The Role of Hydrology in Water Resources Management (Proceedings of a workshop held on the island of Capri, Italy, October 2008). IAHS Publl. 327, 2009.

Water supply management of the New York Metropolitan area and future challenges from population growth and global climate change

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Abstract The New York Metropolitan Area (NYMA), with a population of more than 8 000 000 people consumes more than 4.5 million cubic metres of water daily from a watershed area of more than 4970 km^2. Developed in the late 1800s and expanded in early 1900s, this system was designed according to climatic and demographic conditions existing at that time. Today, the management of one of the largest surface water supply systems in the US experiences new challenges associated with climate change, maintenance and enhancement of current conservation measures, coastal salt water intrusion, and continuing demands for economical development in upstate watershed communities. However, as described here, the large spatial distribution of the system allows effective management of water supply and treatment; and to a large extent, prevents the effects of droughts and floods. Recent changes in climatic conditions and population growth present challenges that require applications of new hydrological tools to develop better economic and political strategies. The main challenges are: (1) the management of the changing hydrological conditions in the watershed area due to climate change; (2) the ability to improve current water supply management and conservation measures or find water alternatives to accommodate the still growing population; and (3) to preserve the currently pure natural water supply for the future generations. Climate change on the Northeastern Coast of the USA is becoming well pronounced, with increasing average winter temperatures, ocean surface temperatures, and general instability in annual weather patterns. This affects the amount of available precipitation, and as a result, the amount of water storage in reservoirs. However, the uncertainty of future climatic changes makes it difficult to make effective forecasts. In this paper we argue that current considerations of presently uncertain climate change effects on the New York City watershed system might be less challenging to the future management than the current trends in population growth and maintenance and enhancement of existing conservation measures.

Key words New York City water supply; climate change; water quality; hydrology; management

INTRODUCTION

The New York City surface water supply provides more than 4.5 million cubic metres of water daily to more than 8 million residents of New York City (NYC). The water arrives from the system of 19 reservoirs and three so-called “controlled lakes”, all connected by tunnels and aqueducts. They are located within a distance of 200 km from New York City (Fig. 1). The water arrives at the NYC distribution system by gravity, without the help of pumps. Its quality is controlled by measurements made in intake and outflow shafts located in the terminal Kensico reservoir, closest to the city, and by water quality stations within the NYC distribution system.

Three main hydrological systems as defined by watershed boundaries, contribute water to NYC: Catskill, Delaware and Croton. The Catskill system has two large reservoirs: Ashokan and Schoharie; The Delaware system has four large reservoirs: Cannonsville, Pepacton, Neversink and Rondout; and the Croton system has 12 reservoirs and three controlled lakes. The Croton system is also the oldest; built in the 19th century, mainly by Italian immigrants, as reflected in the renaissance art in the design of aqueducts, dams and tunnels. The Catskill/Delaware System was built between 1915 (Kensico Reservoir) and 1964 (Cannonsville Reservoir).

The Catskill and Delaware systems provide >90% of the total water supply, and the Croton system provides only 10%. However, in 2002 during a severe drought, the Croton system supplied approximately 20% of the water. An elaborate system of aqueducts and tunnels provides an efficient way to manage water supply during droughts and storm events. The differences in the amount of water supply are explained by the sizes of available reservoir storage. The Catskill system capacity is

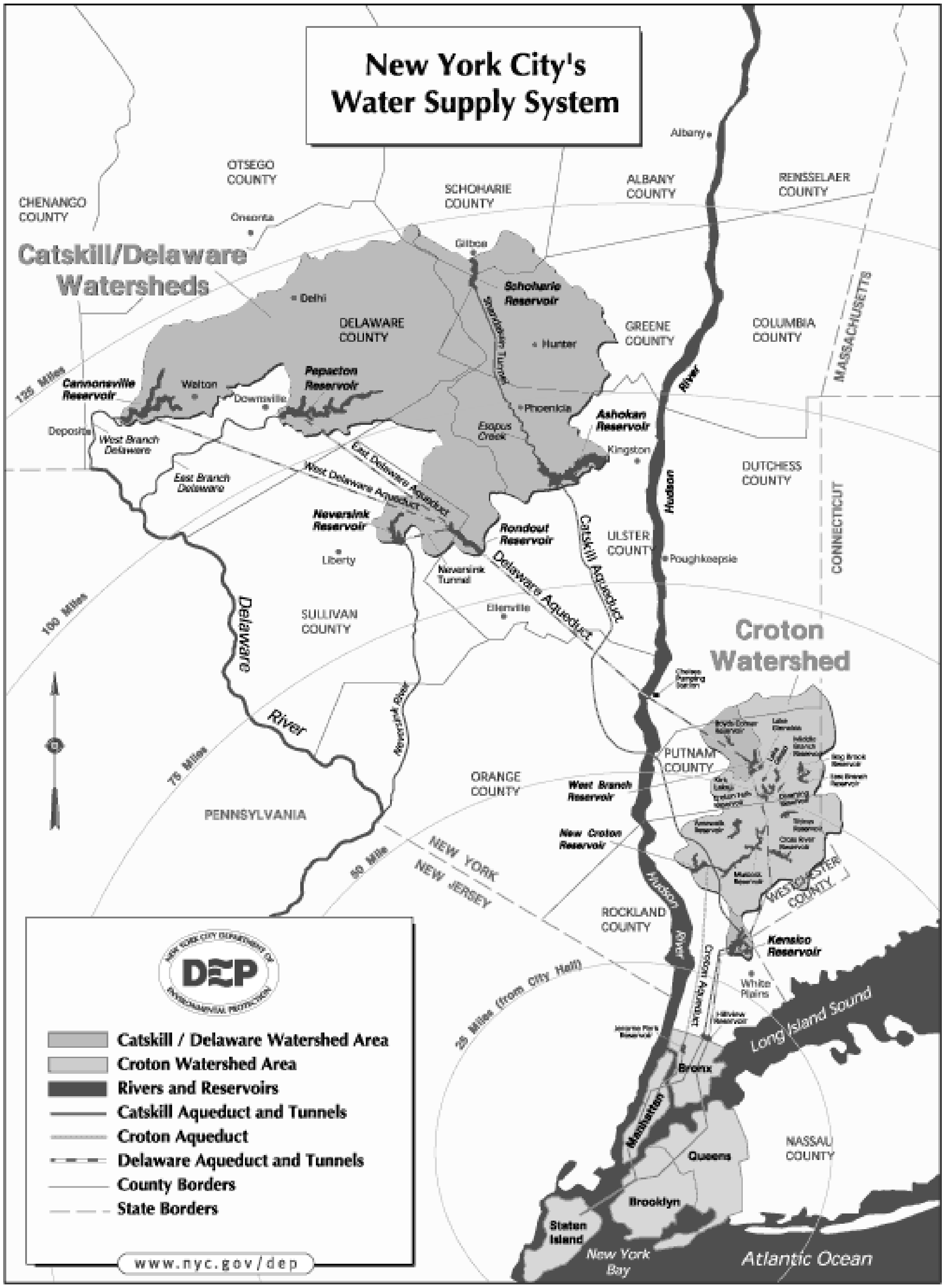

Fig. 1 NYC water supply map (adapted from NYCDEP, http://nyc.gov/html/dep/html/drinking_water/-wsmaps_wide.shtml).

140.5 billion gallons (531.8 million cubic metres); and the Delaware system capacity is 320.4 billion gallons (1,212.8 million cubic metres).

The Croton system, with a capacity of 30.6 billion gallons (115.8 million cubic metres), also includes the Kensico reservoir, which receives both the Catskill and Delaware water, passing it down to the NYC distribution system via the Croton aqueduct. Thus, altogether the Croton system has a capacity of 87.8 billion gallons (332.3 million cubic metres), approx. 15% of the total capacity. A separate aqueduct from Croton reservoir reaches NYC directly, and discharges water into the Jerome Reservoir in the Bronx.

Besides having low water storage capacity, the Croton system also does not meet the special criteria assigned by the "Surface Water Treatment Rule" which was implemented in 1989 under the 1986 amendments to the Safe Drinking Water Act. This requires all surface water supplies to be filtered. Although Croton's water continues to meet all federal and State health-related water quality standards, except for elevated coloration due to organic matter and minerals, its' closeness to the highly populated NYC and suburban area raises concerns. A proposed filtration facility will be able to improve colouration as well as reduce microbiological contamination.

Being in a very rural area, the Catskill/Delaware system was granted exemption by the Environmental Protection Agency (EPA) from this filtration rule. This led to implementation of the USEPA Filtration Avoidance Determination (FAD) in 1993, a management plan designed to implement a series of watershed protection measures, as well as monitoring, and modelling systems. Summarized in environmental impact statements (EIS), the new regulations were designed to improve water quality parameters and to comply with federal and state regulations without the necessity to filter its water supply.

However, the implementation of the new EIS watershed anti-pollution regulations negatively influenced the economic development in the counties within the Catskill/Delaware system, creating unprecedented tensions between these counties and New York City. The Coalition of Watershed Towns within five counties was created to oppose watershed regulations and numerous meetings were held between them and NYC officials. These tensions were eased in 1997 when New York City signed a Memorandum of Agreement (MOA) between NYC and the Catskill/Delaware counties in the watershed system. The MOA was also facilitated by USEPA, New York State and various environmental groups. It helped not only implement necessary measures for improving and maintaining water quality within the watershed, but also provided upstate counties with job opportunities and involvement in watershed protection. According to NYCDEP (2008), "DEP's operations and investments translate into 1833 jobs in the West of Hudson watershed in addition to the more than $100 million in taxes that DEP pays to the watershed communities each year."

In 2007, the NYC water supply was granted a 10-year FAD from USEPA. More than $1.5 billion was invested in the previous FAD, primarily in watershed protection programmes such as land acquisition, septic repairs, storm water controls for new development, wastewater treatment plant upgrades and economic development grants and loans through a local not-for-profit corporation. New York City currently owns approximately 125 000 acres (505.8 million square meters) of land surrounding its watershed and plans to invest an additional $300 million in land acquisition over the next decade" (NYCDEP, 2008). A new FAD will target similar goals, but will also expand on stream restoration projects, enhancement to the existing Watershed Agricultural Program, and invest in a new UV Disinfection facility to add an extra measure of protection to the Catskill/Delaware drinking water systems (NYCDEP, 2008).

Water conservation measures implemented during the last 30 years decreased water consumption per capita despite noticeable population growth (Fig. 2). During the 1950s, 1960s and 1970s water consumption increased at about 1% a year. Conservation measures implemented between the 1980s and 2002 such as metering, education, leak detection, toilet replacement and water use regulations (EPA, 2002; Liebold, 2008) decreased water consumption despite the concurrent increase in population.

Today, the management of one of the largest surface water supply systems in the US experiences new challenges associated with climate change, continuing water demand due to population growth, enhancement and maintenance of current conservation measures and continuing demands for economic development in upstate watershed communities. The combination of these factors poses unique social, economic, political, geological and hydrological challenges that help to identify future risks for water supply management.

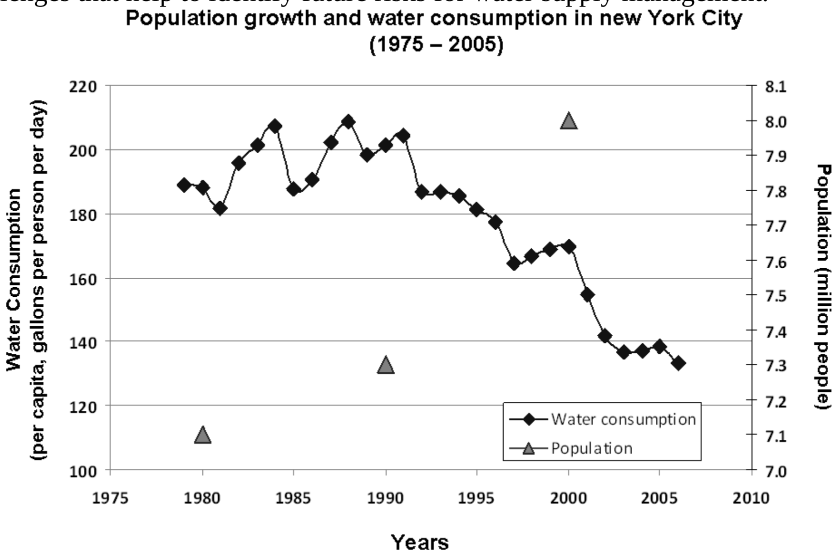

Fig. 2 Water consumption and population in NYC during last 30 years (data on water consumption were obtained from (NYCDEP, 2007)).

NYC WATER SUPPLY SCALE AND OPERATION

NYC watershed area covers more than 4970 km^2. Table 1 contains information on the characteristics of each of the water supply reservoirs. It should be noted that the Ashokan reservoir receives much of its water from the Schoharie reservoir via the 18.1 mile-long Shandaken tunnel that releases water into the Esopus Creek, a major tributary of the Ashokan reservoir. The Kensico reservoir, part of the Croton system, has a very small watershed area. However, as a terminal receiving reservoir for the Catskill/Delaware systems it routes approximately 85% of the annual drinking water supply for NYC. Kensico receives water from the Catskill/Delaware supply system by gravity through tunnels under the Hudson River. The Croton system consists of 12 reservoirs that supply water to New York via the Jerome Reservoir in the Bronx (i.e. northern NYC). It is connected with the Croton reservoir by an aqueduct.

The safe yield is the amount of water that can be delivered to NYC considering the potential occurrence of the latest and most severe drought. This amount was determined using the worst droughts of the 1960s. Fig. 3 shows that the water consumption for the city on 3 June 2008 was 1.09 billion gallons (4.1 million cubic metres) which is lower that the safe yield currently estimated as 1.29 billion gallons (4.9 million cubic meters). Variations in yield depend on reservoir

Table 1 Morphometric characteristics of NYC water supply.

Reservoirs and watershed systems	Drainage area (km^2)	Storage (cu m^2) × 10^6	Safe yield (mgd)
Delaware system			580
Rondout	237.6	190	
Neversink	234.7	134	
Pepacton	940.6	530	
Cannonsville	1,146.0	366	
Catskill system			470
Ashokan/Schoharie	1,443	562	
Croton system			240
Kensico	26	115.7	

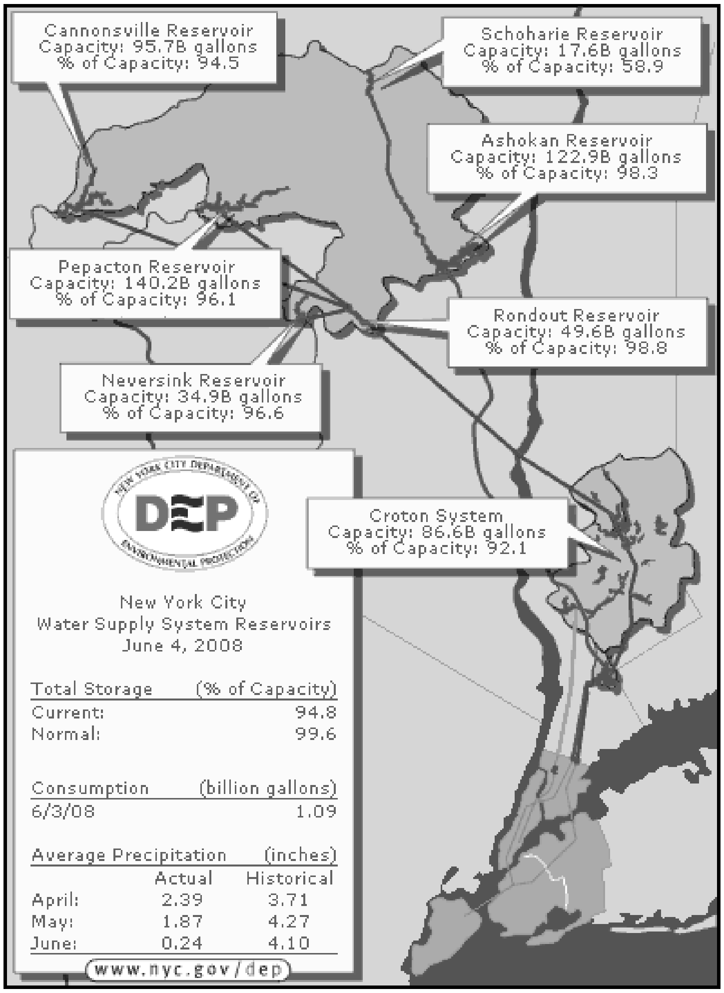

Fig. 3 Current state of NYC water supply (for 4 June 2008) (adapted from NYCDEP, http://nyc.gov/-html/dep/html/drinking_water/maplevels_wide.shtml).

levels, associated with variations in weather patterns (droughts, floods, etc.) For example, on 2 August 2006, during extremely hot and humid weather, the daily flow was 1560 mgd (5.9 million cubic metres per day) and the peak flow reached 2020 mgd (7.6 million cubic metres per day) (NYCDEP, 2008).

The size of the system, reservoir design and the inter-connectivity between reservoirs plays an important role in its management during the periods of droughts and floods. Water can be transferred and diverted. This gives operational flexibility to prevent local water shortages, reduce water excesses during floods, and also deal with water quality issues by closing the gates of the reservoir containing degraded water quality. Periods of severe droughts prompted NYC to develop a Drought Management Plan. The latest version includes three main drought phases outlined in NYCDEP (1998).

Drought criteria are based on an analysis of historical data together with the current situation for the period of the "water year" that spans from 1 June to 31 May. If a comparison reveals a hazardous situation, there are contingency and emergency operations that can be implemented. They include conservation measures (street washing restrictions, lawn care, etc.), use of pumping stations located along aqueducts and tunnels, increase of gravity water distribution, use of additional water supplies from the Hudson River, use of wells in the southeastern part of Queens (NYC), and an increase of water supplied by the Croton system. The total current system condition is depicted daily on a web site of NYC DEP (Fig. 3).

The size and connectivity of the NYC water supply was a focal point of one of the first optimization studies using a Geographic Information System (Greenberg *et al*., 1971).

Thus, the water supply system experiences constant management changes in response to changing population and weather events. As Major & Goldberg (2000) point out, the system is a mature infrastructure that is operated by agencies already used to dealing with weather variations; this "makes the implementation of institutional and infrastructure adjustments to increase resilience more feasible".

POTENTIAL RISKS AND RESULTING MANANGEMENT STRATEGIES

Population growth of NYMA and adjacent areas was always a focus of the water supply system development. Since its first structure (Croton dam) was built in 1842 the system is constantly growing in terms of size and implementation of protection measures and management policies. One of the most comprehensive studies includes a population model of conservation *vs* non-conservation scenarios. It was done by Hazen & Sawyer (1989). The study projected future needs increase from 1611.3 mgd (6.1 million cubic metres per day) in 1995 to 2061.4 mgd (7.8 million cubic metres per day) in 2035 without conservation measures and from 1425 mgd (5.4 million cubic metres per day) in 1995 to 1473 mgd (5.6 million cubic metres per day) in 2035 with conservation measures.

Conservation measures can reduce the effect of climate change (Boland, 1997) on the water supply system and therefore should be considered as preventive measures. Currently implemented conservation measures (Liebold, 2008; EPA, 2002) in NYC have already produced more optimistic results than predicted by the Hazen & Sawyer study. The water consumption dropped from 1326 mgd (5.0 million cubic meters per day) in 1995 to 1,069 mgd (4.05 million cubic meters per day) in 2006 (NYCDEP, 2008). It is possible that maintenance and expansion of conservation measures will continue to reduce the risks of increasing population demands for water consumption.

The Metropolitan East Coast Study (Major & Goldberg, 2000) discusses risks to the NYC water supply system from climate change, based on the Palmer Drought Severity Index (PDSI) and on the scenarios from Hadley Centre climate general circulation model (GCM) and Canadian Centre GCM. While most models agree on temperature rise and associated high probability of drought, models disagree on precipitation changes. This brings high uncertainty in predictions. The study therefore acknowledges that the uncertainty of climatic change makes it difficult to make effective forecasts. It lists several strategies for the adaptation of the system to potential effects of temperature and precipitation change, and of sea-level rise. It also acknowledges that PDSI index is a physical concept while the Drought Management Plan takes into account a physical drought and a specific use of water in a certain time period to define appropriate drought strategy.

The most recent New York Regional Energy-Water Workshop, in April 2004, outlined risks associated with future water and energy demands. These risks are associated with growing population and demands for water and energy in NYMA and Long Island. They are summarized as following:

- There will be continuing growth in population in the New York metropolitan region, causing increased consumption of water and electricity.
- Electricity deregulation coupled with strict environmental regulation will make planning for increased electricity generation difficult.
- New York City has challenging post 9-11 energy and water security considerations.
- Climate change is likely to reduce the region's capacity to provide power and water at the same time that there will be increased demand for power and water.
- Saltwater intrusion in coastal areas is projected to increase, reducing the availability of fresh water from the Long Island aquifer and pushing the saltwater–freshwater interface further up

the East River and the Hudson River (an alternate source for drinking water in emergency situations).

– Extremes of weather are likely to be more frequent and more intense, including the likelihood of more severe droughts, heat waves and floods (Columbia Earth Institute, "Climate Change and a Global City – Metro East Coast", 2001).

CHALLENGES FOR HYDROLOGISTS AND WATERSHED MANAGERS

Challenge no. 1

Despite the existing scientific evidence of climate change, the use of global models for local systems, such as NYC water supply is limited by the "global" character of the applied GCMs, which usually have a coarse spatial resolution (2.5° × 3.75°, approx. 250 × 400 km). The NYC water supply system is influenced by local variability's in climate and weather patterns and therefore, the successful application of GCMs for these settings requires a specific downscaling of GCM results or modifications of its internal parameters to improve its spatial resolution. If such an approach were possible, this would decrease the existing uncertainty level in forecasting, and provide more justified recommendations for watershed managers.

Therefore, the most current challenge is in reduction of the uncertainty associated with climate predictions. This would then place more accurate physically-based numbers on hydrological and atmospheric changes that would ultimately affect the quality and quantity of the future water supply.

Challenge no. 2

Physical values associated with climate and weather variations have to be linked with management definitions and terms. For example, definitions of climatic variations in terms of probabilities (which varies with each new model), and quantitative indices, are not helpful to NYC managers for modifying existing drought management plans, or addressing the issue of how urgently should these plans or other management decisions be implemented. Economic costs associated with these decisions can be very high. What would be the effectiveness of these decisions if scientific justification is highly uncertain (often varies between models) or vague for managers to understand? The economic cost of untimely or incorrect decisions can be huge for NYMA, with more than 8 million residents.

Challenge no. 3

Growing population and water demands in NYMA and adjacent geographic regions places considerable pressure on the NYC water supply system, maintenance and enhancement of current conservation measures. These problems are definite and more certain than the speculative climate change effects. In the realm of climate change, the most intriguing (and definitely certain) factor is the sea-level rise that relentlessly affects the aquifers of Long Island, a home to almost 3 million people. It should be noted that the sea level rise along the US East coast has been occurring at least since tide gauges have been installed and able to quantify it, and is largely due to tectonic coastal sinking. Currently, the two Long Island counties, Nassau and Suffolk, have over 500 public water systems that rely on more than 1500 different groundwater wells for their water supply. Due to the expansion of urban areas and development on Long Island, the recharge areas for these aquifers is decreasing and thereby reducing the available groundwater supply.

The continued sea-level rise, together with increasing water usage and decreasing recharge areas, will cause more salt water intrusion into the Long Island aquifer. This phenomenon caused New Yorkers in the 19th century to draw upon the surface water supply from the nearby Croton reservoir. The same will likely happen to Long Island residents as degradation of water quality by intrusion of chloride and sulfates continues into the 21st century, as anticipated. The current construction of New York City Tunnel no. 3 will make it possible to divert water from NYC to supply Long Island residents. However, the result will be a large increase in demand with the increase in the population served.

Therefore, one of the next challenges for NYC hydrologists and watershed managers will be to provide better quantitative forecasts regarding the salt water intrusion and groundwater balance in Long Island; and evaluate the operational possibility of including the Long Island area in the NYC water supply. In addition, water conservation measures on Long Island should be made comparable to ones implemented in NYC, and thereby similarly offset the effect of growing population on water demand.

CONCLUSIONS

The New York Metropolitan Area (NYMA), with a population of more than 8 000 000 people, consumes daily more than 4.5 million cubic meters of water from a watershed area of more than 4970 km^2 located at a distance of 200 km from New York City.

The large growth of population in NYMA, and the change of climatic conditions during the last 100 years, presents certain challenges to the NYMA watershed management strategies that will have to be solved by hydrological and political means.

The main challenges are: the management of the changing hydrological conditions in the watershed area due to climate change; the ability to enlarge the current water supply or find alternative water sources to accommodate the still growing population; the maintenance and enhancement of existing water conservation practices; the preservation of the existing pure natural water supply for future generations; and increasing the Long Island water supply in order to offset the challenges posed by salt water intrusion caused by rising sea level. At present, only water conservation measures show the potential to offset any negative impact by the documented growing population, or possibly from potential climate change. This has been shown to be effective for the last 20 years.

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