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ORIGINAL PAPER

Managing climate change risks in New York City's water system: assessment and adaptation planning

Cynthia Rosenzweig · David C. Major · Kate Demong · Christina Stanton · Radley Horton · Melissa Stults

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Abstract Managing risk by adapting long-lived infrastructure to the effects of climate change must become a regular part of planning for water supply, sewer, wastewater treatment, and other urban infrastructure during this century. The New York City Department of Environmental Protection (NYCDEP), the agency responsible for managing New York City's (NYC) water supply, sewer, and wastewater treatment systems, has developed a climate risk management framework through its Climate Change Task Force, a government-university collaborative effort. Its purpose is to ensure that NYCDEP's strategic and capital planning take into account the potential risks of climate change—sea-level rise, higher temperature, increases in extreme events, changes in drought and flood frequency and intensity, and changing precipitation patterns—on NYC's water systems. This approach will enable NYCDEP and other agencies to incorporate adaptations to the risks of climate change into their management, investment, and policy decisions over the long term as a regular part of their planning activities. The framework includes a 9-step Adaptation Assessment procedure. Potential climate change adaptations are divided into management, infrastructure, and policy categories, and are assessed by their relevance in terms of climate change time-frame (immediate, medium, and long term), the capital cycle,

C. Rosenzweig
NASA Goddard Institute of Space Studies, New York, USA

D. C. Major (✉) · C. Stanton · R. Horton · M. Stults · C. Rosenzweig
Center for Climate Systems Research, Columbia University, Armstrong Hall, 5th Floor, 2880 Broadway, New York, NY 10025, USA
e-mail: dcm29@columbia.edu

K. Demong
NYC Department of Environmental Protection, Flushing, USA

Present Address:
C. Stanton
Natsource, Inc., New York, USA

costs, and other risks. The approach focuses on the water supply, sewer, and wastewater treatment systems of NYC, but has wide application for other urban areas, especially those in coastal locations.

Keywords Adaptation to climate change · Climate mitigation · Risk management · Sea-level rise · Urban infrastructure · Water quality · Water supply · Sewer systems · Wastewater treatment

1 Introduction

From the early part of the 19th century, far-sighted planners developed the New York City (NYC) water system, which has provided clean and copious water supplies for the city and upstate areas, and laid the foundation for the growth of the city into the world metropolis that it is today. Planners today are showing the same foresight in considering what the next 100 years may bring, including the challenges of a changing climate. The impacts of climate change on urban infrastructure, including water supply, sewer, and wastewater treatment systems, are expected to be substantial and long-lasting. Climate changes that will significantly affect these systems include sea-level rise, higher temperature, changing precipitation patterns, and increases in the number of droughts and floods. Moreover, hurricanes, which currently pose great risks to the system, are expected to increase in intensity in the coming decades (Emanuel 2005). The resulting risks to the area are economic, environmental, physical, social, and fiduciary. Because of the long-lived infrastructure involved, it is important to confront and manage the risks of climate change by prudent early planning, management, and investment decisions.

This article describes one of the first substantial efforts to undertake climate-change planning for infrastructure in a large urban area. The effort is based on the Metro East Coast (MEC) regional study (Rosenzweig and Solecki 2001) carried out for the U.S. National Assessment of the Potential Consequences of Climate Variability and Change, and ongoing NYC operations and planning activities. The MEC study found that significant characteristics of the NYC system are that it is a mature infrastructure system, that its managers are skilled at dealing with existing hydrologic variability, and that there are many potential adaptations to the risk of climate change in the NYC water supply, sewer, and wastewater treatment systems. The work of the NYCDEP Climate Change Task Force has focused on the water supply, sewer, and wastewater treatment systems of NYC, but the approach described here should have wide application for other urban areas, especially those in coastal locations, as well as for other coastal and upland infrastructure. It should also be noted that many climate change adaptations, focused on increasing the robustness of systems, are valuable in dealing with the risks of present climate variability, thereby providing immediate benefits. Other cities in which significant climate change adaptations are being considered include Halifax, London, and Toronto (LCCP 2002; CDNR 2005; Clean Air Partnership 2006). An extensive report on climate impacts in the Boston metropolitan area (Kirshen et al. 2004) came to many conclusions similar to those in the NYCDEP work; see also Greater London Authority (2006) for a review of work relating to lessons for that city. There is a critical need for similar work in the developing world's burgeoning mega-cities, many of which are situated in vulnerable coastal areas. In locations where a strong foundation for climate adaptation is missing, additional pre-planning and development stages may be required.

2 The New York City Department of Environmental Protection climate change program

The New York City Department of Environmental Protection (NYCDEP), the agency responsible for managing NYC's water supply, sewer, and wastewater treatment systems (NYCDEP 2005), initiated an agency-wide Climate Change Task Force (Task Force) in 2004 (Major et al. 2005). The Task Force was created in recognition of the wide-ranging effects that climate change will have on NYCDEP's planning, management, and investment decisions, and includes representatives from all of the operating and planning bureaus in NYCDEP along with experts from Columbia University's Center for Climate Systems Research (CCSR) and other universities and engineering firms. The mission of the Task Force has been to ensure that NYCDEP's strategic and capital planning take into account the potential effects of climate change on NYC's water supply, sewer, and wastewater treatment systems. The Task Force has evolved into an agency-wide Climate Change Program.

From October, 2004 to December, 2005, the Task Force held a series of monthly meetings, each focused on particular elements of its work, provided advice to senior agency planners on climate change, held climate change workshops for agency personnel, and engaged in outreach to other city and regional agencies to build links for work on projects and programs of mutual and interrelated interest, with the ultimate aim of building a regional climate change consortium. The work of the Task Force included science, adaptation, mitigation, outreach, and coordination, key elements of which are described in this article. The NYCDEP Task Force's pioneering work has taken a comprehensive agency-wide approach that provides organizational benefits beyond climate change assessment.

The NYCDEP Climate Change Task Force is developing a risk management plan by evaluating climate change forecasts, impacts, indicators, and adaptation and mitigation strategies to support agency decision-making. Task Force activities include the development of downscaled climate change scenarios and the coordination of scientific projects to yield maximum benefit from research and development. Mechanisms for updating scenarios over time are being developed, using climate information on trends and extremes provided by university and government scientists. In addition to its adaptation activities, the Task Force has developed an initial greenhouse gas (GHG) management program, using GHG inventory software to assess current emissions.

A key perception underlying the program is that climate change will have wide-ranging, pervasive impacts on NYC water supply, sewer, and wastewater treatment systems. Thus the characterization and management of a range of risks that the system faces over the long term is an important element in the NYCDEP's effort to fulfill its operating, investment, and fiduciary obligations.

The hydrologic conditions for which planning has taken place have, in standard practice, been regarded as describable by stationary processes, often with the frequency of very rare, but high-impact events being underestimated. It is now recognized that the relevant climate and hydrologic variables will be, for the long term, non-stationary, providing planners with new challenges. This recognition has helped to shape the institutional response of NYCDEP and provides a structure for the planning, evaluation, and implementation of adaptation and mitigation programs. The infrastructure on which this work is focused is in some cases so long-lived that the effort is one of century-scale planning.

3 System description

The NYC water system constitutes a monumental hydraulic and civil engineering achievement. The water for the system is collected from 3 upland watersheds, impounded by dams and held in 18 storage reservoirs and 3 controlled lakes. It is carried via 210 miles of aqueducts, 2 balancing reservoirs, distribution facilities and tunnels, to over 6,200 miles of distribution mains in the City. In addition, there are connections to the NYC water system by communities in Southeastern New York State (Fig. 1).

The three upland reservoir systems north of NYC are Croton, on the east bank of the Hudson River, which began service in 1842 and was completed as a system prior to World War I; Catskill, on the west bank of the Hudson, completed in 1927; and Delaware, on the upper branches and tributaries of the Delaware River, completed in 1967. The total area of the watersheds is nearly 2,000 square miles. The three systems meet respectively about 10%, 40%, and 50% of the total daily system demand. Annual precipitation on the City's watersheds averages about 44 inches. The total storage capacity of the upland system is 547.5 billion gallons, with a safe yield of 1,290 million gallons daily (mgd). There is an additional 33 mgd of safe yield from well fields (this groundwater system provides approximately 1% of total supplies) in the southeastern part of the Borough of Queens, NYC (NYC DEP 2005; NYC Municipal Water Finance Authority (NYCMWFA) 2005a).

Water from the system is used to supply all of NYC; in addition, the NYC system supplies 85% of the water used in Westchester County and 5-10% of the water used in Orange, Putnam, and Ulster Counties. In recent years, the system has provided water to about 9 million users. In addition to water supply, the system also provides legally mandated augmentation and conservation releases within New York State and to the neighboring Delaware Basin.

The other major component of NYCDEP operations is the sewer and wastewater treatment system. The NYC sewer and wastewater treatment system includes over 6,600 miles of sanitary, storm, and combined sewer pipes. This system processes 1,500 mgd of wastewater at 14 Water Pollution Control Plants (WPCPs), spread across NYC's five boroughs and located on the coast to allow for treated water discharge. The NYC sewer and wastewater treatment system also includes a combined sewer overflow (CSO) treatment plant, 8 sludge dewatering facilities, 93 pumping stations, 490 sewer regulators, and 553 tide gates.

NYCDEP's water and sewer operations group is also involved in restoring and preserving wetlands as a natural alternative to storm sewers. NYCDEP's Staten Island Bluebelt Program (Fig. 2) is a leading example of this type of endeavor, naturally draining over 14,000 acres and saving over $80 million in conventional sewer costs (Vokral et al. 2001). One measure of the size of the water supply, sewer, and wastewater treatment systems managed by NYCDEP is that, taken together, the capital program for the next 10 years is $16.5 billion US (NYCMWFA 2005, p. 20).

4 Climate change science

The principal scientific work of the NYCDEP Climate Change Task Force has been the development of regional climate scenarios for the next century. These are used to guide the

Fig. 1 Map of NYCDEP water system

development of adaptations through the Adaptation Assessment steps (described below). The scenarios are based on global climate model (GCM) simulations for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change; see also IPCC (2001a, b, c). These are a recent set of global coupled ocean-atmosphere climate

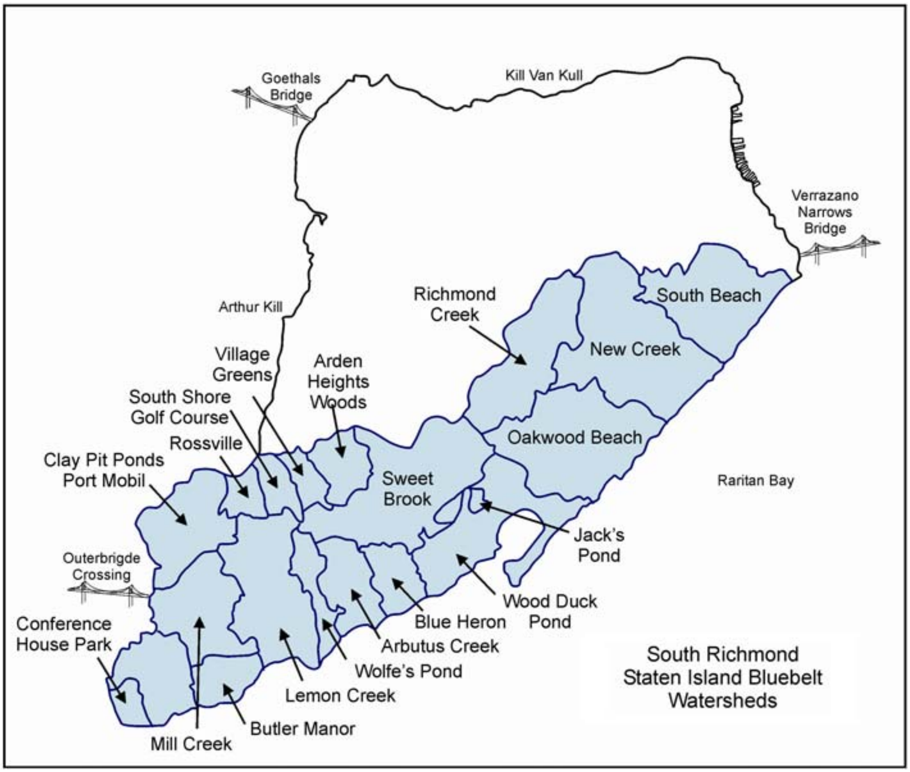

Fig. 2 Staten Island Bluebelt Watersheds

simulations using state-of-the-the art versions of the world's leading models, based on a range of emissions scenarios from the IPCC Special Report on Emissions Scenarios (SRES) (IPCC 2000). Their use ensures that the work of the NYCDEP Climate Change Task Force is linked to worldwide current, peer-reviewed, climate change science, and also provides a framework for revising scenarios as new GCM simulations become available. (Earlier climate scenarios for the MEC region are provided in Rosenzweig and Solecki 2001.)

The Task Force selected five GCMs and three scenarios from the IPCC's SRES GHG emissions scenarios (IPCC 2000): B1, A1B, and A2, to provide a suite of future scenarios to guide adaptation. The GCMs were selected based on their robust long-term development programs and documentation in the peer-reviewed literature and through validation based on comparison of hindcast runs based on historical GHG concentrations with observed historical climate in the NYC watershed region. The GCMs (with lat. x long. grid size in parentheses) are: Max Planck Institute ECHAM 5 (1.875° x 1.875°); Goddard Institute for Space Studies ModelE (4° x 5°); Geophysical Fluid Dynamics Laboratory CM2.1 (2° x 2.5°); National Center for Atmospheric Research CCSM3.0 (~1.4° x 1.4°—T42 spectral model); and Hadley Centre CM3 (2.5° x 3.75°). The outputs from the models are temperature and precipitation; for the GISS model sea level rise is also an output; for the other models, this must be derived from additional analyses. The 5 GCM x 3 emissions scenario matrix provides a reasonable framework for dealing with uncertainties regarding climate sensitivity and development pathways. In ongoing work, the recalibrations of extreme events in the MEC report (Rosenzweig and Solecki 2001) will be updated to provide new estimates of, for example, recurrence intervals of floods and droughts.

This approach provides a range of outcomes suitable for risk management planning that incorporates both emissions scenarios and the variation inherent in different climate models. Using the AR4 runs creates a ‘‘shelf life’’ of 3–5 years for the planning scenarios, after which they will be revised when the next generation of GCMs become available. In addition to the three main GHG scenarios chosen, which represent lower-range, medium-range, and moderately high-range scenarios, the A1F1 (IPCC 2000) scenario simulated with the HadCM3 model is being used to represent the high end of current climate projections. Using a 5 x 3 matrix approach based on multiple runs for each model and scenario, enables the Task Force to address risk and uncertainty associated with climate change through the development of model-based probabilities (Fig. 3). In Task Force discussions, these scenarios were used as guides to the development of agency responses and adaptation design in terms of thresholds, ranges, and hydrologic traces.

Daily and monthly temperature and precipitation results from the GCM simulations chosen for the regional scenarios are downscaled for the NYC watershed and urban region using standard interpolation techniques, applied to the appropriate grids for the different models (Rosenzweig and Solecki 2001). Sea-level rise estimates are taken from the applicable GCM model grid and adjusted as needed for local subsidence, thermal expansion, and freshwater influx. Other GCM outputs, such as specific humidity, solar radiation, and windspeed that are relevant to the NYC water supply, sewer, and wastewater treatment systems are also downscaled from the grids.

The outputs of the scenarios can be presented and utilized in a variety of forms to fit the needs of particular adaptations, for which time frames will differ. In addition to basic

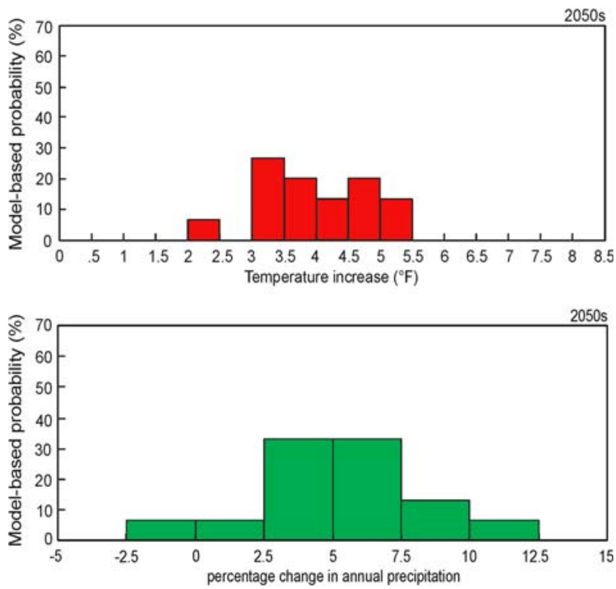

Fig. 3 Model-based probabilities for climate change in the 2050s (compared to the 1980s) for the New York City watershed region, based on 5 GCMs and 3 Greenhouse Gas emissions scenarios

variables (such as the mean, standard deviation, and trends), thresholds, ranges, probability distributions, or tables and charts are used to present scenario findings (see Figs. 3, 4). Climate change has wide-ranging effects on the elements of the system, and appropriate risk management through adaptation can utilize different types of model results. For some adaptations, such as the installation of flood walls in WPCPs, a threshold rise in sea-level will be appropriate. The time frame for such work can be measured in decades, with planners tracking climate changes and integrating this knowledge with capital rehabilitation and replacement schedules. For other adaptations, such as watershed protection programs, a probabilistic range of outcomes can be specified from temperature and precipitation scenarios. For still others, including the assessment of system operations in conditions of climate change, synthetic hydrology methods (the use of statistical assumptions to extend or shift historical traces) based on scenario outputs are appropriate. For some applications, monitoring appropriate indicators based on the scenarios is the right approach, either to plan initial adaptations or to review the effectiveness of adaptations in place. The development of an agency monitoring framework must follow on an iterative basis as adaptations are planned and implemented.

4.1 Science coordination

A second principal activity of the NYCDEP Climate Change Task Force is science coordination. It is essential, if agencies are to get the most out of their investments in research, that climate change science be coordinated across the research spectrum, such as by the use of consistent assumptions from scenarios, and inputs from social scientists, and other experts. As an example of science coordination, Columbia University has coordinated a multi-institution project that integrates scenarios of climate change and sea-level rise, hurricane and nor'easter storm-surge modeling, and a digital elevation program to estimate flooding risks to coastal infrastructure. An initial application of this coordinated science effort has resulted in estimates of storm surges with and without sea-level rise. For this comparison, the Nor'easter of 1992 and a sea-level rise of 47.2 cm for the 2050s was used (NYCDEP 2006 prepared by HydroQual) (Fig. 5).

The map in Fig. 5 has been important in calling the attention of NYC's decision-makers to the need for adaptation to sea-level rise and storm surges. It also provides an early guide to the need for floodwalls at various locations as well as the need to address the effects of sea-level rise on wetlands. It should be noted that the 1992 storm was a moderate event and that much greater inundation for the projected sea-level rise shown can be expected over a wider range of storms.

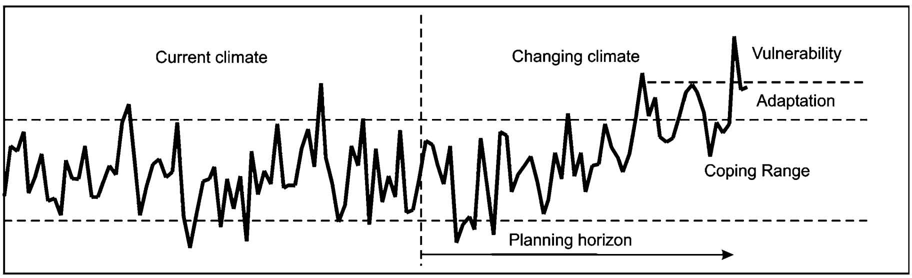

Fig. 4 Coping ranges and strategies (re-drawn based upon Ayers et al. 2003)

Fig. 5 Comparison of Nor'easter of 1992 and a sea level rise estimate of 47.2 cm for 2050

Additional coordinated efforts may include updating the region's rainfall intensity-duration-frequency (IDF) curves to include possible effects of climate change on extreme rainfall. These curves are instrumental to the design of adequate sewer infrastructure that minimizes the occurrence of CSO events. Preliminary work is also being conducted on how NYCDEP watershed models can be linked to regional climate scenarios. Because forecasts of water quality and quantity from these NYCDEP models assist NYCDEP decision-making, incorporating climate change data can help to plan future policy, operations management, and investment decisions.

In addition to the scenarios, several low-probability but high impact events are considered as a way of insuring that the possibility of surprises is factored into long-term adaptation planning. Examples of these are the potential melting of the West Antarctic and Greenland Ice Sheets (see, e.g., Overpeck et al. 2006) and the slowing or cessation of the North Atlantic thermohaline circulation (Peterson et al. 2002). While these events need to be considered within a timeframe of several centuries in contrast to the timeframe of the GCM scenarios of a single century, their impacts are far reaching and need to be recognized. For the former, each of the icesheets could add 4–6 m to regional sea level rise, presumably over a long time period; the latter could result in a cooling influence in Northern Europe. These serve both as concrete possibilities in and of themselves and also as examples of other possible surprises. In the relatively recent past, an extraordinary event that affected climate was the great earthquake in Krakatoa, Indonesia, in 1883, which affected, through the cooling effects of aerosols, ocean temperatures for decades (Gleckler et al. 2006).

5 Adaptation assessment

The NYCDEP Climate Change Program is designed to encompass the full range of decision-making tools required to go from climate impacts and scenarios to project and program adaptation, review, and monitoring. A comprehensive framework for analyzing climate change has been created, including a 9-step Adaptation Assessment procedure (see Table 1). Potential climate change adaptations are divided into management, infrastructure, and policy categories, and are assessed by their relevance in terms of climate change time-frame (immediate, medium, and long term), the capital cycle, costs, and other impacts. The steps take into account changes that occur over time (such as population growth and changes in per capita water use) irrespective of climate change. Potential adaptations are designed to manage the risks of climate change to the NYCDEP's infrastructure, providing an overall coping strategy (Ayers et al. 2003) for the agency. The Adaptation Assessment steps are based on standard water-resource planning procedures (Goodman et al. 1984; Orth and Yoe 1997), with the significant addition of climate change and an explicit link to agency capital cycles to provide for efficient incorporation of adaptations during rehabilitation and replacement. While these steps are comprehensive, climate adaptations for particular circumstances may require additional steps (as, for example, securing external funding for adaptations in developing countries). (For a general review of adaptation issues, see IPCC 2001b, ch. 1.)

Table 1 Adaptation assessment steps

Adaptation assessment
Identify risk
Proposed project
Current infrastructure component
Ability to fulfill mandated responsibility
Identify main climate change impacts to that project
Apply future climate change scenarios
Characterize adaptation options:
Operations management
Investments in infrastructure, and/or
Policy
Conduct initial feasibility screening
Link to capital cycles
Evaluate options: e.g., benefit and cost analysis
Develop implementation plans, including timeframe for implementation
Monitor and reassess

The NYCDEP Climate Change Task Force has proceeded in a variety of ways to implement the Adaptation Assessment procedure, with the majority of early work being done on the first steps. However, certain identified adaptations have already progressed to the point where the development of implementation plans can be considered (Step 8 of the Adaptation Assessment framework).

Monitoring and reassessment (Step 9) are usually thought of as characteristics of completed adaptations, but work has also proceeded in this area through the development and evaluation of indicators that can be tracked to assess and monitor the need for, as well as the performance of, specified adaptations (see, e.g., Clean Air—Cool Planet 2005). For example, potential indicators include the melting dates of snowpack, tracked over time to assist in adapting reservoir system operations to climate change. Similarly, flora and fauna transitions in the upland watersheds can be monitored and used as indicators of the need for changes to watershed protection programs, or additions to water quality improvement measures.

5.1 Potential adaptations

A wide range of potential adaptations has been examined, including *management and operations adaptations*, such as new criteria for system operations that reflect non-stationary hydrologic processes; *infrastructure investment options*, such as storm surge barriers for WPCPs; and *policy changes*, such as integrated operations with other systems. It should be noted that many identified adaptations fall into several categories. The process of developing adaptations in the Climate Change Program began with suggestions and examples from the MEC report (Rosenzweig and Solecki 2001 ch. 6; Hansler and Major 1999), dealing primarily with the upstate water collection and delivery systems. Then, the Bureaus of the NYCDEP developed a variety of other potential and more specific adaptations for their infrastructure and programs, working with university researchers.

The NYCDEP is currently undertaking a Water Dependability Study, an intensive effort to identify ways for the City to continue supplying adequate amounts and qualities of water if any element of the water supply system goes off line in an emergency or for an extended period of time for system repairs (NYCDEP n.d.). Alternatives under consideration include redundant tunnels, demand reduction measures, and alternate supplies and storage such as system interconnections, expansion of the groundwater system, groundwater banking of surface water, and desalination of brackish ground water and harbor water. This effort to improve the robustness and resiliency of the water supply system will have the co-benefit of decreasing the vulnerability of the system in the face of climate change. Additionally, proactive planning can allow NYCDEP to integrate climate change considerations into the Dependability Study. For example, sea-level rise and storm surge must be taken into account when selecting coastal sites for new system facilities.

5.1.1 Examples of potential management and operations adaptations

Perhaps the most significant early adaptation study at the NYCDEP is a proposed assessment of the design and operation of the sewer and wastewater treatment systems with rising sea levels and increases in storm intensity. In NYC, as in most coastal jurisdictions, these systems have been designed for existing sea levels. As sea levels rise and storm surges increase, the operations of the systems will be increasingly compromised. This study will investigate time-phased management and investment adaptations, such as an enhanced tide gate program and operational changes to deal with backsurge problems in the early stages of sea-level rise. For still higher levels of potential infrastructure investments, other adaptations may be necessary, such as increasing pumping capacity at WPCPs that now discharge effluent by gravity outfalls, even though pumping is very costly and energy intensive.

Another important area for management and operations adaptations is the incorporation of scenario results into the design process for drainage structures; on the whole this is a new challenge for planners and engineers (Frederick et al. 1997). One example in the NYCDEP work is the use of updated rainfall IDF curves to design drainage structures. Updated curves have been produced with data, including extreme events, for recent decades as a result of the Task Force program. An assessment is underway to consider how to best adapt to new precipitation regimes (HydroQual 2006) (Fig. 6). This work will involve the use of GCM simulation results for future time periods to adapt or re-scale the new IDF curves to take into account changing rainfall patterns. These assessments can then be used in the design of drainage elements in place of those calculated on the basis of current data; the extent of design changes, a matter of detailed engineering review, remains to be determined.

Many operational adaptations may come from the use of water system simulation models run with outputs from the scenarios. The NYCDEP is the only non-European member of the European Union CLIME project (Moore et al. 2004), and in this context is using integrated regional climate and water quality models to study how climate change may affect water quality in the upstate watersheds (Fig. 7). In other NYCDEP modeling efforts, attempts are underway to consider how reservoir system simulation models and

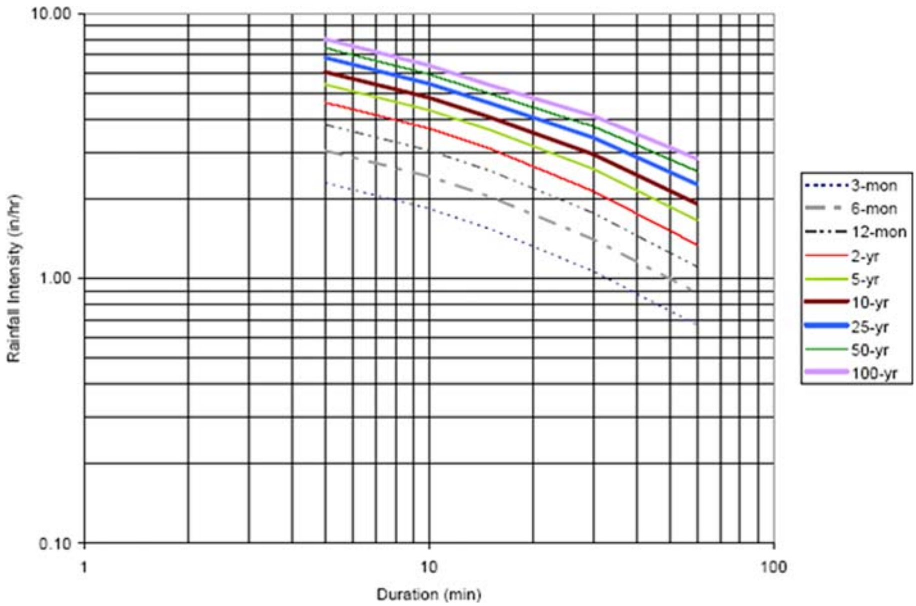

Fig. 6 Precipitation intensity duration frequency curves for the NYC study area for 5–60 min. Application of the *N*-min ratios to the 60-min quantiles results in the 5, 10, 15, and 30-min duration IDF curves for each return interval. The 60-min precipitation quantiles are used with the *N*-minute ratios to form the estimates at the lesser durations. This figure shows the sub-hourly durations

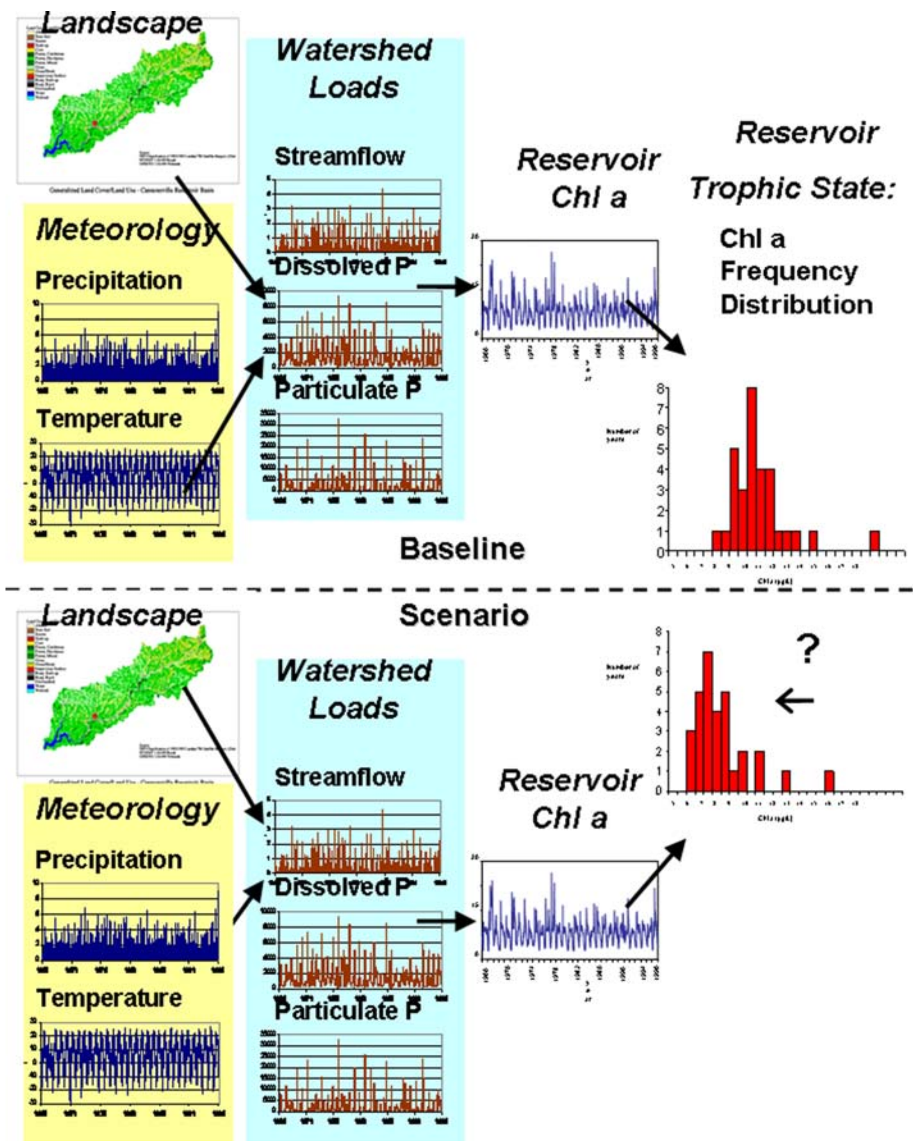

Fig. 7 Simulating reservoir loadings with the CLIME model system (source: Moore et al. 2004)

in-City sewershed models can be used with inputs from the GCMs, perhaps using synthetic hydrology methods, to study the operation of the water supply system at times when there are expected to be both more frequent floods and more frequent droughts.

Other operational changes may include further efforts to reduce consumption, which itself is an important adaptation to climate change because of its ability to increase the resiliency of the existing system. NYCDEP's successful conservation programs since the mid 1980s, including a program for universal metering of water use and a change-out program for toilets, decreased consumption in the 1990s by 300 mgd, more than twice the current daily yield of the entire Croton system (New York City Department of Environmental Conservation 2004). There are still opportunities for further conservation, including programs for more efficient water use in restaurants and other small businesses (NYCDEP 2005b). Another potential change is in drought rules; if droughts become more frequent, as is expected based on climate simulations, these rules may need to be adapted to provide, through regulation and pricing, more effective water restrictions. Finally, the incorporation of climate change considerations into NYC's environmental review process can be studied. To facilitate this, an analysis of the current review standards (NYC OEC 2001) was undertaken by the Task Force to identify the entry points in the document where considerations of climate change impacts and responses could be required.

5.1.2 Examples of potential infrastructure investment adaptations

Climate change will bring with it the need for substantial adaptations in infrastructure, including, perhaps, substantial financial outlays. Among the many potential infrastructural adaptations are flood walls for WPCPs (Fig. 8), implemented during the rehabilitation cycle to reduce costs; system interconnections; the potential relocation of the Hudson River intake of the Chelsea Pump Station (Fig. 9), the City's emergency water pumping facility, as the salt front intrudes further into the Hudson estuary; and physical changes in the sewer system (including increased pumping) as sea-level rises (Rosenzweig and Solecki 2001). An important next step is planning for detailed cost-benefit studies to estimate net benefits and reduce fiduciary risk.

5.1.3 Examples of potential policy adaptations

Adaptations that require policy decisions include those involving joint operation of systems run by different authorities, of which some examples exist already. These include a recent

Fig. 8 Photo of treatment tanks overflowing at a Bronx WPCP during March 2001 storm

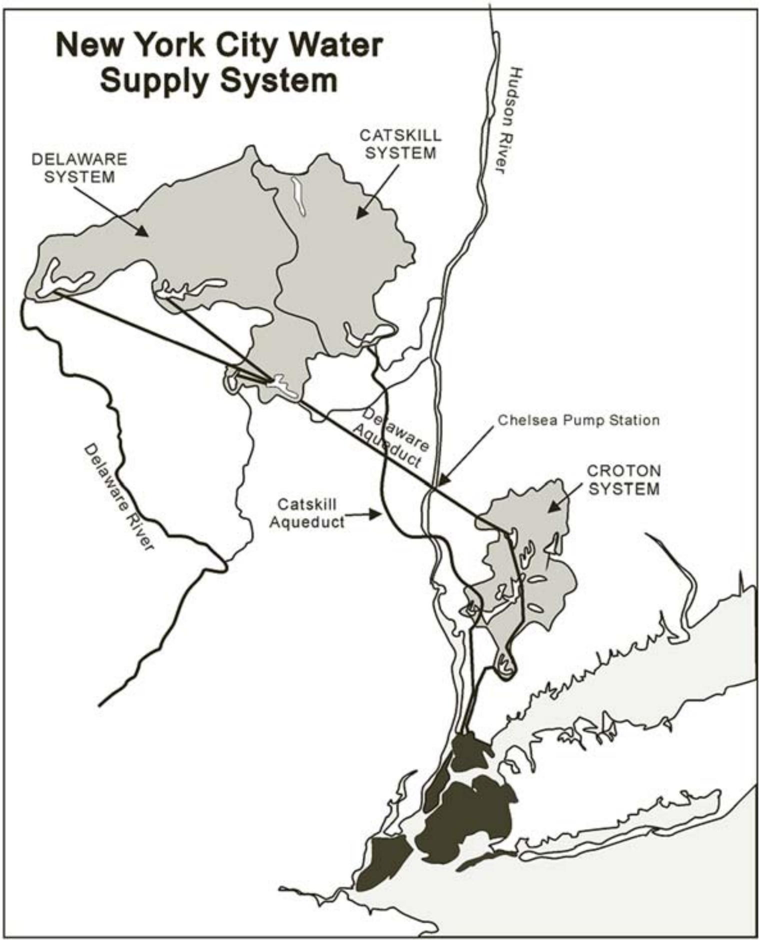

Fig. 9 NYC Water Supply System, note Chelsea Pump Station

modification of operating rules at Lake Wallenpaupack, in the Delaware Basin, to provide for changes in releases and more flexible joint operations involving a private utility, the Delaware River Basin Commission, and NYC (DePalma 2004). Another example is storage reallocation at the F.E. Walter Dam in the Lehigh Valley, built as a Federal flood control dam (Rosenzweig and Solecki 2001). The storage allocations have been modified to provide water supply both from formal agreements and informally during drought. Further into the future large potential adaptations involving joint operations and investment might include joint operations with Delaware River Basin facilities or even a proposed NYC-Long Island interconnection (Rosenzweig and Solecki 2001).

6 Mitigation

In addition to its adaptation activities, the NYCDEP Climate Change Program included the development of a GHG management program, with the aim of fostering an internal capability to monitor and evaluate agency-wide emissions and to advance emission reduction opportunities. GHG inventory software has been used for an initial emissions assessment of 1995 and 2004 electricity and natural gas consumption (ICLEI 2005). Because this assessment identified the WPCPs as NYCDEP's major emitters (without taking into account process or fugitive emissions), NYCDEP's first step in emissions reduction is the development of WPCP Facility Greenhouse Gas Management Plans. For example, methane from the treatment process can be used as an energy source. While mitigation and adaptation are frequently dealt with separately in planning and implementation, there is an internal logic, as well as practical benefits, to considering them within the same institutional structure.

7 Interactions with other regional agencies

An outcome of current NYCDEP Climate Change Task Force outreach efforts and interaction with other agencies, both in NYC and regionally, is the inclusion of climate change as one of the key topics in Mayor Michael Bloomberg's newly created Office of Long-term Planning and Sustainability. This activity could contribute to the eventual formation of a regional climate change consortium and risk management working group. NYCDEP Climate Change Task Force efforts have included numerous meetings with other city agencies, as well as contacts with and presentations to regional groups. Such a regional effort is needed since many climate change impacts and adaptation strategies span several agencies and jurisdictions, including shared infrastructure and coordinated operations of reservoirs and other facilities.

A key area is coastal development in urban areas under long-term sea-level rise, which presents a looming challenge. A long-term institutional relationship among city and regional agencies along the lines of the NYCDEP Climate Change Task Force could greatly facilitate planning and implementation of these efforts. Such an interagency group effort will be able to coordinate efficiently by relying on a consistent set of scenarios based on the regional scenarios developed for NYCDEP, thus ensuring that the City of New York as a whole and the greater New York Metropolitan Region are prepared for future climate change.

8 Conclusions

NYCDEP has made substantial progress toward embedding climate change into the standard decision-making process of a large agency responsible for steady provision of clean water and its safe disposal after use. The methodology, operational structure, and accomplishments of the NYCDEP Climate Change Program are believed to be practical, implementable, and worthwhile for many of the coastal cities of the world, all of which face broadly similar problems from sea-level rise, higher temperatures, changing precipitation patters, and potential increases in extreme events. It should be noted, however, that applications in many developing countries will face challenging problems of funding and engineering, scientific and management capabilities. The total amount of funds required for urban adaptations worldwide has not been estimated, but the dollar amounts will be significant for water supply, sewer, and wastewater treatment systems, let alone for transportation and other sectors. However, great fiduciary advantages can be gained by early planning linked to the capital cycles of different types of infrastructure, and many of the advantages accrued will extend beyond the realm of climate-related issues.

The elements of the NYCDEP program that have been most successful to date include the substantial time spent in intra-agency discussions on climate change, its impacts, and possible adaptations, and the strong link of the program to climate science. It is foreseen that NYCDEP will continue to have relationships with universities and research institutions to take advantage of continuously advancing scientific research. The two most important results of the program to date both emerged from the extensive agency discussions that were part of the climate change program: (1) a sewer and wastewater treatment study, now in development, of the impacts of sea level rise; and (2) the development of an integrated modeling system, based on current NYCDEP watershed models, to examine the effects of climate change on the watersheds and system operation, The linkage to climate science has focused on the need to prepare for a range of outcomes, i.e., risks, in planning, and, in detailed engineering design, to focus on non-stationary rather than stationary processes. Perhaps the most limiting factor in agency planning, including that of the NYCDEP, is the very long lead times required for decision-making, which for large projects can stretch into several decades due to bidding and approval processes, regulatory issues, and the allocation of funds. Incorporating climate change into decisions at the earliest possible stage is the most effective and least costly way of dealing with such lags. One element that remains to be developed, and will no doubt require interactions between regulators and planners, is the development of suitable review procedures and criteria for climate change within the context of environmental assessments.

Managing risk by adapting long-lived infrastructure to the effects of climate change must become a normal part of urban and watershed planning during this century. One additional step forward should be the development of linkages among coastal urban areas to share approaches and results, both for adaptation and mitigation. The work of the NCYDEP Climate Change Task Force provides a framework that enables agencies to incorporate the impacts of climate change in their management, investment, and policy decisions over the long term. Another key attribute is the consideration of both climate change mitigation and adaptation actions within the same institutional structure, since some adaptation actions can serve mitigation purposes (e.g., establishment of green roofs on facilities can simultaneously cool employees and reduce fossil fuel consumption for air-conditioning). The NYCDEP approach is one of the most advanced thus far, and has benefited from several favorable elements, including excellent agency management and the availability in the urban region of a strong scientific community, including a leading climate science institution (NASA's Goddard Institute for Space Studies, located on the Columbia University campus). But as more experience is gained, adaptation to climate change will become more routine and will not require exceptional circumstances. The most important point is that risk management for climate change in urban areas should begin now. Such planning will improve current decision-making, and ensure that an optimal framework is in place for future decisions based on evolving climate information.

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