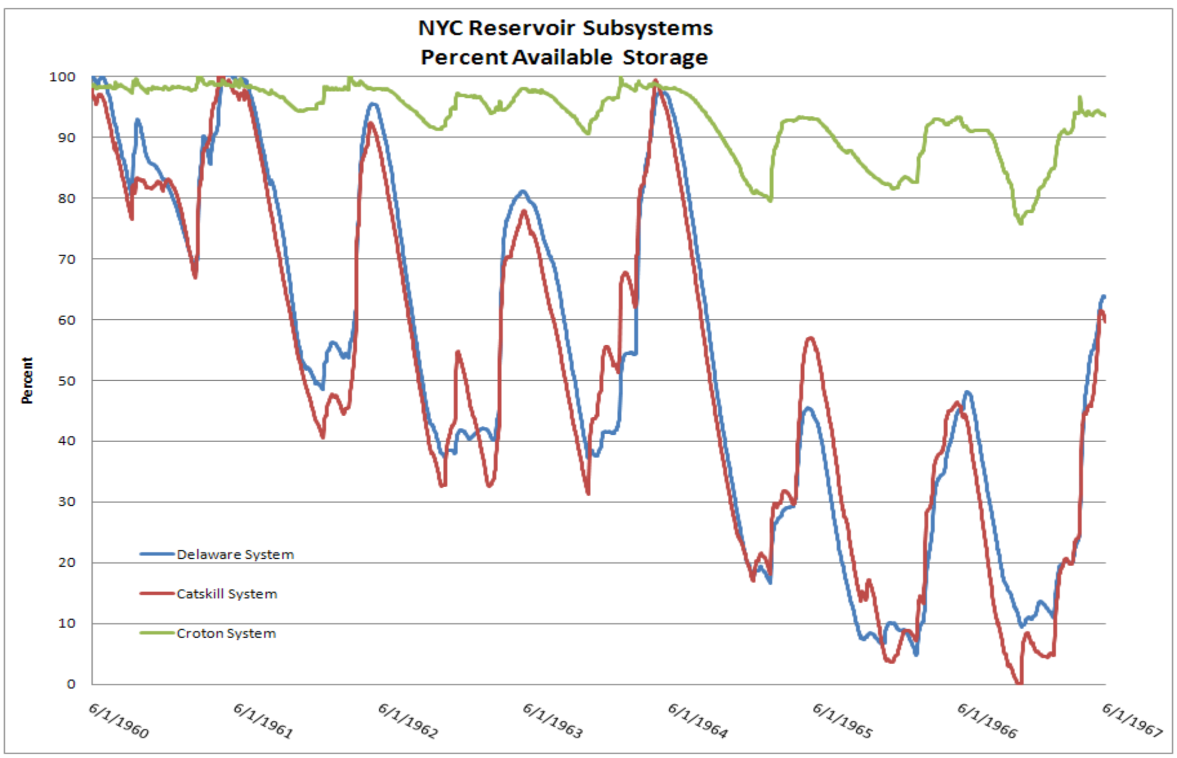


Figure 13: Estimated Storage Catskill, Croton, Delaware

In this calculation, the Delaware Basin reservoirs would be emptied while some storage is maintained in the Rondout Reservoir. Total system storage declines to levels below 20%, reflecting the combined Catskill, Croton, Rondout reserve, which is a minimum level of 25% for these reservoirs.

Present conditions represent a severe case because of the lack of availability of the full capacity of the Croton System. At present, although it is permissible to utilize the Croton supply, infrastructure improvements underway to support the construction of the Croton Water Filtration Plant limit the ability to place Croton water into the distribution system. Even with pumping, the amount of water available for use under drought conditions is limited and the Croton system remains relatively full in this scenario. Water quality constraints effectively shift the reserve amount to a portion of the system that may not be completely available due to ongoing construction. A comparison of present and future storage volume in the Croton System is shown in Figure 14.

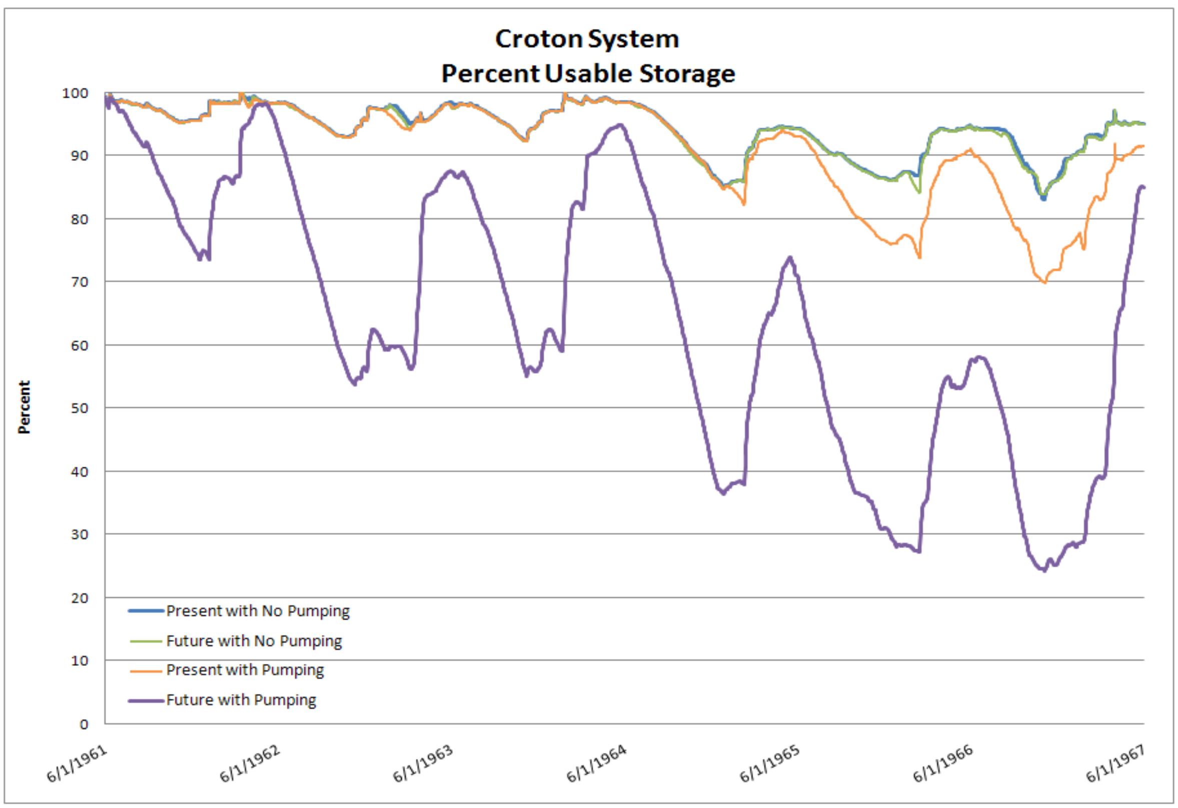


Figure 14: Croton System Storage

4.3. Present Water Demands

The calculation of the safe yield of the system under a design drought condition provides a useful benchmark. If hydrologic conditions similar to the design drought occur again, the comparison of safe yield to current water demands demonstrates the need for demand management in earlier drought stages. Over the years, the City has aggressively pursued water conservation initiatives and this has resulted in a measureable and meaningful decline in water consumption.

Figure 15: Cannonsville Reservoir - November 2001

In the last ten years, the amount of water delivered to water users has declined from nearly 1,365 MGD to roughly 1,159 MGD – a decline of 15%. For the past five years, water demands have average 1,179 MGD. This is significantly lower than the peak system demands recorded in 1979 when the average daily demand for in-City uses was 1,512 MGD. The decline in water use has occurred even while the population of the system has grown dramatically. In 1980, the population of New York City was 7,071,639,[x] and this has grown by 15.6% to 8,175,133 in 2010.[xi] Aggressive mandatory conservation measures, including the advent of the leak and waste detection program in 1981, the universal metering program (implemented in 1988), and the general impact of the U.S. Energy Policy Act of 1992, which resulted in the manufacture of more water efficient home appliances, have all worked to reduce water consumption.

The safe yield estimated for the system under present conditions without pumping is less than the average demand for the past five years by a margin of 8.4%. With pumping from the Croton system, the safe yield estimate is 1,140 MGD, an amount that is less than the recent average demands by 3.3%.

Under future system conditions, treatment will allow the Croton System to be used to a greater extent. Without pumping, the safe yield will match recent demands and with pumping, the safe yield will exceed recent demands by 11%.

Citations

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Footnotes

[i] Agreement of the Parties to the 1954 U.S. Supreme Court Decree, December 10, 2008; Section 15, Reassessment Study, p. 19.

[ii] More recently, the Delaware System, which includes Rondout Reservoir, has been used to meet 60-70% of the City demand.

[iii] Tree-Ring Analysis as a Predictor of Pre-1927 Reservoir Inflows; Department of Environmental Engineering; Manhattan College; New York; April 2004.

[iv] *See* AWWA's "Principles and Practices of Water Supply Operations: Water Sources" (2003).

[v] 347 U.S. at 998, Amended Decree, Paragraph III(B)(1)(c); June 7, 1954.

[vi] Dependable Supply of New York City's Water Supply Sources Based on 1961-1967 Drought; Mekenian, George, P.E. and Rosen, Herman, P.E.; City of New York Department of Water Resources; February, 1974.

[vii] Safe Yield Study of the New York City Reservoir System; Mayer, Robert A., P.E.; City of New York Department of Environmental Protection; December 29, 1993.

[viii] Studies within the NYC Watershed include: Effler & Bader, 1998, Effler, et al., 1998, Effler & Matthews, 2004, and Marzec, et.al., 2009. A major drawdown at Cannonsville in 1995 demonstrated the impacts that drawdown can have including: 1) Increased TP and decreased Secchi depth due to sediment re-suspension; and 2) enhanced phytoplankton growth.

[ix] The 70 MGD contribution from the Croton System represents water that can be taken into the distribution system from the Croton System under this scenario without treatment. This water would be available only in emergency conditions and with the prior approval of the New York Department of Health, which may not be granted. In order for this water to be treated, some low level pumping through the treatment plant is required.

[x] 1980 Census of Population, Volume 1, Chapter B, Part 34; General Population Characteristics, Table 16; U.S. Department of Commerce; Washington D.C.; August 1982; p. 34-56.

[xi] U.S. Bureau of Census; State & County Quickfacts; New York (city), New York; http://quickfacts.census.gov/qfd/states/36/3651000.html