Environmental
Protection

New York City's Operations Support Tool (OST) White Paper Prepared for The Delaware River Basin Supreme Court Decree Parties

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1. Operations Support Tool Background

The New York City Department of Environmental Protection (City) is developing a state-of-the-art decision support system to improve operations and planning throughout the water supply system. The Operations Support Tool (OST) is a forecast-driven simulation and analysis tool that will provide the City's operators and managers with probabilistic predictions of future system status based on simulation scenarios. The OST will significantly impact all three of the City's systems, the Delaware System, the Catskill System, and the Croton System. The purpose of this paper is to describe OST and discuss the potential that it offers for supporting and improving releases from New York City Reservoirs in the Delaware River Basin.

This section provides an introduction of OST in the context of the challenges faced by the New York City Water Supply System. Sections 2 and 3 describe the major components of OST, while Section 4 describes usage of OST, including potential usage for Delaware River Basin releases. Finally, Section 5 presents OST project timeline.

1.1. New York City Water Supply System

1.1.1. Complex Water Supply System Facing Future Challenges

New York City's reservoir system is among the most complex water supply systems in the world (Figure 1-1). More than 1 billion gallons (BG) of water flows each day by gravity from the Delaware, Catskill, and Croton Systems to meet the demand 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 New York City Delaware System includes Pepacton, Cannonsville, and Neversink Reservoirs, from which water is diverted to Rondout Reservoir. From Rondout Reservoir, water can be diverted to West Branch and Kensico Reservoirs via the Delaware Aqueduct. Water from Kensico, which includes water from the Catskill and the Delaware Systems, is diverted to Hillview Reservoir and subsequently conveyed to the City via City Tunnel Nos. 1, 2, and 3. On average, the Delaware System is used to meet 60-70% of the City demand. In addition, Delaware water is historically the highest quality water in the system and there is often a need to divert more from the Delaware System, such as during turbidity events in Schoharie and Ashokan Reservoirs, during droughts, or when a critical piece of infrastructure is offline (e.g. for repairs or inspection).

It is in this context that the City must manage the Delaware System carefully 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 obligations to the lower Delaware Basin communities.

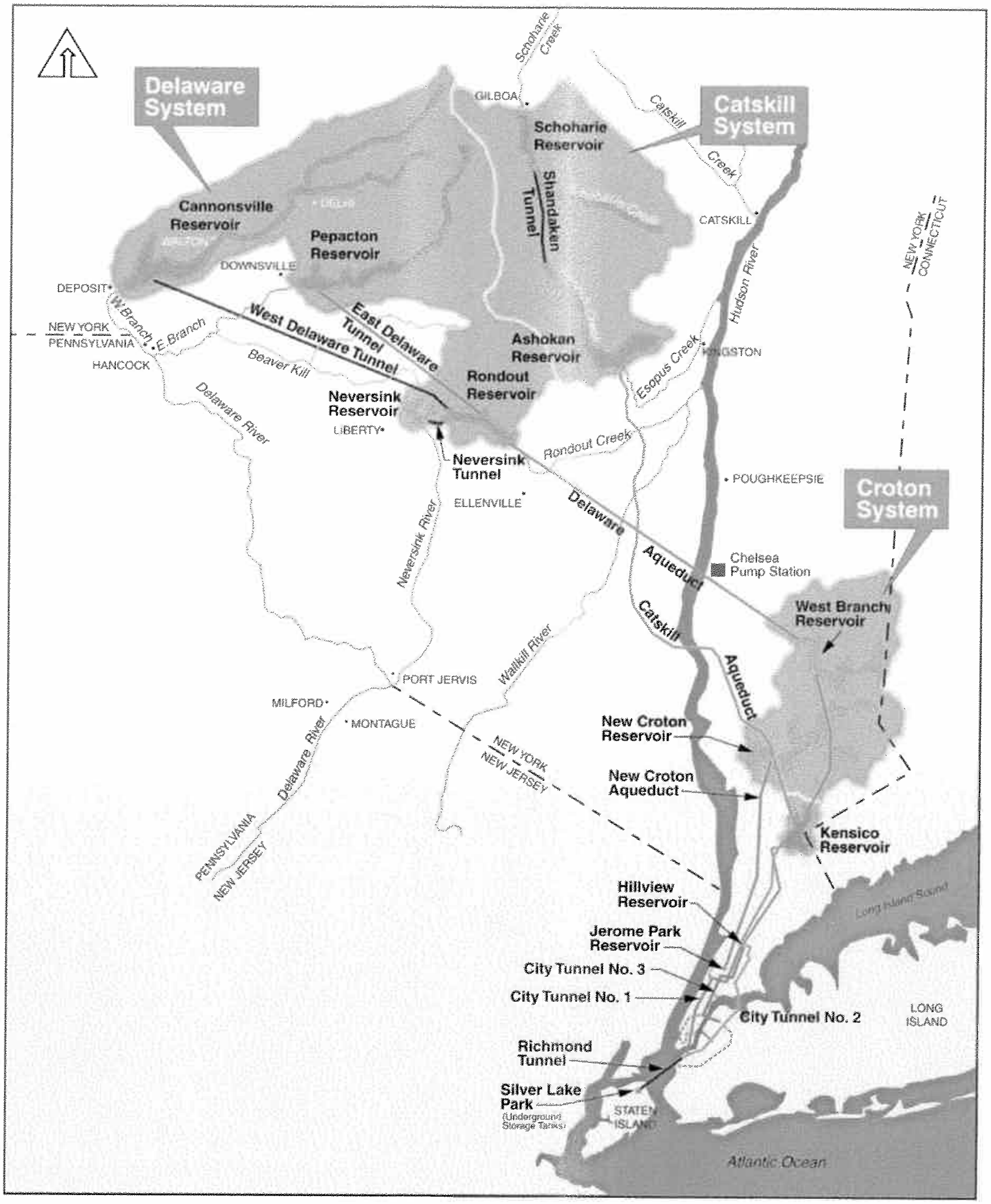

Figure 1-1: New York City Water Supply System

Although the City has operated its complex reservoir system for decades professionally and in compliance with water quality requirements and Delaware Basin agreements, new challenges and regulatory requirements require development of a robust analytical tool to guide system operations and evaluate alternative operational strategies.

This already complex water supply system faces additional challenges in the future due to aging infrastructure, a projected increase in City and outside community demand over the next few decades, potential storage and water quality impacts due to climate change, and an evolving regulatory environment. The City is taking a proactive approach to meeting these varied challenges in developing OST, an innovative, real-time decision support system that will assist the City in making short-term and long-term water and demand management decisions using real-time data and forecasted future reservoir inflows.

1.1.2. Regulatory Drivers

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: 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 by the City, among others. 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 an Operations Support Tool 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. The 2006 State Pollution Discharge Elimination System (SPDES) discharge permit that governs releases from Schoharie Reservoir through the Shandaken Tunnel also establishes the requirement for an Operations Support Tool (New York State Department of Environmental Conservation, 2006).

1.1.3. Multiple Objective Management Philosophy

OST fits well within the City's overall multi-objective water supply management philosophy. It provides the City with the analytical tools to better meet its various objectives while accounting for uncertainty in future hydrologic conditions. OST will further allow the City to better manage the tradeoffs between competing objectives and provide the capability for evaluating the impacts (positive and negative) for various operating strategies.

From a broader perspective, OST serves as a template for water supply operators throughout the US and globally as they face increasingly difficult decisions about balancing water quality, water quantity, environmental, and economic objectives. As population, water consumption, and environmental concerns increase, so will the need for state-of-the-art tools for effectively managing our water resources. These same tools are equally critical in demonstrating to utilities, managers and stakeholders when capital expenditures are necessary and, when they are not.

The following sections review in more detail the major objectives for which the New York City water supply is operated.

1.1.3.1. Water Supply Reliability

The City's main priority is to meet the water supply needs of the City and upstate users. Accordingly, management of the system must maintain overall system reliability as the most important objective. There are serious consequences for poor management of the water supply; thus it is critical that the City consistently operates the system in a proactive manner such that it is prepared for unplanned events that could impair its ability to deliver high-quality water. As the highest quality, 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 (June 1^{st}). Operators and managers then balance reservoir drawdown, taking in account 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 upcoming 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 complex as New York City's.

It is important to note that 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. Although this type of operation is assumed in determining the "safe yield" of the system, it is unworkable in actual practice. 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 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."[1] 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.

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

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

OST will provide an analytical tool for improving operation of the New York City water supply to maximize reliability. It will allow operators and managers to compare different sets of operating rules and evaluate the predicted impacts on water supply reliability criteria quickly and efficiently so that they can make appropriate short-term and long-term decisions. It will also provide a means to document the rationale for those decisions. While the overall water supply management philosophy will not change, the ability of the City to make objective, risk-based decisions will be strengthened by OST.

1.1.3.2. 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 (e.g. turbidity events, chemical spills in or near a reservoir, or an increase in concentrations of disinfection by-product (DBP) precursors, which are naturally organic matter compounds that can react with chlorine to produce DBPs). An integral part of maintaining water quality reliability includes management of the reservoir system such that quality of delivered water is maximized. In the event that contaminants in delivered 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 FAD (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

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

quality water to consumers. OST will integrate water quality monitoring data on a near-real time basis to facilitate decision-making by the City's operations staff.

As described below, the OST concept arose from the need to provide analytical and predictive support for controlling turbidity in the Catskill System and meeting the requirements of the FAD. Preliminary rules for operating the Catskill reservoirs during a turbidity event are already encoded in OST. Additional rules for other water quality events will likely be developed and tested using this tool. Therefore, use of OST will enable the City develop operations that will protect the water supply against a diverse range of specific water quality impacts.

1.1.3.3. 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 which serve to protect downstream users as well as fish habitat and stream ecosystems. See New York State Environmental Conservation Law 6 NYCRR Parts 670-672. Reservoir releases are made in accordance with these regulations 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 amongst the Parties of the Decree, DRBC dockets, and the current Flexible Flow Management Program (FFMP).

As described further in Section 4, there is great potential for use of OST to support decisions to make releases that provide additional benefits to downstream communities and the Delaware River. Increased knowledge of system operations and probability of future inflows, coupled with the analytical power of OST, should provide substantial benefits for both New York City and downstream interests.

1.1.3.4. Economic Considerations

The suggestion that we operate at all times in a prescriptive manner based on the safe yield (rather than using the safe yield as a threshold for reliability during drought conditions) could require the City to pump and treat Croton or Catskill water when there is other high quality water available. Such a practice would not be reasonable or consistent with conventional principals of water supply management, nor would it be consistent with the Decree in that sources of water that require pumping are specifically excluded from the City's calculation of safe yield for the purposes of determining the Excess Release Quantity. This would also result in additional unnecessary environmental impacts associated with increased energy use. Moreover, the economic costs for pumping and treating could be significant.

1.1.3.5. Other Objectives

Other system objectives include, to the extent consistent with City's mandate to provide an adequate supply of high quality and affordable water, flood mitigation and support for recreation. In both cases, OST will allow operators to support these needs by providing assurance that any actions ultimately taken will not significantly impact the ability to achieve New York City's primary operating objectives.

1.2. Operations Support Tool Background

OST is an analytical tool designed to help guide operating decisions. It simulates and evaluates operating alternatives using forecasted and near-real time system information. A given OST simulation is comprised of operating rules and scenario assumptions (e.g. which facilities are currently in or out of service). Most often, the rules and assumptions used will reflect New York City's current operating policies and current or planned system conditions. The model input that reflects current policies and conditions will be stored and immediately available for analysis. However, OST itself is not bound to a specific set of rules or assumptions. Rather, it is a platform for developing and testing a variety of operating policies that will provide feedback to operators as to the impacts of particular policies on system performance.

OST is being designed to allow and encourage operators and managers to test the implications of modifying existing rules and system assumptions. OST does not control how operators/managers proceed, but rather it provides data based on realistic simulations that can help guide development of successful operating policies/decisions necessary to achieve short-term and/or long-term objectives. Standard performance criteria for a given simulation are automatically generated by OST, and the user can create additional performance criteria and displays as desired.

The concept for OST was identified in the CTCP as the most effective and cost-effective method of controlling turbidity for the Catskill System. OST is being developed as part of the overall program to sustain the City's FAD, as well as comply with the SPDES permit parameters for turbidity and temperature of diversions from Schoharie Reservoir into the Esopus Creek. Under the Catskill Turbidity Control Study (Gannett Fleming/Hazen & Sawyer, 2009; Gannett Fleming/Hazen & Sawyer, 2008), the City evaluated a range of structural and operational alternatives for (a) improving control over turbidity and temperature levels in diversions from Schoharie Reservoir into Esopus Creek, and (b) reducing the frequency of alum treatment at Kensico Reservoir subsequent to major storm events. The key finding of this multi-phase study was that modification of reservoir operations could provide substantial improvements to Catskill water quality, provided the City was equipped with robust monitoring and analytical tools to provide near-real time operational guidance.

Though the genesis of OST was in Catskill turbidity issues, OST will provide multiple benefits to the City throughout the water supply system. OST will provide City operations staff with the analytical guidance necessary to operate the complex New York City reservoir system and strike a balance between multiple objectives – water supply reliability, water quality goals, environmental concerns, downstream objectives, and treatment/ pumping costs. This is particularly important as numerous planned system improvements (e.g., Croton Water Filtration Plant, Catskill/Delaware Ultra Violet Disinfection Facility, Catskill-Delaware Shaft 4 Connection) are brought on-line in the coming years. OST will also provide a robust analytical basis for supporting and documenting the City's operational decisions.

2. Operations Support Tool Components

OST builds upon the New York City OASIS-W2 model, an analytical tool developed to meet the objectives of the Catskill Turbidity Control Study and designed for use primarily by modelers and engineers. In virtually all cases the functionalities of the existing model and the underlying OASIS software will be preserved in OST. However, OST represents a major overhaul and advancement of the OASIS-W2 model, itself an upgrade of the City's previous system models.

The OASIS-W2 linked model combined the OASIS model for the Delaware River Basin (developed for and used by the DRBC) and the City's previous OASIS model, resulting in a more robust tool that accounts for the impacts of the lower Delaware Basin needs with New York City operations, and vice-versa. It further included water quality models for Schoharie, Ashokan, and Kensico Reservoir to account for the impacts of Catskill turbidity on system operations, and vice-versa. Thus, New York City's approach to the use of system models to guide management decisions has proceeded in a step-wise manner, with each step adding complexity and providing an improved tool overall. OST will continue this step-wise approach, with intermediate upgraded functionality along the way to final deployment of OST.

The conversion from the existing desktop analytical tool to a near-real time and forecast data-driven operations support system serving multiple users represents a fundamental shift in the tool's overall functionality. As such, this project is much more than a set of incremental enhancements to the OASIS-W2 model, and is rather a complete overhaul to effectively convert the tool to its new purpose. Major modifications include (Figure 2-1):

- Providing connectivity with a large array of near real-time system operations, water quality, and environmental data;
- Developing and incorporating near real-time National Weather Service and statistical ensemble inflow forecasts;
- Designing a completely new interface to make the tool accessible to multiple City user groups with diverse needs and technical skills;
- Improving model post-processing capabilities for easier and more powerful data analysis and presentation; and
- Developing a database to store and manage multiple data sets from multiple users, and deploying OST across the City's network.

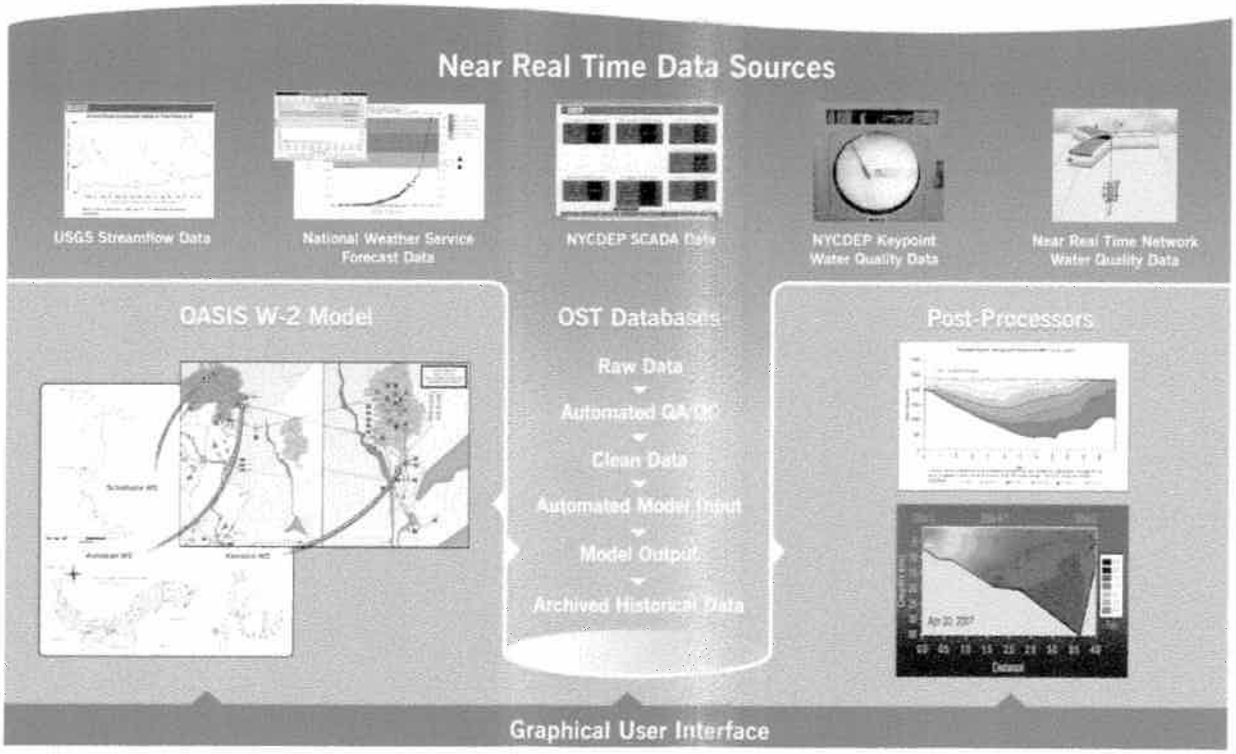

Figure 2-1: Major OST Components

Key features of OST data acquisition utilities and the OASIS and W2 models are described in the following sections, followed by descriptions of the underlying OASIS and W2 models and the post-processing and reporting capabilities of OST. Because of their complexity and importance in OST, the forecasts are described separately in Section 3.

2.1. OASIS Model

OASIS is a generalized computer program for modeling the operation of water resources systems (HydroLogics, Inc., 2007). OASIS represents a system using nodes (reservoirs, junctions) and arcs (aqueducts, streams) and uses linear programming optimization to simulate water routing decisions (e.g., reservoir releases or diversions) in the system, subject to both human operating rules and physical constraints. The OASIS model of the City's reservoir system simulates daily operations throughout the entire system and the Delaware River Basin (Figure 2-2).

OASIS is a simulation model and simulates the system as the user has defined it, including demand level, infrastructure scenario, and operating rules. In this way, the user can efficiently simulate several different operating scenarios and use the simulation results to evaluate the best course of action based on the chosen performance criteria.

Major components of the OASIS model include reservoir inflows, consumptive demands, system physical data, and operating rules. These components are described in the following sections.

2.1.1. Inflows

In OASIS, inflow to a reservoir represents the local inflow to that reservoir, not including flows from upstream reservoirs. Flows between reservoirs are based on release and diversion decisions made by the model, while the local inflow is a daily time series representing possible future hydrologic conditions. Future inflows can be represented by historical hydrology, statistically based forecasts, or climatologically based forecasts. In addition, synthetic inflows can be used to drive the model, as for example, in sensitivity studies evaluating the potential impacts of increasing flows under climate change scenarios. The inflow options included in OST are discussed in more detail in Section 3.

2.1.2. Demands

Demands in the OASIS model include both New York City and outside community (OC) demands. New York City demand is withdrawn from the model via one demand node downstream of Hillview and Jerome Park Reservoirs. OC demands on the New York City system are aggregated into 12 different demand nodes, each drawing from the reservoir or aqueduct reach from which they are served.

Demands are modeled as recurring annual patterns throughout the simulation period. The annual patterns consist of constant values for each month. Demand in a given month is calculated as the product of the annual average demand level and a monthly peaking factor. Default monthly peaking factors for New York City and each OC demand are currently based on historical data from 1987 through 2005. Annual average New York City and OC demands are specified by the user.

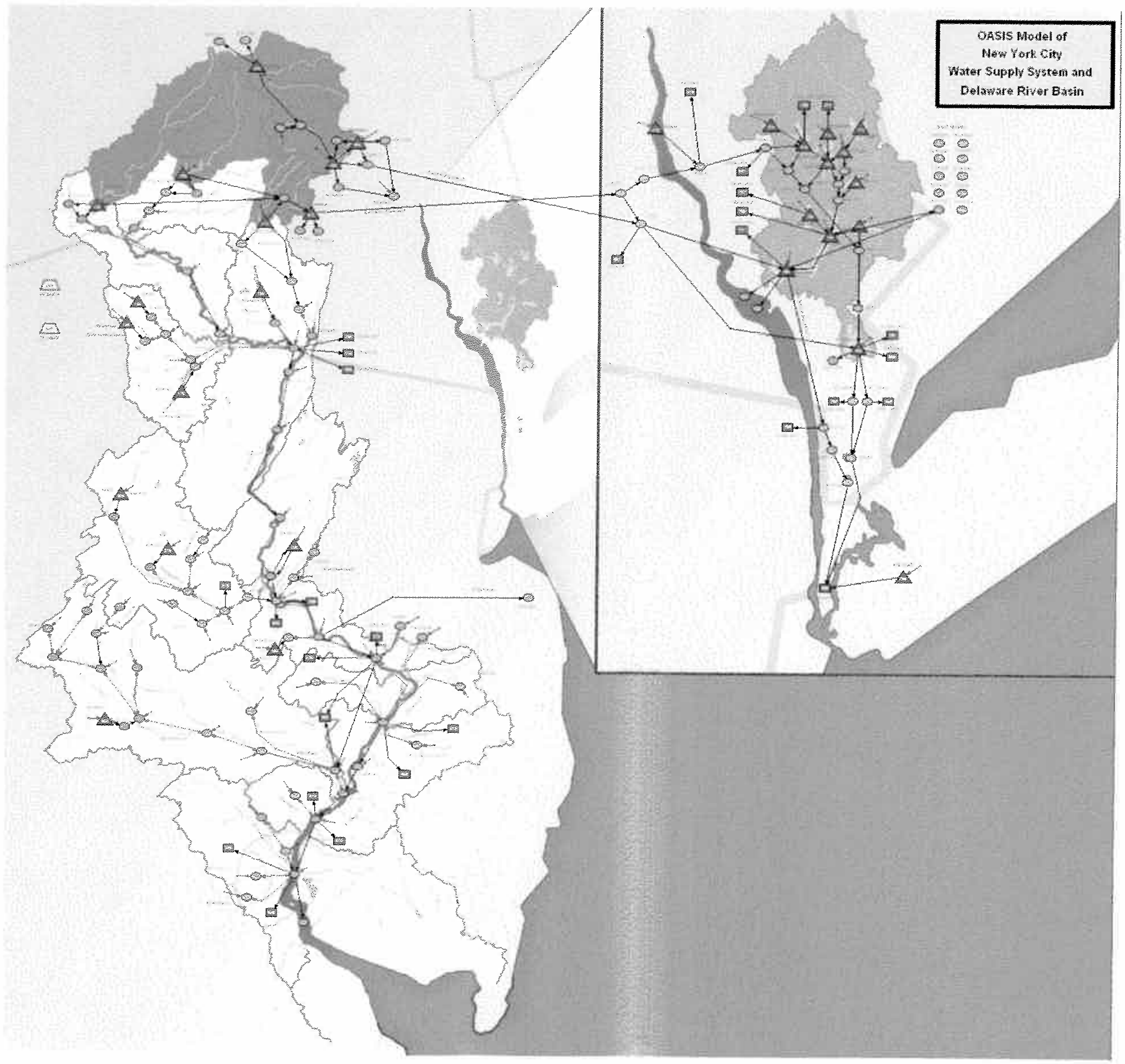

Figure 2-2: New York City OASIS Model Schematic

2.1.3. System Physical Data

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). Prior to deployment of the final version of OST, a comprehensive review of system physical data will be conducted.

2.1.4. Operating Rules

The OASIS model, through its operations control language (OCL), is able to be coded to simulate any number of operational requirements, procedures, or constraints. Default rules include:

- Diversion rules for the Delaware, Catskill, and Croton Systems to account for: turbidity conditions in the Catskill System; forecasted inflows in all three systems and associated probabilities of refill; and Croton system operating logic under either pre- or post-Croton filtration scenarios.
- Alum addition rules at Kensico Reservoir
- Release requirements for New York City reservoirs
  - Croton system (per requirements in NYSDEC Part 672-3)
  - Schoharie Reservoir (per requirements in NYSDEC Part 670 and the Shandaken SPDES Permit)
  - Rondout Reservoir (per requirements in NYSDEC Part 672-2)
  - Cannonsville, Pepacton, and Neversink Reservoirs (per the current FFMP). These rules in the OASIS model reflect provisions which are intended to adaptively manage releases from Cannonsville, Pepacton, and Neversink to meet multiple objectives (e.g., water supply, drought and spill mitigation, tailwaters fishery protection, and habitat needs, recreation).[2] Other rule sets can also be simulated.
- Release and diversion requirements for lower Delaware River reservoirs (Beltsville, Blue Marsh, Nockamixon, and Merrill Creek) per current DRBC rules. Alternative rules can be simulated.

The OASIS model is fully capable of simulating any combination of rules for the system. As such, the model is not limited to the current set of rules and can be modified to add alternate rules for testing or comparison of proposed operating policies. As future operating rules are developed and codified, they will be added to OST.

2.2. W2 Water Quality Models

Two-dimensional water quality models of Schoharie Reservoir, the West and East Basins of Ashokan Reservoir, and Kensico Reservoir were developed by the Upstate Freshwater Institute (UFI). These models are based on CE-QUAL-W2 (W2), a dynamic, laterally averaged, two-dimensional (longitudinal-vertical) hydrothermal/transport model developed by the Army Corps of Engineers(Cole & Wells, 2006). In addition to the underlying fluid motion and mass transport framework, the Catskill W2 models include a three particle size class turbidity submodel that simulates the fate and transport of turbidity in the reservoirs, and accounts for both settling and resuspension processes. Specification of model coefficients and model testing for the Catskill W2 models is supported by process studies and by extensive, temporally and spatially detailed, in-reservoir automated and event-based water quality monitoring.

[2] Agreement of the Parties to the 1954 U.S. Supreme Court Decree (Provisional) (9/27/07).

2.3. OASIS/W2 Linkages

W2 models for Schoharie, West and East Basins of Ashokan, and Kensico Reservoirs have been linked as external modules to the OASIS model. The water quality models run in parallel with OASIS, such that for each simulation day, the W2 models simulated one day of reservoir water quality before OASIS continues on to the next simulation day. In this way, OASIS-simulated water supply decisions are informed by the simulated water quality and vice-versa. Therefore, the linked water supply – water quality model is able to simulate the feedback between reservoir operations (e.g., diversion and release decisions) and water quality for the Catskill System and Kensico Reservoir.

Furthermore, each of the four W2 modules provides dynamic feedback to the other modules. For example, the W2-predicted turbidity and temperature levels in Schoharie diversions via the Shandaken Tunnel become inputs to the Ashokan West Basin W2 module; likewise, turbidity loads leaving the West Basin over the Dividing Weir spillway or through the Dividing Weir gates are inputs to the East Basin W2 module. Thus, the combined OASIS/W2 model incorporates realistic, relevant water quality information into operations for reservoirs in the Croton, Catskill, and Delaware basins that cannot be simulated with simplistic tools.

2.4. Data Sources, Data Acquisition, Data Scrubbing and Water Information Systems Kisters (WISKI) Integration

OST relies upon near real-time system data from a variety of internal and external sources to drive the underlying OASIS water supply and W2 water quality models. These data must be acquired from the appropriate sources, run through QA/QC routines, and stored within reach of OST modules. The following sections describe data sources and data acquisition/scrubbing routines. In addition, OST will ultimately be integrated with the data management architecture currently being developed for the City under the WISKI framework (Kisters North America, Citrus Heights, CA; www.kisters.net).

2.4.1. Data Sources

2.4.1.1. USGS Data

The USGS maintains a network of continuously telemetrically monitored gaging stations to measure surface elevations and associated flow rates for many streams in the New York City watershed and the Delaware Basin. OST will automatically acquire stream flow data for gaging stations that are primary to the core requirements of the model and stations that could provide proxy values should primary stations become unavailable.

2.4.1.2. National Weather Service Forecast Data

Ultimately, inflows for OST operations support runs will be based on long-term ensemble streamflow forecasts provided by the NWS, using basin rainfall-runoff models that either exist or are developed under OST. When fully implemented, NWS ensemble forecasts and associated hindcasts will be acquired by OST via File Transfer Protocol (FTP), Secure File Transfer Protocol (SFTP), or Local Data Manager (LDM) protocol and subjected to automated bias correction and mapping/scaling functions within OST.

The meteorological drivers for the water quality models (air temperature, dew point temperature, wind speed, wind direction, cloud cover, solar radiation) will also be informed by NWS surface weather forecasts. Additional post-processing functions within OST will convert NWS surface weather forecast products into the necessary water quality meteorological model drivers.

2.4.1.3. SCADA Data

The City operates and maintains an automated reservoir and transmission system supervisory control and data acquisition (SCADA) system to support system monitoring and control. The SCADA system provides real-time monitoring of remote facilities and sensors and electronically archives associated data.

2.4.1.4. New York City Keypoint Water Quality Data

The City monitors selected water quality parameters at critical locations within the water supply system through its Keypoint Monitoring Program. Some data are collected as grab-samples and analyzed in a laboratory while others are collected using automated monitoring equipment and are transmitted continuously.

Keypoint data are currently generated and managed separately for East of Hudson (EOH) and West of Hudson (WOH) operations. EOH turbidities are monitored telemetrically and are viewed and archived through a dedicated SCADA/Historian system. Once collected and archived, turbidity data are managed and distributed using a WISKI data management system. WOH turbidities are monitored telemetrically via the WOH SCADA/Historian system, with the data being available in real time to water supply operators in the Water Supply Control Center and archived for future use.

2.4.1.5. Near Real Time Network Water Quality Data

Under terms of a contract with the City, the Upstate Freshwater Institute (UFI; Syracuse, NY) operates in-reservoir sampling buoys at selected reservoirs to support water quality modeling and the City's operational efforts. The buoys measure turbidity, temperature, conductivity and dissolved oxygen at 1 meter intervals from the water surface to the near bottom. Additional automated sampling instruments measure temperature, conductivity and turbidity at major reservoir inflow points.

Data from both reservoir and stream sites are currently collected by UFI telemetrically, subjected to a QA/QC evaluation and distributed via FTP.

2.4.1.6. New York City Meteorological (Met) Station and Snow Pillow Data

Meteorological and snow pillow data are collected by the City from its own distributed network of weather stations. Data are transmitted telemetrically using radio telemetry to base stations at five City facilities in the New York City watersheds, and then retransmitted to a server in Grahamsville via the City's local area network (LAN) where they are compiled and archived.

2.4.1.7. New York City Laboratory Water Quality Data

Laboratory data associated with both keypoint and reservoir grab-sampling are processed and managed through the City's Laboratory Information Management System (LIMS). Daily water quality reports can be distributed though a very flexible Web Services module associated with the LIMS application. Water quality data for OST model initialization and limnological data for backup to UFI NRT data, will be obtained automatically through the LIMS Web interface.

2.4.1.8. Manual Data

Currently, EOH operations data (reservoir elevation, instantaneous and totalized flow) at reservoirs upstream of New Croton are logged weekly by operations staff from observations of local devices typically located at reservoir gate houses. Hand-logged reservoir surface elevation and outflow data from reservoirs upstream of Croton will, in the near term, be summarized in a daily report in delimited file format and transmitted to WOH operations for publishing to an FTP site along with WOH operational data.

The City has begun a project that will implement a fully functional SCADA system for monitoring key EOH reservoir and water transmission system variables. At present, New Croton Reservoir is the only site integrated into this SCADA system. It is expected that all EOH reservoirs, including Kensico Reservoir, will be monitored from the EOH SCADA servers.

WOH operations data (reservoir elevation, instantaneous and totalized flow) are typically logged weekly and are used to assist in quality control of automated SCADA monitoring functions.

2.4.2. Data Acquisition and the WISKI Framework

Kisters' WISKI data management platform provides an interface to diverse water management data sources including databases, a variety of sensor technology, and manual entry from field personnel. The City's selection of WISKI followed an evaluation of numerous water quality and flow time series data management software packages. The City has been using WISKI since 2006 to manage EOH hydrology time series data (stream gages, flow and rating curves, weather station data and USGS data). OST will be integrated with WISKI as an existing, common platform for storing system data.

WISKI is not a SCADA system, in that equipment is not controlled through WISKI. It is a time series data management, acquisition and visualization tool. The provisional goal is to implement data acquisition solutions for all OST data sources within the WISKI framework. The solutions may include direct connectivity with the City's SCADA systems as well as direct import of time series data from non-City sources, e.g. NWS, USGS, etc.

WISKI further provides a calculation framework for the implementation of automated QA/QC data scrubbing routines specific to each of the above listed data sources. Unless otherwise required, these routines will execute daily. Email alerts may be sent to designated City staff when manual inspection / data completion is required for one or more OST data sources.

2.5. Post-processing / Reporting

OST will support the City's need to routinely prepare reports and documentation for both internal and external usage. OST will archive a substantial body of operations, water quality, and environmental data. OST will provide the City's users with the ability to interact with these data via built-in tables, plots, and reports, or retrieve the data and export to common data processing software (e.g. MS Excel). Example reports could include daily system operations summaries, monthly Shandaken SPDES Permit reports, and turbidity after-action reports. OST will also generate system summary data suitable for inclusion on the City's website or other venues for disseminating information to the public and/or stakeholder agencies.

Reports and documentation will be customizable to meet the needs of the City and other stakeholders. The City expects to consult with other Decree Parties in developing outputs for use in describing, presenting, and evaluating the results of proposed near-term and long-term operations.

3. Use of Forecasts in OST

In order to ensure overall water supply reliability, the City's operators and managers must understand the risks and uncertainties associated with operating decisions. Probabilistic streamflow (reservoir inflow) forecasts are critical in helping to quantify those risks. In addition, streamflow forecasts will aid water managers in developing robust long-term operating rules for the New York City system.

This section introduces and describes the probabilistic streamflow forecasts to be incorporated into OST, and presents an outline for how the forecasts will be utilized within OST framework. There are essentially two types of forecasts that will be included in OST: (1) forecasts based solely on historical streamflow observations (Section 3.2) and (2) forecasts based on a combination of historical information, estimates of current meteorologic, hydrologic and climatic conditions, and meteorological forecast information (Section 3.3).

3.1. Utilizing Forecasts in OST

In OST, forecasts will be used to inform real-time day-to-day operating decisions and to evaluate the near-term (up to a year) expected benefits of alternative operating rules and policies.

3.1.1. Real-time Operations Decisions

The use of probabilistic inflow forecasts allows the user to assess the risks and uncertainties associated with operating decisions. Should the level of risk be undesirable, the City can then use OST to assess options that may better manage the risk at hand. A flow chart detailing the real-time operation decision making process is presented in Figure 3-1.

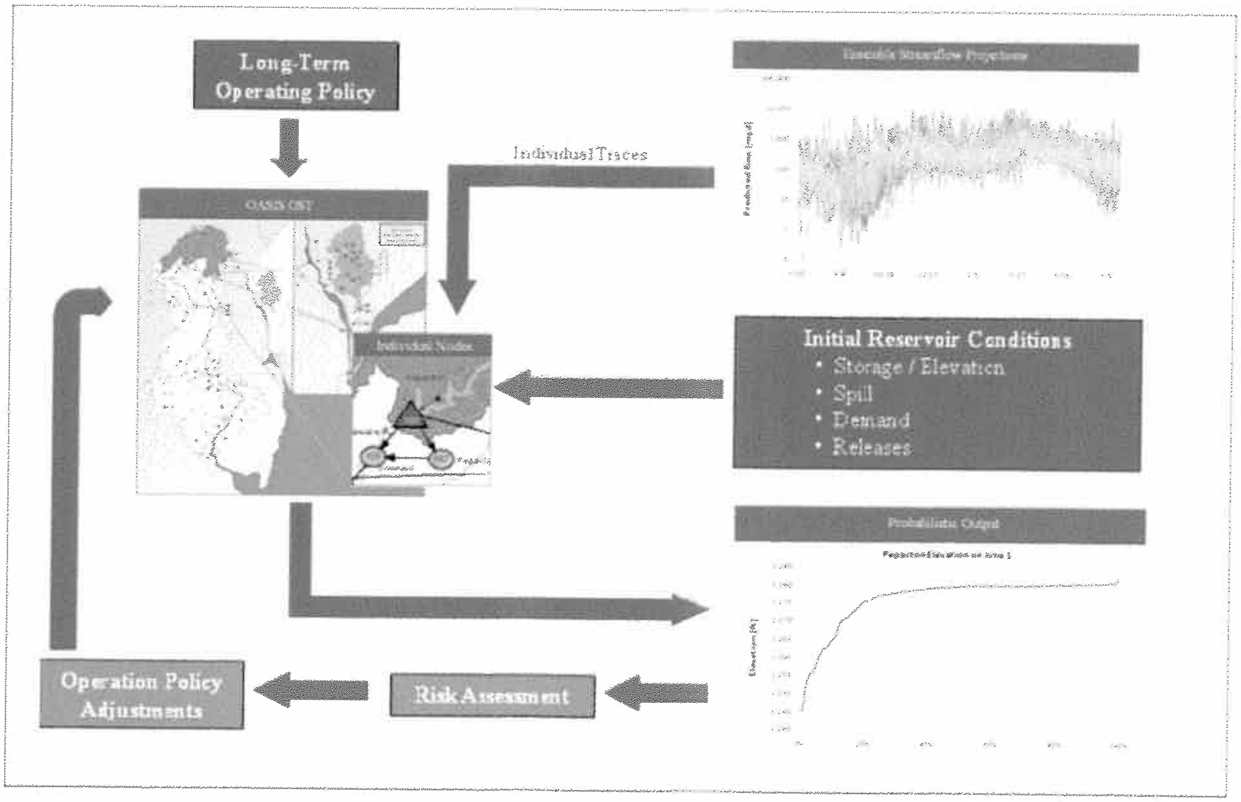

Figure 3-1: Flow Chart of Simulation for Real-time Operations

When making real-time operating decisions, water managers will use OST in Position Analysis (PA) mode (see Section 4). PA involves multiple simulations of potential operations over a future period (several weeks to a year). Each simulation starts with the system at its current state (current reservoir elevations, current water quality, etc.), but uses a different projection of future inflows and other important system drivers.

Each individual projection consists of a set of time series of future values (a "trace") for each and every driver. The set of projections used in PA mode is called an ensemble, and the members of the ensemble (the individual projections) are be generated such that each has an equal likelihood of occurrence.

Each of the projections is simulated independently starting with the current system state. Each of the simulations generates a single value for any parameter of interest (e.g. system storage) on any date (e.g. June 1) within the simulation horizon (a week to a year). The values of a parameter/date combination over all the simulations define points on a predicted probability distribution for that parameter on that date (e.g. the probability distribution of the value of system storage on June 1). These distributions quantify the uncertainty of future reservoir and system states and help managers judge the risk associated with the simulated operation.

Because initial storage conditions are near certain and demands are more or less static in the short-term, most of the uncertainty inherent in these questions is caused by the uncertainty about the volume of future streamflow into the system. Probabilistic streamflow forecasts utilized in OST position analysis will make it possible to quantify this uncertainty. Using OST, the water manager can utilize these forecasts and adjust operational decisions to reduce the risk of not meeting one or more system objectives (e.g. supply reliability, water quality, environmental flows, economic assessments, etc.).

3.1.2. Developing Long-Term Operating Rules

In addition to assisting in short-term operational decisions, forecasts will be needed to help managers develop robust long-term operating rules. Long-term operating rules are fundamentally different from short-term operational decisions. Long-term operating rules can be described as fixed rules that will best manage the system under a specific set of real-time information (e.g. reservoir levels, demand levels, stream inflows, release requirements, meteorological and hydrologic forecasts, etc). Short-term operating decisions that differ from the long term rules can be classified as "adjustments." Adjustments are desirable because they allow operators to use their judgment, their knowledge of the system, and additional, real-time information about current conditions to continuously improve system performance above and beyond what might be achieved by strictly following set rules. Long-term operating rules set the benchmark against which adjustments are evaluated, and the better the long-term rules, the better the overall system performance.

Over a number of previous studies of the New York City system, a set of preliminary long-term rules has been developed for the current OASIS-W2 model.[3] However, the current long term rules do not use forecast information. This is because historical forecasts (hindcasts) are currently not available, so it is impossible to simulate the performance of rules that used forecasts (forecasts could not be a part of the information available to the rule). Hindcasts will be available as a part of OST, and thus, OST can be used to develop better long term rules that use the forecast information that will be available to operators in real-time.

When setting long-term operating rules, OST is operated in "Simulation" mode rather than PA mode. In Simulation mode, operating rules can be developed and evaluated by analyzing their

[3] Note that these rules are relatively informal and were designed to reflect current City policies. Part of OST development process will focus on review of these operations. In addition, it is expected that these rules will evolve over time as the City uses OST to improve operations where appropriate.

performance[4] over the entire length of the historical hydrologic record. A critical part of the long-term operating rule design involves developing ways in which managers *could* use reservoir inflow and other forecasts to enhance operating performance. OST simulation runs will have access to the hindcasts required to simulate the performance of forecast-based rules over the historical hydrologic record.

Long-term operating rule development using Simulation mode can be illustrated using June 1st system refill as an example. For water supply reliability, all of the major sub-systems should be near full by roughly June 1st of each year (start of the drawdown season). In order to support this goal, there should be robust baseline operating rules that have been validated over a long period of time under the range of potential hydrologic drivers. In Simulation mode, managers can use hindcasts and the historical record to develop, test, and standardize operating rules that increase refill probability for June 1st.

3.1.3. Forecast Selection and OST Flexibility

The final build of OST will be an extremely flexible tool in terms of forecast selection. Currently, OST allows the user to select between historical and conditional Hirsch forecasts (see Sections 3.2.1 and 3.2.2.1, respectively). However, as more forecast products become available, the user will be able to choose between the traditional Hirsch forecasts, extended daily Hirsch forecasts (Section 3.2.2.2), and the National Weather Service (NWS) ensemble hydrologic forecasts (Section 2.4.1.2).

3.2. Stochastic Forecasts Based on Historical Hydrologic Observations

Currently, the forecasts that are available as inputs to OST are statistical in nature and are based solely on historical streamflow observations. The two methods included in OST include these historical "forecasts" and conditional Hirsch forecasts, originally described by Hirsch (Hirsch, 1979) (Hirsch, 1981).

3.2.1. Historical Observations

Use of historical data to define the potential range of future inflows is the simplest forecasting technique utilized for OST. The method assembles an ensemble using the historic daily inflow time series beginning from a user-defined start date extending over a period of the user's choice. For example, the historical record of daily inflows to Pepacton Reservoir has been developed for the period October 1927 through September 2008. Assume the water manager wishes to generate a forecast from today's date (say, July 13th) out to 1 year in the future. The inflow ensemble will consist of 80 projections[5], each extending from July 13th through July 12th of the following year

[4] Operating rule performance is typically evaluated based on performance metrics defined by water managers. Often the performance metrics are aggregated over the entire simulation.

[5] The 80 projections correspond with the 80 unique years in the period of record. For example, in this instance, the first flow projection will consist of the Pepacton inflows from July 13, 1928 to July, 12, 1929. The second projection

(Figure 3-2). Each projection in the ensemble is assumed to have an equally likely chance of occurring in the future. Essentially, this method assumes that future inflows for a given time of year can be represented by the range of past inflows for the same relative time of year. In this method, the projections do not take into account current or recent hydrologic or meteorologic conditions.

3.2.2. Conditional Forecasts

Conditional Hirsch forecast ensembles are generated using a stochastic model based on the historical record conditioned on recent observed flows (Hirsch, 1981). Conditional Hirsch forecasts can be generated using monthly data or daily data (extended Hirsch).

3.2.2.1. Monthly Forecast Algorithm

At the monthly time scale, streamflows often exhibit serial correlation (essentially, monthly streamflow can be imagined as the continuation of the current hydrologic trend). This "memory" is commonly attributed to month-to-month persistence in baseflow and/or soil moisture. According to Hirsch (1981), this serial correlation allows for the generation of monthly streamflow forecast ensembles based on flows from the preceding month and the application of random noise. Generally, this serial correlation allows for forecasts with tighter distributions (less variance and uncertainty) when compared to the historical method presented in the last section. This means that the forecasts reflect more forecast skill. The monthly conditional Hirsch forecasts used in OST utilize this assumption.

will consist of inflows from July 13, 1929 to July, 12, 1930. The final (80^{th}) projection will consist of inflows from July 13, 2007 to July, 12, 2008.

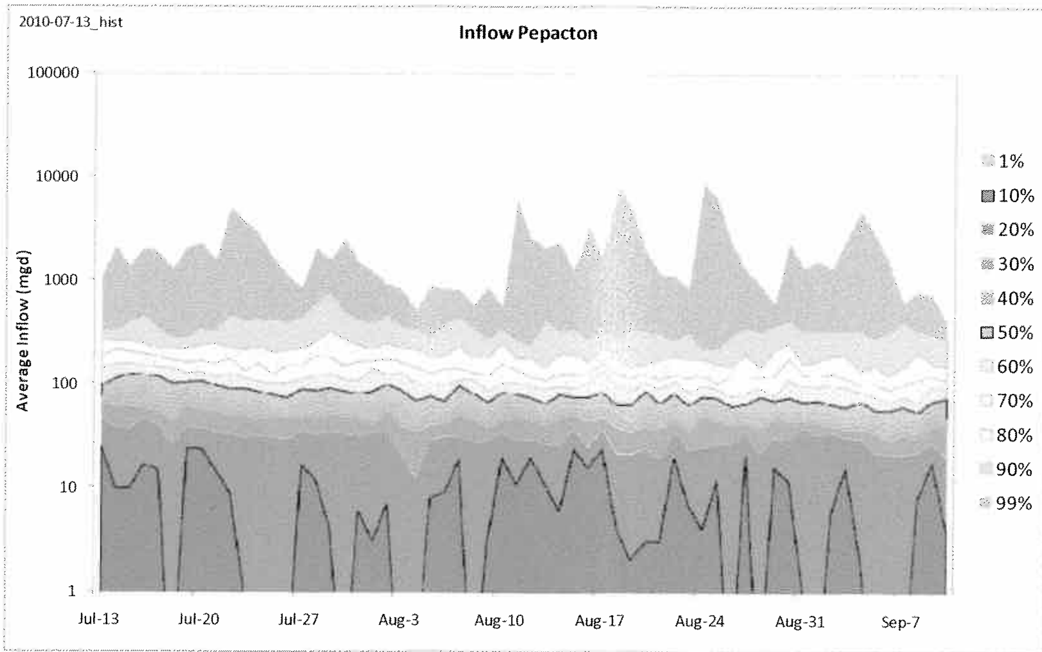

Figure 3-2: Range of Historical Inflows for Pepacton Reservoir (July 13 – September 10)

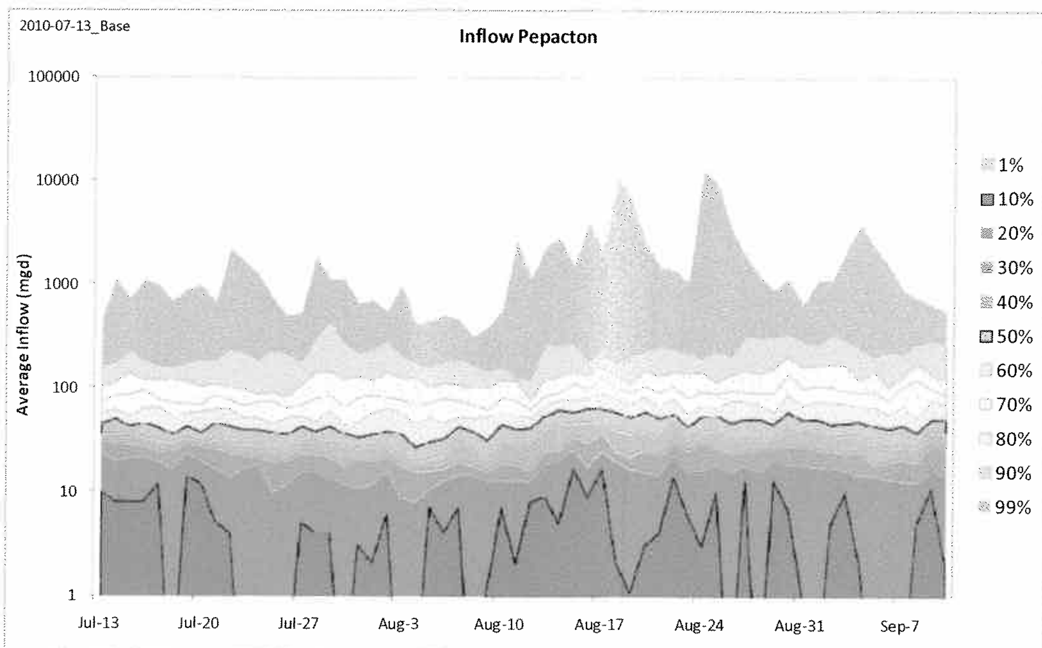

Figure 3-3: Example Inflow Forecast for Pepacton Reservoir using the Historical Hirsch Forecast Algorithm with a July 13th Forecast Start Date and a 1-year Forecast Horizon

An example inflow forecast for Pepacton Reservoir using the conditional monthly Hirsch forecast algorithm with a June 29th forecast start date and a one year forecast horizon is shown in Figure 3-3. Note that the conditional forecasts (Figure 3-3) are lower than the historical flows (Figure 3-2), reflecting the fact that the recent conditions leading up to the forecast date were drier than normal. Further, the lower and higher percentiles of the forecast are slightly closer to the median (lower variance) when compared to the historical forecast data in Figure 3-2.

3.2.2.2. *Extended Daily Hirsch Method*

An extended daily version of the conditional Hirsch forecasting scheme is currently under development. The conceptual design is similar to the monthly forecast algorithm in that it will also have random components derived from historical data to preserve joint relationships among inflow forecasts to different reservoirs. The extended daily version is expected to improve the forecast skill compared to the monthly algorithm, especially in the initial days/weeks following the forecast date.

The stochastic Hirsch forecasts have a number of strengths that recommend their use in OST. First, these forecasts are a relatively simple way to generate probabilistic streamflow forecast ensembles and they are available for use immediately. From an accuracy standpoint, both the historical and conditional Hirsch forecasts have relatively good skill over long forecast horizons (months to a year) since they preserve the month-to-month serial correlations[6]. For forecast lead times less than a month, the forecast skill diminishes for both the historical and conditional methods; however, on average the conditional forecasts will perform better than the historical since they are conditioned on the previous month's observed flows.

While Hirsch forecasts are a simple and versatile method for developing ensemble inflow forecasts for OST, it should be noted that they do not incorporate any climate or meteorological information. This has the largest consequences for operating decisions having a short forecast horizon (days to weeks). Over days to weeks subsequent to an initial forecast date, concurrent meteorological information (e.g. precipitation, humidity, evapotranspiration) has a large effect on streamflow. Since the Hirsch method does not incorporate this meteorological signal, its short-term daily forecasts tend to lack skill. The extended daily method is expected to improve this weakness; however the extent of the benefit has not yet been quantified. The long-term plan for incorporating climate and meteorological data into OST is described below.

3.3. NWS Products for Climate/Meteorological Driven Forecasts

The City is currently cooperating with the National Weather Service (NWS) to share data and develop forecasting products to improve OST. The products produced by the NWS utilize climatological and meteorological information in conjunction with local hydrologic models to produce ensemble streamflow forecasts.

Currently, the NWS issues two types of weather-based streamflow forecasts that are utilized by the City on a qualitative basis. These products include single-value streamflow forecasts for the New York City system with 24 and 48 hour lead times, as well as 1 to 3 month average streamflow forecasts from the Advanced Hydrologic Prediction Service (AHPS). While these

[6] Since the historical Hirsch forecasts use purely historical data, serial correlation in the historical time series will be preserved.

forecast products are useful on a short-term qualitative basis, they lack the resolution and forecast length to be used quantitatively in OST. The NWS is currently in development of a new ensemble streamflow forecast system that will address these issues and allow quantitative evaluation.

The City has offered support to NWS to expedite the development of these new ensemble streamflow forecasts. At the time this white paper was released, NWS was actively evaluating how it could best expedite forecast development with New York City support. It is anticipated that an agreement will be in place by early 2011.

3.3.1. Anticipated Hydrologic Ensemble Forecasts

Like the current NWS forecast products described above, the anticipated ensemble forecasts are based on climate/meteorological information driven hydrologic forecast models. The anticipated ensemble forecasts will have a daily output and will predict inflows up to a year in advance. In this format, the anticipated ensemble forecasts can be directly entered as input to OST and may be used interchangeably with the Hirsch forecasts. A brief methodology describing how the NWS is expected to generate these forecasts followed by their strengths and weaknesses are presented below.

3.3.1.1. Brief Methodology

Before the NWS generates the ensemble hydrologic forecasts, it gathers atmospheric ensemble (precipitation, temperature, etc.) forecasts from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP). The NWS must "pre-process" these atmospheric forecasts to produce atmospheric forcing at the space and time scales of the hydrologic forecast models. This includes spatial and temporal downscaling[7], statistical model bias correction, and an analysis of model hindcasts together with corresponding observations to calibrate the pre-processing algorithms.

After the pre-processing is complete, the NWS hydrologic models are initialized with the current basin conditions and the atmospheric ensemble members are run through the hydrologic model one at a time, generating a hydrologic ensemble forecast. At this point, OST routines will "post-process" the NWS ensemble flow forecasts by correcting any statistical bias in the hydrologic model and will appropriately format the ensemble traces for input into OST. The post-processing step will also compensate for any differences between the flow variables predicted by the NWS and inflow variables required by OST (e.g. differences in drainage area). A flow chart illustrating the critical aspects of the forecast methodology is presented below in Figure 3-4.

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[7] NCEP's atmospheric forecast models used by the NWS, the Global Ensemble Forecast System (GEFS) and the Climate Forecast System (CFS), contain ensemble output at a relatively large, low-resolution spatial domain and time step. In order to be properly input to the NWS hydrologic models, the NCEP forecast ensembles must be "downscaled" from the default low-resolution output to a higher resolution.

The most important strength of the anticipated NWS hydrologic ensemble forecasts is that atmospheric forecasts and current hydrologic conditions are used to develop the predictions. Over short forecast horizons, the atmospheric and hydrologic drivers in the NWS forecasts will theoretically improve forecast skill compared to the Hirsch method. At long lead times, if climate predictions have skill, the NWS hydrologic ensembles should also improve upon the Hirsch forecast skill. However, again at long lead times, if no addition information is gained by climate forecasts, the hydrologic predictions will default to historic hydrology and should have similar skill to the Hirsch predictions.

Additionally, the NWS forecast ensembles have potential to provide ensemble hydrologic forecasts for future climate change scenarios. The NCEP atmospheric forecasts can be run using varying CO_2 and other greenhouse gas forcing scenarios which can be run in the NWS hydrologic models. These potential hydrologic scenarios could be run in OST simulation mode, and would be extremely valuable for developing long-term operating rules.

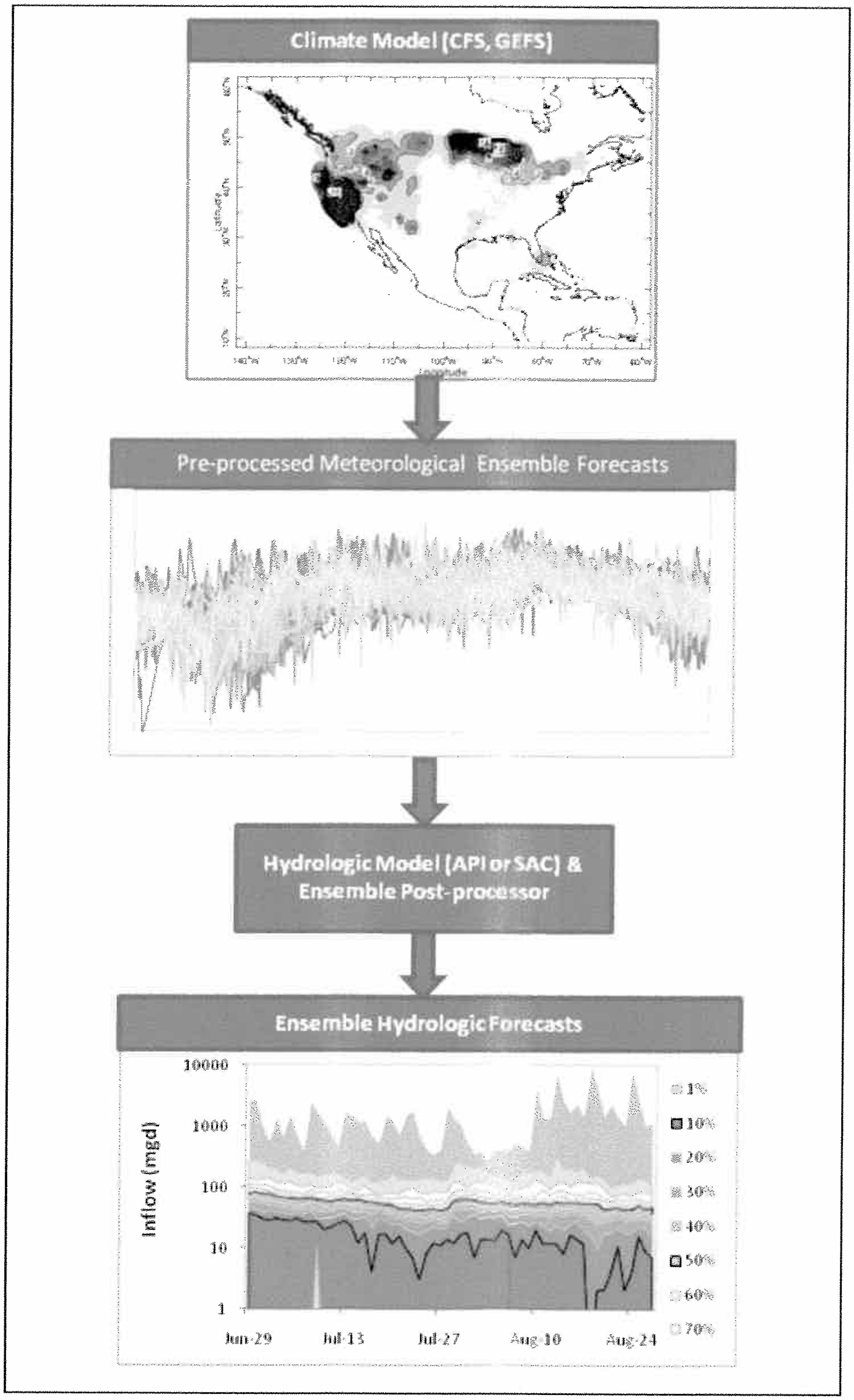

Figure 3-4: Flowchart Illustrating the Anticipated Generation of NWS Ensemble Hydrologic Forecasts

4. Operations Support Tool Usage

OST is an analytical tool for supporting the City's operators and managers in both short-term and long-term decision making. OST makes use of real-time system information (e.g. reservoir levels, streamflows) and forecasts (e.g. streamflows, meteorological drivers) to provide the City with objective, data-based decision support that will improve operations system-wide, including operation of the Delaware reservoirs and potentially in improving the Delaware release program.

The following sections describe the expected use cases for OST, with respect to the overall system (Section 4.1) and in the context of the Delaware Reservoir release program (Section 4.2).

4.1. OST Usage - General

There are two operating modes for OST, Position Analysis (PA) and Simulation (Sim) modes. PA mode generally is intended to support near-real time operations decision-making. PA simulations begin on today's date and look forward (days, months) using the forecasted inflow and meteorological drivers. All members of the forecast ensemble begin from the same set of initial system conditions, which would include today's reservoir storage levels, recent streamflows, etc. Typically, these PA simulations might include a "baseline" operations scenario plus one or more scenarios representing alternate operating rules. The impact of these alternate operations can then be evaluated based on system performance measures.

In contrast, rather than running an ensemble of forecasts for a short period of time (i.e. less than one year), Sim mode consists of a single long-term (e.g. 80 years of historical hydrology for the New York City OST) simulation. This allows for evaluation of operating rules or infrastructure changes over a long-term basis and will typically be used for development/testing of long-term operating rules and for capital planning. In addition, Sim mode could be used to evaluate the sensitivity of system parameters to long-term hydrologic changes (e.g. climate change scenarios).

4.1.1. Operational Projections

System operators/managers will use OST to evaluate the potential status of the New York City water supply system for periods of up to roughly one year in the future under current and/or alternative operating policies. OST will allow operators to conduct such PA simulations using historical reservoir flows, Hirsch inflow forecasts, or National Weather Service (NWS) inflow forecasts.

OST will facilitate the rapid development of alternatives for testing and provide efficient and effective means of comparing the predicted results for the alternatives. The projections will specifically include both hydrologic and water quality parameters. The water quality analyses will be specifically targeted at evaluating filtration avoidance criteria and relevant in-stream water quality standards, including temperature and turbidity. OST will automatically archive all evaluations supporting operational decisions, and provide a means for capturing real-time and retrospective comments on the basis for decisions.

4.1.2. Refill Probability and Drought Risk Analysis

OST will enable system operators and managers to quickly and routinely conduct robust refill probability analyses using PA mode. OST will automatically access ensemble inflow forecasts that take into account current basin conditions, and characterize the likely range of reservoir inflows over the coming months. Each of these forecasts is fed into the OASIS model, which then simulates operations – under realistic operating rules and release requirements – for the length of the planning period (e.g. until June 1). The results of the PA simulations can be interpreted to estimate the probability of refill by the following June 1. Operators will be able to conduct runs under baseline versus alternative operating rules, and thereby compare the potential impacts of near-term operational decisions on long-term supply reliability. In addition, OST will allow for estimation of the probability of reaching a low storage threshold at the height of the drawdown period that could trigger a drought response.

4.1.3. Outage Planning and Emergency Management

The problem of aging infrastructure is perhaps the greatest single challenge facing utilities nationwide, and New York City is no exception. Critical portions of the system will have to be taken off-line for planned repair/rehabilitation for extended periods of time without service interruptions, while minimizing any potential impact on public health and safety. In addition, as is the case for any utility, there is always the risk of unplanned infrastructure outages that require rapid decision-making to maintain system function. System managers and operators need to be able to assess the long and short-term risks associated with taking facilities off-line and be able to evaluate mitigation plans for these outages.

OST will support the City's efforts to prepare for planned outages of critical facilities. OST will allow operators to schedule a planned facility shutdown, test rules for balancing the system prior to the shutdown, and evaluate the probability that the system can sustain and recover from the shutdown without encountering low storage levels. OST will also support the City's efforts to rapidly respond to unplanned facility outages and water quality contamination events by allowing operators/managers to test alternative operations response and demand reduction strategies on-the-fly.

4.1.4. Operating Rule Development and Water Supply Planning

OST will provide the City with an analytical platform to conduct long-term planning analyses, evaluate and adopt formal system operating rules, and perform climate change impact assessments and other studies. All of the analytical capabilities of the New York City OASIS-W2 model that currently support long-term planning and rule-development applications will be preserved in OST. In addition, OST will provide planners with the ability to test operations based on Hirsch or NWS inflow forecasts. OST inflow database will include hindcasts that can be referenced to test such operating rules.

In testing potential long-term operating rules, the user would prepare several long-term simulations representing baseline or default operations as well as the alternative sets of operations to be tested. These simulations would be conducted using the historical inflows (e.g. using the 80-year record), allowing the user to evaluate the performance of each rule set over the range of hydrologic conditions represented by the historical record. Rules that would rely on inflow forecasts could be tested over the historical record using the hindcasts, which represent the forecasts that would have been available for each day in the record.

The user's ability to construct alternatives and compare runs will also be enhanced. Provision will be made to allow users to drive the underlying OASIS and W2 models with alternative hydrologic and meteorological scenarios. Hardware specifications for OST servers and databases will support intensive usage by modelers, planners, and system operators.

4.1.5. Climate Change Planning and Demand Management Studies

OST is driven by a set of reservoir inflows, which may be historical inflows, forecasted inflows, or some other time series of interest. Model simulations can be conducted with OST using inflow time series that represent flows under different climate change operations. This will allow the City to evaluate the probability of water supply and water quality challenges associated with climate change. For example, larger and more frequent storm events could increase the frequency and magnitude of turbidity events in the Catskill reservoirs, leading to the need for increased reliance on the Delaware supplies.

In addition, OST simulations can be used to evaluate the impacts of increased future demands, as the City's current projections indicate an increase of roughly 100 mgd by the year 2020. Scenarios can be developed to look at possible changes in operations, demand reduction strategies, and alternate supplies to mitigate increased demand.

4.1.6. New Infrastructure

A major function of OST will be to provide decision support for planning and utilization of new infrastructure, such as the Delaware Aqueduct Shaft 4 connection to the Catskill Aqueduct and the repair of the Rondout West Branch (RWB) Tunnel. When installing and repairing Aqueduct infrastructure, the tunnels need to be drained and kept dry until work is completed. In these instances, it is important to understand the risks to the system's water supply and water quality reliability. Using the ensemble streamflow forecasts, OST will assist in quantifying these risks.

OST will further assist operators in developing operating rules for optimum use of new infrastructure. For example, when the Delaware Aqueduct Shaft 4 connection is complete, the City may use OST to optimize its operation for turbidity control. Suppose the streamflow forecasts in the Catskill system are predicting a turbidity event in the coming week. The City can use OST to determine probability of the need for Catskill Aqueduct alum treatment based on the predicted turbidity at Kensico Reservoir. If the probability is sufficiently high, the City can use OST to determine the optimal amount of Delaware Water to transfer to the Catskill Aqueduct though Shaft 4 to decrease the probability of alum addition.

4.2. OST Usage in the context of the Delaware River Basin

OST is a robust platform for real-time operations that accounts for multiple objectives and system complexity in a way that static analyses (e.g. safe yield and table-based approaches) cannot. OST therefore is a platform that is well-suited for developing and testing release rules for the Delaware reservoirs. Initially, OST could be used to provide near term support for the FFMP program and ultimately, in association with a commitment to provide long term sustainable source(s) of water by the other Decree Parties, could form the basis for an enhanced future release program.

The following sections describe the potential role of OST in a DRB release program.

4.2.1. Conceptual Use of OST in DRB Release Program

As an example for illustration purposes, a current conditions PA simulation was conducted using OST to evaluate the potential for additional water available to make releases. The figures below show results from this simulation, including cumulative Pepacton, Cannonsville, Neversink (PCN) forecasted reservoir inflows (Figure 4-1), cumulative PCN diversion to Rondout Reservoir (Figure 4-2), cumulative PCN release to the Delaware Basin (Figure 4-3), and PCN usable storage fraction (Figure 4-4). The simulation runs from early August 2010 through mid-June 2011. The blue lines in the plots represent the 80 Hirsch forecast traces that represent the range of potential future inflows. The red, orange, and green lines represent the 10th, 50th, and 90th percentiles, respectively, for each simulation day.

In the early months of the simulation, the forecasted inflows are very tight, with more variability in the later months (Figure 4-1). The cumulative inflow for the entire simulation by June 15 ranges from ~200 BG to ~450 BG, demonstrating the uncertainty in future inflows. Diversions to meet New York City supply needs and releases to comply with the FFMP agreements vary as a function of the forecasted inflow trace (Figure 4-2 and Figure 4-3). The range of PCN storage levels in each trace is presented in Figure 4-4. By applying a different release schedule for the PCN reservoirs in OST, and then re-running the simulation, the impact of the new release schedule on probability of future storage could be evaluated. Such an analysis would allow comparison of cost and benefits of the new schedule across multiple objectives.

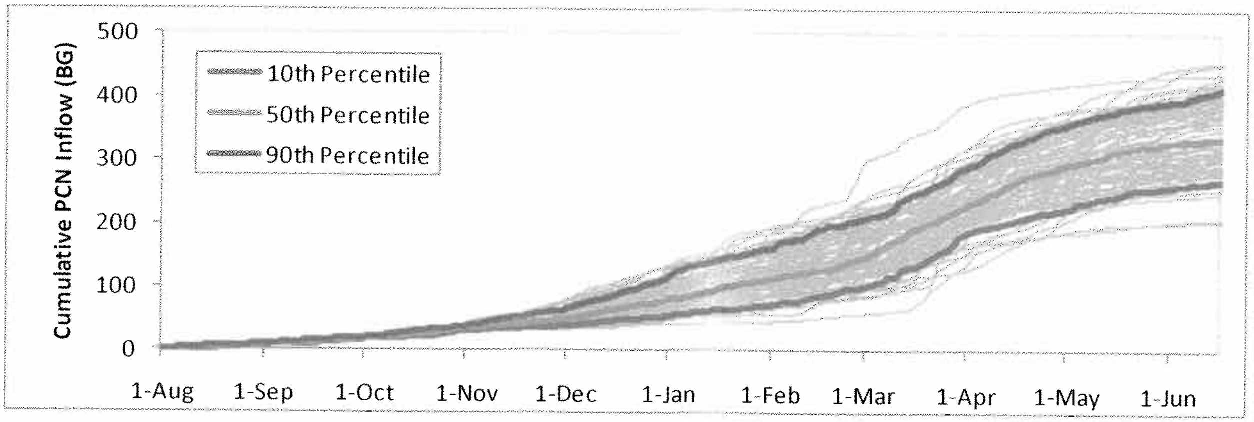

Figure 4-1: Example OST Simulation Results – Cumulative PCN Forecasted Inflow

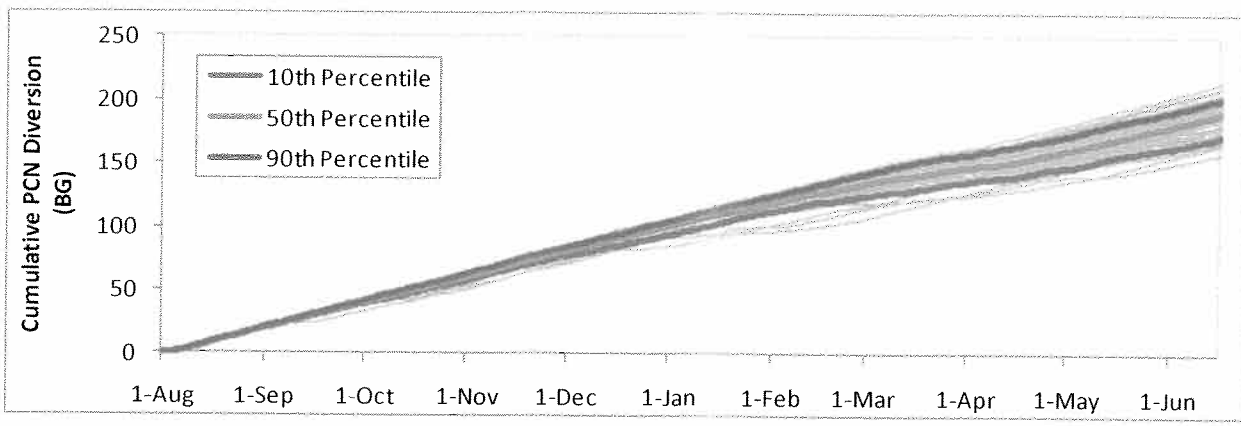

Figure 4-2: Example OST Simulation Results – Cumulative PCN Diversion to New York City

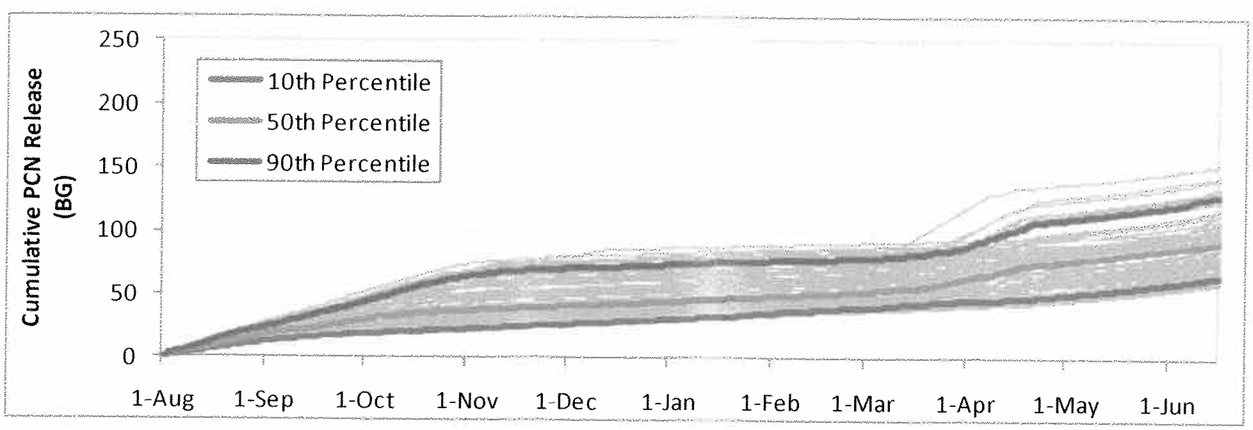

Figure 4-3: Example OST Simulation Results – Cumulative PCN Release to Delaware Basin

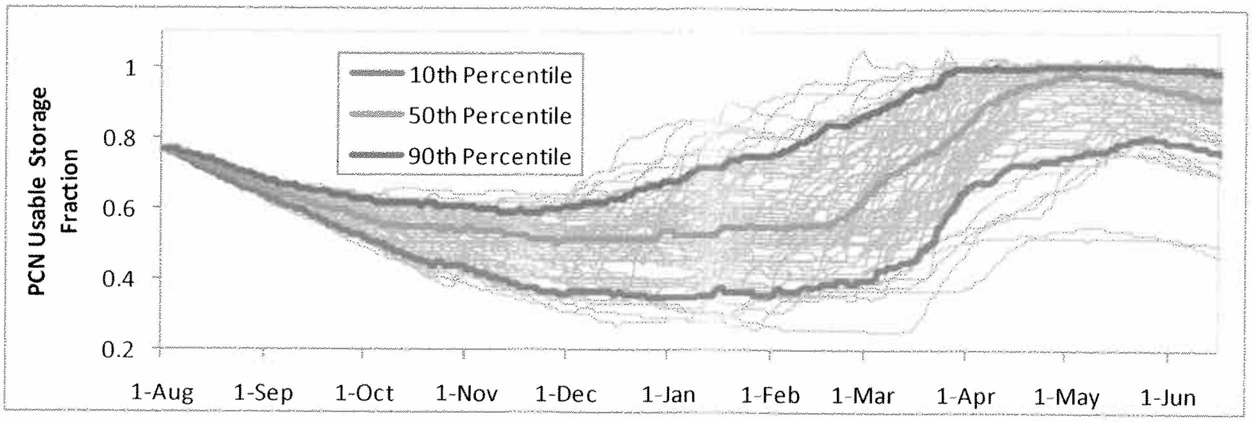

Figure 4-4: Example OST Simulation Results – PCN Usable Storage Fraction

4.2.2. OST in Support of the FFMP Agreement

OST can initially support releases under the current FFMP program by providing an analytical tool to evaluate the volume of water available for release. Since OST includes operating rules for the entire New York City System, it necessarily accounts for water quantity, water quality, economics, and other objectives throughout the system, providing a more realistic accounting of water and protecting water supply reliability objectives, such as ensuring refill prior to the start of the drawdown season.

Since OST relies on ensemble forecasts of possible future inflows, this approach would represent a risk-based approach, in which the risks of not meeting water supply and water quality objectives can be quantified. A risk-based approach would protect the nine million people who rely on the City's water supply system daily while helping to define a forecast-based excess release quantity of additional water from unallocated Delaware Basin storage that can be made available to meet enhanced Delaware Basin release objectives, given a commitment by the other Decree Party members to provide long-term, sustainable source(s) of water in the future. More generally, better system-wide operation with OST will protect the New York City supply and provide benefits to downstream basin stakeholders.

4.2.3. OST Use under Modified Release Plan

OST would further enable the DRB Decree Parties to develop enhanced FFMP programs (similar to the releases program suggested by Fisheries staff of NYS DEC and PA FBC in their Joint Fisheries White Paper (JFWP)) based on Decree Parties' commitment to long-term sustainability. OST enables sensitivity testing of alternative operating rules to variable system parameters (e.g. demand, infrastructure etc). Better system-wide operations with OST will ensure the City is able to meet its water supply needs and provide a great opportunity for enhanced fisheries habitat protection as well as enhancing the peak flow attenuation that the reservoirs already provide by modifying the reservoir releases on a regular basis.

The JFWP, submitted to the Decree Parties on January 12, 2010, calls for large reservoir releases, particularly from Neversink Reservoir. The proposal also results in increased drought days based on 35 mgd currently available for releases from the unused portion of the New York City diversion allocation of 800 mgd and violates the drought neutral criterion prescribed by the Decree Parties. The JFWP may require an additional 100 mgd to make it drought neutral.

Hence, the JFWP needs to be modified by reducing releases from all Delaware Reservoirs, especially from Neversink. The following three schedules are possible examples, for illustrative purposes, of enhanced releases with OST-based excess release quantities of 100 mgd, 75 mgd, or 50 mgd available (Table 4-1, Table 4-2, and Table 4-3, respectively). Adjustments in releases may be needed to ensure that the drought day criterion is not violated with these tables. These tables supplement the four schedules of releases with 35 mgd, 20 mgd, 10 mgd, or 0 mgd, in the current FFMP.

Release schedules would be determined using Figure 1 (Modified Delaware System Usable Combined Storage Rule Curves) and Figure 2 (New York City Delaware System Usable Individual Storage Rule Curves).

Figure 1 shows a split in the L2 storage zone into two subzones by a line 43 billion gallons above the L2 (Drought Watch) line. The subzone above the line shall be denoted L2-High, and the subzone below the line shall be denoted L2-Low. The remaining zones, L1, L3, L4 and L5 shall continue to be the same as in the current FFMP. Figure 2 defines three zones of reservoir-specific storage (L1-a, L1-b and L1-c) as is also in the current FFMP.

Figure 1
New York City Delaware System Usable Combined Storage Zones (Cannonsville, Pepacton, and Neversink Reservoirs)

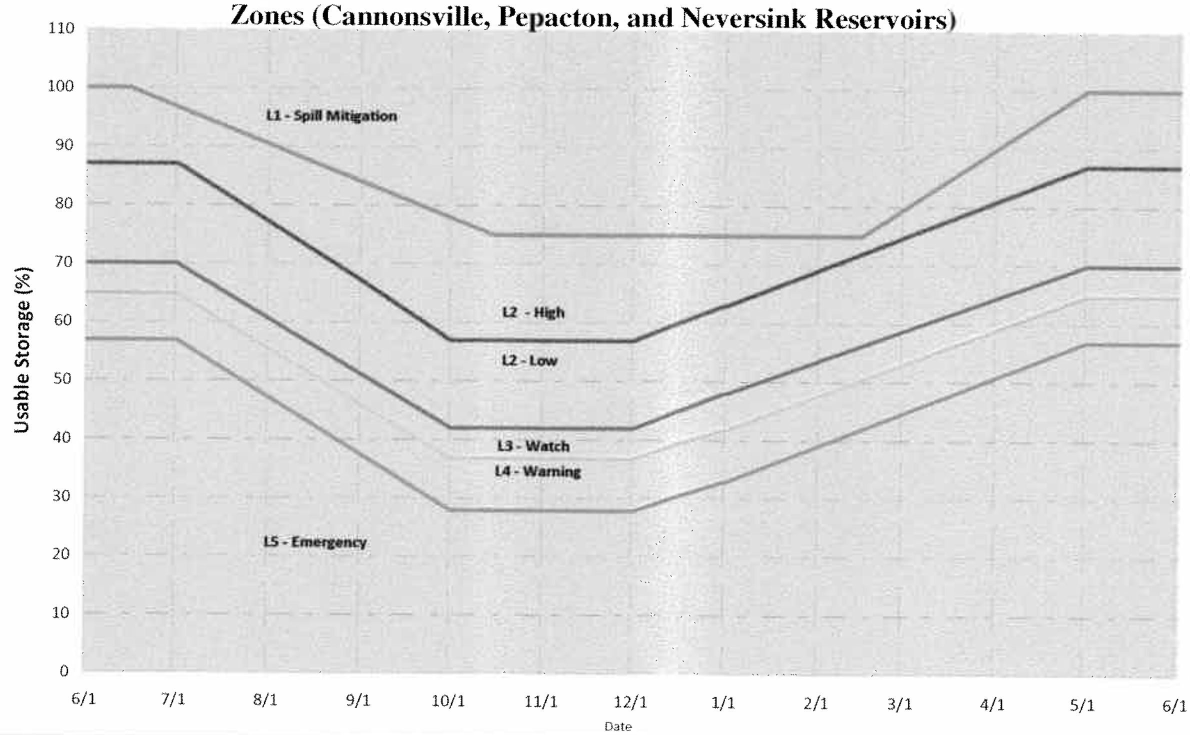

Figure 2
New York City Delaware System Usable Individual Storage (Cannonsville, Pepacton and Neversink Reservoirs)

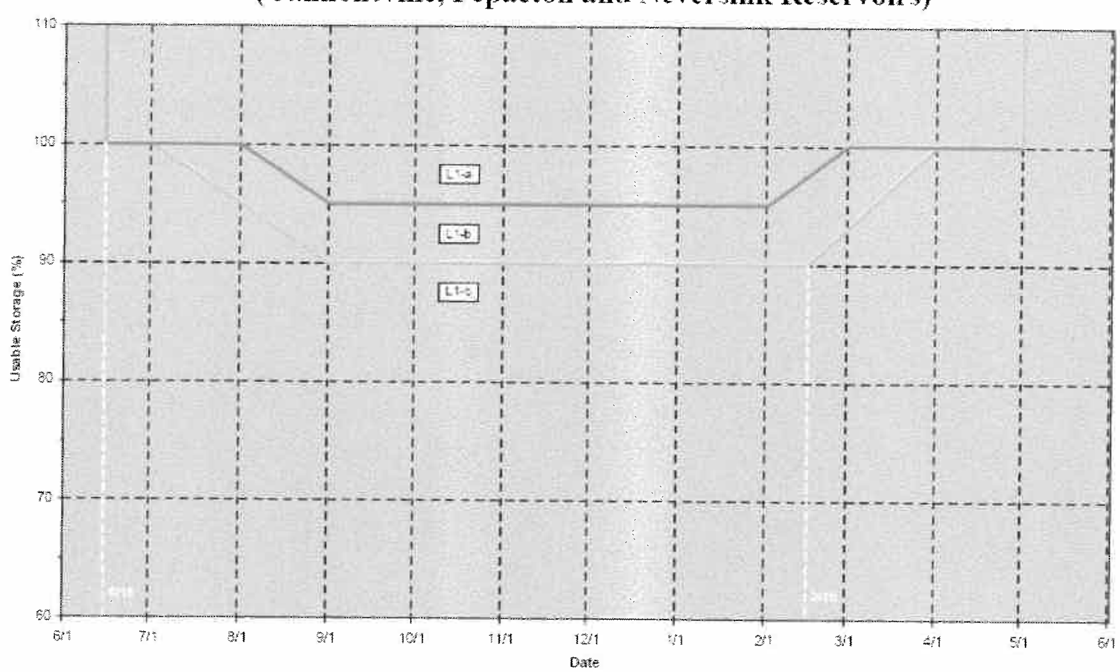

Table 4-1:

FFMP Table 3 Supplement (with 100 mgd Available) compared to Current FFMP Table 3 (with 35 mgd Available);

Modified NYS DEC / PA FBC Fisheries Proposal

	Winter		Spring		Summer			Fall		
Cannonsville Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	1500/1500	1500/1500	*	*	*	1500/1500	1500/1500	1500/1500	1500/1500	1500/1500
L1-b	250/250	*	*	*	*	*	525/350	400/300	300/275	250/250
L1-c	150/110	400/110	400/200	400/250	500/275	525/275	525/275	400/275	300/140	150/110
L2-High	135/80	325/80	325/190	350/240	400/260	425/260	425/260	350/260	250/115	135/80
L2-Low	115/80	300/80	300/190	325/240	400/260	400/260	400/260	325/260	250/115	125/80
L3	100/70	125/70	150/100	175/100	200/175	200/175	200/175	150/95	125/95	100/70
L4	55/55	55/55	75/75	75/75	130/130	130/130	130/130	55/55	55/55	60/60
L5	50/50	50/50	50/50	50/50	120/120	120/120	120/120	50/50	50/50	50/50

	Winter		Spring		Summer			Fall		
Pepacton Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	700/700	700/700	*	*	*	700/700	700/700	700/700	700/700	700/700
L1-b	185/185	*	*	*	*	*	250/250	200/200	200/200	185/185
L1-c	125/85	125/85	125/110	125/130	150/150	150/150	150/150	125/150	125/100	125/85
L2	100/65	100/65	100/100	100/125	140/140	140/140	140/140	100/140	100/85	100/60
L3	80/55	80/55	80/80	80/80	100/100	100/100	100/100	80/55	80/55	80/55
L4	45/45	45/45	50/50	50/50	85/85	85/85	85/85	40/40	40/40	40/40
L5	40/40	40/40	40/40	40/40	80/80	80/80	80/80	30/30	30/30	30/30

	Winter		Spring		Summer			Fall		
Neversink Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	190/190	190/190	*	*	*	190/190	190/190	190/190	190/190	190/190
L1-b	110/100	*	*	*	*	*	125/125	125/125	110/85	110/95
L1-c	90/65	90/65	90/85	90/100	125/110	125/110	125/110	90/110	90/75	90/60
L2	75/45	75/45	75/75	90/90	110/100	110/100	110/100	90/100	75/70	75/45
L3	60/40	60/40	60/50	60/50	90/75	90/75	90/75	60/40	60/40	60/40
L4	35/35	35/35	40/40	40/40	60/60	60/60	60/60	30/30	30/30	30/30
L5	30/30	30/30	30/30	30/30	55/55	55/55	55/55	25/25	25/25	25/25

Table 4-2:

FFMP Table 3 Supplement (with 75 mgd Available) compared to Current FFMP Table 3 (with 35 mgd Available);

Modified NYS DEC / PA FBC Fisheries Proposal

	Winter		Spring		Summer			Fall		
Cannonsville Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	1500/1500	1500/1500	*	*	*	1500/1500	1500/1500	1500/1500	1500/1500	1500/1500
L1-b	250/250	*	*	*	*	*	525/350	400/300	300/275	250/250
L1-c	150/110	400/110	400/200	400/250	500/275	525/275	525/275	400/275	300/140	150/110
L2-High	125/80	300/80	300/190	350/240	425/260	425/260	425/260	350/260	275/115	125/80
L2-Low	100/80	250/80	250/190	300/240	350/260	350/260	350/260	300/260	200/115	100/80
L3	75/70	75/70	100/100	100/100	175/175	175/175	175/175	100/95	100/95	75/70
L4	55/55	55/55	75/75	75/75	130/130	130/130	130/130	55/55	55/55	60/60
L5	50/50	50/50	50/50	50/50	120/120	120/120	120/120	50/50	50/50	50/50

	Winter		Spring		Summer			Fall		
Pepacton Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	700/700	700/700	*	*	*	700/700	700/700	700/700	700/700	700/700
L1-b	185/185	*	*	*	*	*	250/250	200/200	200/200	185/185
L1-c	125/85	125/85	125/110	125/130	150/150	150/150	150/150	125/150	125/100	125/85
L2	90/65	90/65	90/100	90/125	140/140	140/140	140/140	90/140	90/85	90/60
L3	80/55	80/55	80/80	80/80	100/100	100/100	100/100	80/55	80/55	80/55
L4	45/45	45/45	50/50	50/50	85/85	85/85	85/85	40/40	40/40	40/40
L5	40/40	40/40	40/40	40/40	80/80	80/80	80/80	30/30	30/30	30/30

	Winter		Spring		Summer			Fall		
Neversink Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	190/190	190/190	*	*	*	190/190	190/190	190/190	190/190	190/190
L1-b	110/100	*	*	*	*	*	125/125	125/125	110/85	110/95
L1-c	90/65	90/65	90/85	90/100	125/110	125/110	125/110	90/110	90/75	90/60
L2	75/45	75/45	75/75	90/90	110/100	110/100	110/100	90/100	75/70	75/45
L3	60/40	60/40	60/50	60/50	90/75	90/75	90/75	60/40	60/40	60/40
L4	35/35	35/35	40/40	40/40	60/60	60/60	60/60	30/30	30/30	30/30
L5	30/30	30/30	30/30	30/30	55/55	55/55	55/55	25/25	25/25	25/25

Table 4-3:

FFMP Table 3 Supplement (with 50 mgd Available) compared to Current FFMP Table 3 (with 35 mgd Available);

Modified NYS DEC / PA FBC Fisheries Proposal

	Winter		**Spring**		**Summer**			**Fall**		
Cannonsville Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	1500/1500	1500/1500	*	*	*	1500/1500	1500/1500	1500/1500	1500/1500	1500/1500
L1-b	250/250	*	*	*	*	*	525/350	400/300	300/275	250/250
L1-c	150/110	300/110	300/200	350/250	425/275	450/275	450/275	350/275	250/140	150/110
L2-High	110/80	200/80	200/190	260/240	350/260	350/260	350/260	300/260	215/115	110/80
L2-Low	90/80	150/80	190/190	250/240	300/260	300/260	300/260	260/260	150/115	90/80
L3	75/70	75/70	100/100	100/100	175/175	175/175	175/175	100/95	100/95	75/70
L4	55/55	55/55	75/75	75/75	130/130	130/130	130/130	55/55	55/55	60/60
L5	50/50	50/50	50/50	50/50	120/120	120/120	120/120	50/50	50/50	50/50

	Winter		**Spring**		**Summer**			**Fall**		
Pepacton Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	700/700	700/700	*	*	*	700/700	700/700	700/700	700/700	700/700
L1-b	185/185	*	*	*	*	*	250/250	200/200	200/200	185/185
L1-c	125/85	125/85	125/110	125/130	150/150	150/150	150/150	125/150	125/100	125/85
L2	80/65	80/65	90/100	100/125	140/140	140/140	140/140	125/140	90/85	80/60
L3	70/55	70/55	80/80	80/80	100/100	100/100	100/100	70/55	70/55	70/55
L4	45/45	45/45	50/50	50/50	85/85	85/85	85/85	40/40	40/40	40/40
L5	40/40	40/40	40/40	40/40	80/80	80/80	80/80	30/30	30/30	30/30

	Winter		**Spring**		**Summer**			**Fall**		
Neversink Storage Zone	1-Dec - 31-Mar	1-Apr - 30-Apr	1-May - 20-May	21-May- 31-May	1-Jun - 15-Jun	16-Jun - 30-Jun	1-Jul - 31-Aug	1-Sep - 15-Sep	16-Sep - 30-Sep	1-Oct - 30-Nov
L1-a	190/190	190/190	*	*	*	190/190	190/190	190/190	190/190	190/190
L1-b	110/100	*	*	*	*	*	125/125	125/125	110/85	110/95
L1-c	90/65	90/65	90/85	90/100	125/110	125/110	125/110	90/110	90/75	90/60
L2	60/45	60/45	75/75	90/90	110/100	110/100	110/100	90/100	75/70	60/45
L3	50/40	50/40	60/50	60/50	85/75	85/75	85/75	50/40	50/40	50/40
L4	35/35	35/35	40/40	40/40	60/60	60/60	60/60	30/30	30/30	30/30
L5	30/30	30/30	30/30	30/30	55/55	55/55	55/55	25/25	25/25	25/25

The proposed method for selecting the appropriate release schedules is to use OST and forecasted inflows to estimate the available water in the Delaware Reservoirs. For example, currently water is released from the Delaware Basin reservoirs based on the 35 mgd available FFMP table. In the event that forecasts predict greater than average flow, and the water managers using OST determine that more water may be released without affecting drought days or June 1st refill, the managers may decide to release water according to one of the proposed supplemental tables (with 50 mgd, 75 mgd, or 100 mgd available). Conversely, if water is projected to be short, and there are significant risks to releasing according to the 35 mgd table, managers may decide to "move down" to the 20, 10, or 0 mgd available FFMP tables.

The general methodology for release table selection will be developed using available inflow "hindcasts" within OST simulation mode. The rule will be evaluated and optimized based on the model's long term performance over a number of critical metrics. In practice, water managers could use OST PA mode to objectively analyze the risks (e.g. drought days, reservoir refill) associated with releasing water over the different release tables.

Using streamflow forecasts and current system conditions as input, the City's operators can run OST in PA mode and obtain probabilities of meeting specified performance objectives. In these OST runs, the individual FFMP table will affect the probability that the performance metrics will be met. The City's operators will use the probabilistic output to determine which FFMP release table has the most favorable probability of meeting the performance objectives.

A conceptual illustration of the general OST approach to supporting release decisions is provided in Figure 4-5.

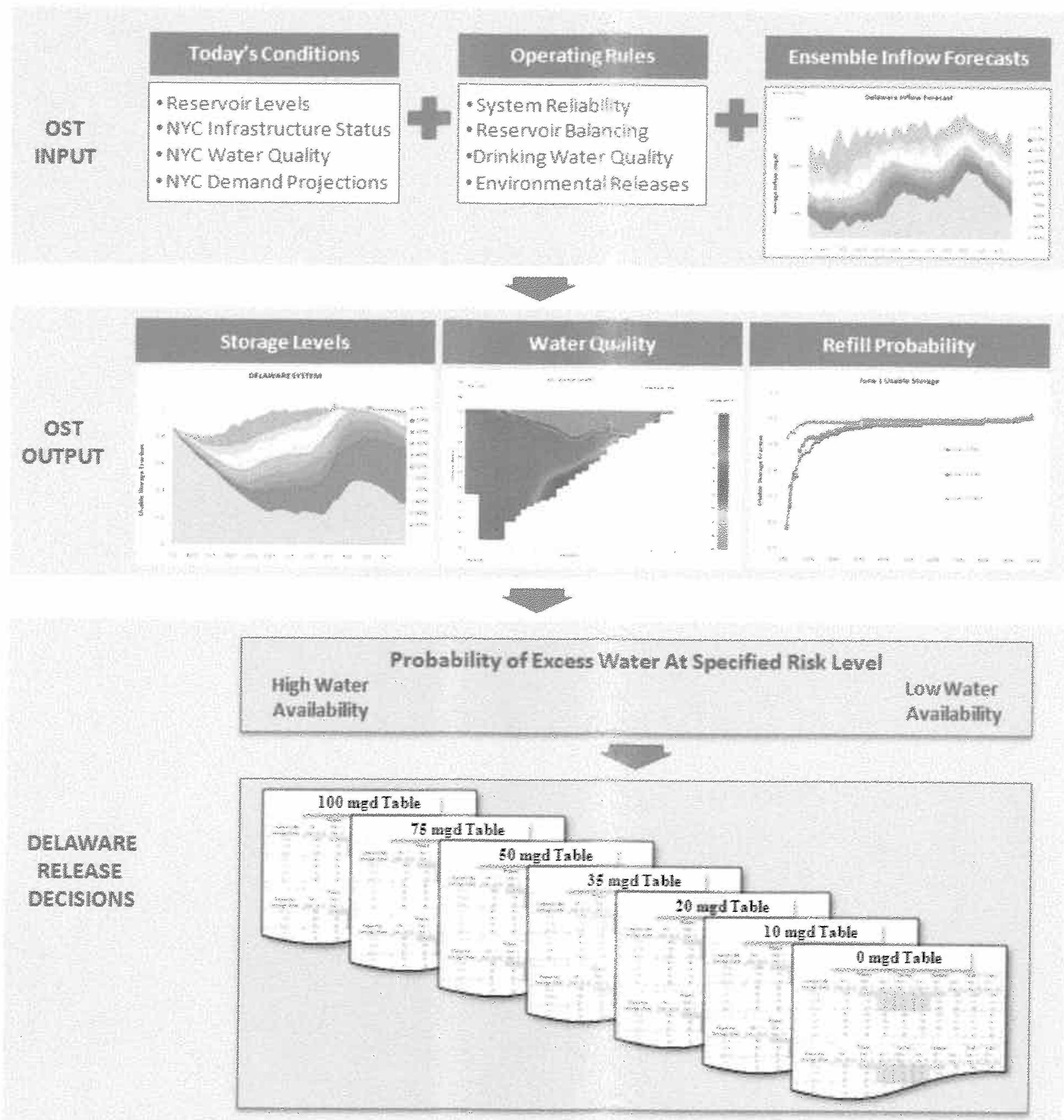

Figure 4-5: Conceptual OST Approach to Supporting Delaware Release Decisions

5. Operations Support Tool Development Timeline

Whereas the final OST is not scheduled to be fully deployed until October, 31 2012, there are a number of interim deployments that will provide the City with substantial analytical capabilities well before this final date. To date there has been one interim deployment on June 30, 2010, which included four core components:

- Hirsch Forecast application
- Data Acquisition utilities
- OST database
- Oasis Assist data QA/QC utility

Earlier versions of OASIS used historical hydrology to drive position analysis runs, providing a range of potential future scenarios without reference to current conditions. The June 30, 2010 deployment updated the model with a Hirsch Forecast application that computes an ensemble of potential traces of future inflow. As described in Section 3.2.2, the Hirsch technique uses an autoregressive time series model to modify the historical hydrology based on antecedent hydrology. The resulting inflow traces are described as "conditional" forecasts and represent the statistical probabilities of various magnitudes of inflow (based on historical flows) as well as the current watershed and stream conditions.

To support this interim OST deployment, four utilities were developed for automatic acquisition of data from the City's EOH and WOH reservoirs, Delaware River Basin reservoirs, and USGS gages. An automated Quality Assurance Quality Control utility was deployed to assist with data verification, and an updated database using Microsoft SQL Server 2008 was developed to store the requisite data.

Upcoming interim deployments include:

- Fall 2010 – Deployment of the W2 water quality models in position analysis mode
- Winter 2011 – Deployment of the Hirsch extended daily forecast and linkages with the City's WISKI database
- Summer 2011 – Deployment of a prototype Graphical User Interface

Prior to final deployment, a beta version of OST and all requisite hardware will be deployed, connected, and made fully operational at a City facility by the fall of 2011. Following deployment, a one-year acceptance phase will allow the City to use the model and receive technical support, troubleshooting, and minor interface customization services. This acceptance phase will be followed by the deployment of the final OST.

Citations:

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