The City of New York

The New York City Department of Environmental Protection

CLIMATE CHANGE PROGRAM

Assessment and Action Plan

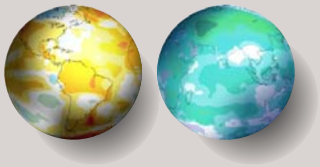
MAY 2008

REPORT 1

A Report Based on the Ongoing Work of the DEP Climate Change Task Force

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

Emily Lloyd, Commissioner



This Report presents the initial steps that the New York City Department of Environmental Protection (DEP) has taken over the past four years to address climate change. The Report includes the findings and recommendations to date of DEP's Climate Change Program and Task Force and the immediate actions that DEP is committed to undertaking to further address this critical issue. The policy and program recommendations of the Report are those of DEP.

Angela Licata
Deputy Commissioner

Gary C. Heath
Director of Bureau Operations

Acknowledgments

DEP wishes to thank the New York City Water Board for its support of DEP's Climate Change Program. The approximately $1.5 million in funding from the Board has allowed DEP to establish a strong foundation on which to build a comprehensive long-term strategy for addressing the challenges of climate change.

DEP's Bureau of Environmental Planning and Analysis, as the leader of DEP's Climate Change Program, wishes to acknowledge and thank the members of the DEP Climate Change Task Force for their dedication, invaluable expertise, and extensive contributions to this Report. Cooperation and involvement throughout DEP helped us meet our primary goals of interdisciplinary awareness of and attention to climate change issues. The Task Force members include representatives from all DEP Bureaus as well as participants from outside the Department: the Columbia University Center for Climate Systems Research, the NASA Goddard Institute for Space Studies, HydroQual Environmental Engineers & Scientists, P.C., the New York City Office of Environmental Coordination, the Mayor's Office of Long-term Planning and Sustainability and the New York City Law Department.

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The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM

Foreword

By Emily Lloyd

The impacts of climate change will be pervasive and profound. Most natural and man-made systems will be affected, and the City of New York's water supply, drainage, and wastewater management systems are no exception. To overcome the challenges of climate change, as stewards of the City's water systems, we at the New York City Department of Environmental Protection are placing our response to climate change at the core of our strategic and capital planning. This Report is the first in a series of reports that presents the many steps that the Department has already taken to address climate change, and it outlines the Department's initial plan of action for continuing to confront the most critical environmental issue of our time. In future reports we hope to chronicle our achievements.

In essence, the Department's plan is to adapt the City's water systems to withstand climate changes in the City and upstate watershed while simultaneously striving to help minimize those changes. First, I am working with the Department's highly-skilled planners, engineers, and operators to adapt our infrastructure so that the City is able to continue to provide water services to New Yorkers even as changes occur to temperatures, rainfall patterns, snowpack, storm intensity, and sea level. Successful adaptation will require that we rethink our traditional approach of designing infrastructure based on the weather patterns and sea level experienced in the past, and move towards a new approach of risk-based design for the range of climate conditions projected for the future. These changes can also help to improve our systems resiliency to current weather extremes. Second, we are working to reduce the Department's greenhouse gas emissions by incorporating process improvements, energy efficiency, and renewable energy into facility planning.

The Department's response to climate change complements the goals of PlaNYC, Mayor Michael Bloomberg's plan for a greener, greater, sustainable New York. Integral to PlaNYC is a strategy for reducing water demand, preserving the first-rate quality of our drinking water, maintaining our City's water infrastructure, and improving the water quality of New York City's great harbor. The Department's Climate Change Program will help the City achieve these PlaNYC goals, and implementation of PlaNYC will make the City's water systems more resilient, thus helping the Department to ensure the reliability of vital water services despite the pressures of a changing climate. Furthermore, to assist the global community in slowing the pace of climate change, PlaNYC aims to reduce New York City government greenhouse gas emissions by 30% by 2017. The Department, which is responsible for 17% of total City government emissions, is committed to reducing its emissions to help the Mayor achieve this goal.

Addressing climate change will prove difficult. The issues are new and complex, the timing and extent of change is uncertain, and modifying large-scale infrastructure systems is expensive and takes time. But with careful planning, we can succeed. The Department is committed to minimizing climate change risk, we have the support of our visionary Mayor, and we will not be tackling the issue alone; we are cooperating with other water agencies and utilities, both nationally and internationally, to share knowledge and spur innovation. The Department has already made significant progress, but there is still much to do and the time to take action is now.

Emily Lloyd
Commissioner, NYCDEP

Executive Summary

The Earth is warming. Atmospheric and oceanic temperatures are rising, and extensive scientific modeling predicts more dramatic increases into the future. As these trends accelerate, sea level will rise, and a more volatile climate with unpredictable precipitation patterns and more intense storms will be likely. In order to effectively anticipate and confront these climatic shifts, policymakers must begin to act now.

Climate change must be considered in all short-term and long-term infrastructure and policy planning initiatives.

Greenhouse gas (GHG) emissions must be rigorously identified and cataloged. Comprehensive plans for emissions reductions must be developed and implemented. And potential risks must be identified and addressed so that essential services can continue to be provided as the climate changes.

In recognition of this charge, the New York City Department of Environmental Protection (DEP or the Department), which is responsible for providing water supply, drainage, and wastewater management services to millions of New Yorkers, has developed a comprehensive Climate Change Program. Through this program, DEP works closely with leading scientists and engineers to project regional climate changes; assesses the impacts of a warming Earth on New York City's water systems; and identifies opportunities for meaningful change.

Based on this work, and in accordance with PlaNYC, Mayor Michael Bloomberg's plan for a sustainable City, DEP has begun to implement many programs that address global climate change and its projected impacts on New York City's drinking water delivery, stormwater management and wastewater treatment systems. The following Report summarizes this substantial process of analysis and action and outlines a comprehensive adaptation strategy for DEP as it prepares for a warmer and more volatile future.

"The impacts of climate change will be pervasive and profound. Most natural and man-made systems will be affected, and the City of New York's water supply, drainage, and wastewater management systems are no exception...the time to take action is now."

Emily Lloyd
Commissioner, NYCDEP

ES1 | A Context for Action: Climate Change Science

Scientific evidence indicates that human activities such as the burning of fossil fuels and land use change are producing unprecedented quantities of heat-trapping GHGs, including carbon dioxide, methane, and nitrous oxide. GHG concentrations in the atmosphere are now greater than at any time in the last 650,000 years. Scientists agree that the pronounced increase in atmospheric GHGs since the mid-19th century is very likely to have fueled the simultaneous increase in global average atmospheric temperature.

Extensive data indicate that changes in New York City's regional climate have been consistent with changes in global GHG concentrations and atmospheric temperature. In the New York City region from 1900 to 2005, the annual average temperature rose by approximately 1.9ºF, the annual average precipitation increased by approximately 4.2 inches (an increase of nearly 10%), and the sea level rose by approximately one foot.

Modeling projections performed for DEP by the Columbia University Center for Climate Systems Research and the NASA Goddard Institute for Space Studies at Columbia University (Columbia University) indicate that by the 2080s the most probable amounts of change in New York City and its Watershed Region will be 7.5ºF to 8.0ºF increase in temperature, a 7.5% to 10% increase in precipitation, and a 15.7 to 17.7 inch rise in sea level. Scientists anticipate that extreme weather events will also be more frequent.

The Intergovernmental Panel on Climate Change (IPCC) states that on a global scale during the 21st century, it is:

>99%

Virtually certain that there will be warmer and more frequent hot days and nights over most land areas

>90%

Very likely that there will be more warm spells, heat waves, and heavy precipitation events over most areas

>66%

Likely that there will be increases in drought-stricken areas, more intense hurricane activity, and an increased incidence of extreme high sea level

ES2 | DEP's Climate Change Action Plan

As the potential impacts of climate change became clearer, and as scientific consensus grew, DEP realized the critical need for an internal program devoted to climate change and its relevance to Department infrastructure and operations. In 2003, DEP established partnerships with a range of scientists and engineers and created a formal Climate Change Task Force to oversee the Department's investigation of and preparation for the potential risks associated with climate change.

In 2004, the Climate Change Task Force which includes members from multiple internal Bureaus and participants from Columbia University, HydroQual, Mayor Bloomberg's Offices of Environmental Coordination and Long-Term Planning and Sustainability, and the New York City Law Department was formed to provide additional guidance to DEP in recognition of the increasing importance of developing a comprehensive climate change assessment and action plan.

Led by the Task Force, the mission of DEP's Climate Change Program is to ensure that all aspects of Departmental planning: 1) take into account the potential risks of climate change on the City's water supply, drainage, and wastewater management systems, and 2) integrate GHG emissions management to the greatest extent possible.

In generating this Report, the Task Force conducted extensive internal interviews to identify potential impacts to DEP, frequently met with key science advisors, initiated a preliminary inventory of DEP's own GHG emissions, and participated in several major national and international conferences to share ideas and establish active partnerships with other municipalities and utilities around the world.

DEP's Action Plan

DEP has developed a comprehensive Climate Change Action Plan to address the effects of atmospheric warming and global climate change on its water supply, drainage, wastewater and water quality protection operations, and strategies for greenhouse gas mitigation.

Using this information as a foundation, the Task Force has established a Climate Change Action Plan in order to properly address the potential repercussions of global climate change on DEP's operations. The Action Plan includes the following tasks:

TASK 1: Work with climate scientists to improve regional climate change projections.

TASK 2: Enhance DEP's understanding of the potential impacts of climate change on the Department's operations.

TASK 3: Determine and implement appropriate adaptations to DEP's water sytems.

TASK 4: Inventory and manage greenhouse gas emissions.

TASK 5: Improve communication and tracking mechanisms.

The following sections summarize the climate change-related issues identified by the Task Force, and the Department's progress and priorities in addressing these concerns. A more detailed presentation of DEP's Climate Change Action Plan is summarized in tabular form in Chapter 6.

TASK 1 Work with Climate Scientists to Improve Regional Climate Change Projections

The Challenge

Until now, much of DEP's water supply, drainage, and wastewater management planning has been guided by historical data for climate-related variables, such as temperature, precipitation, sea level, drought, and flooding. For its systems to continue to effectively function over the coming decades, DEP's planning and investments must instead be informed by the range of future climate conditions projected by global climate models. Because the Department will adopt different strategies for adjusting its systems to climate change, uncertainty in the projections must be minimized. Working with the scientific community, DEP must continually improve its regional climate modeling.

DEP's Progress

DEP has funded the development of a set of regional climate change projections that are based on data from the best available global climate models. DEP now has the most comprehensive set of climate data that has been produced for New York City and its Watershed Region: Columbia University and NASA have provided annual projections for temperature, precipitation and sea level for the 2020s, 2050s, and 2080s. Additional projections have also been provided for shorter time periods and other climate variables.

DEP's Priorities

To further advance this task, DEP will:

- Work with regulatory and other agencies on the PlaNYC initiative to update the existing 100-year flood elevations using current sea level data and develop agreed-upon estimates of future 100-year flood elevations, sea level rise, storm intensity, and maximum probable flood using climate change projections.
- Test a Regional Climate Model to New York City and its watersheds to create projections on smaller spatial scales and timescales that take into account local topography.
- Identify additional data and monitoring stations needed to track global and regional climate changes.

Image courtesy of NASA Johnson Space Center

See Chapter 1 for a full discussion of the climate change science and projections that DEP is now using for its climate change planning and the actions that DEP is taking to reduce uncertainty in climate change trends and projections. The actions are also summarized in Chapters 5 and 6 of the Report.

TASK 2 Enhance DEP's Understanding of the Potential Impacts of Climate Change on the Department

The Challenge

At the magnitudes currently anticipated, climate change could compromise the existing water supply and treatment systems in the following ways:

WATER SUPPLY SYSTEM

- Changing precipitation patterns could increase the frequency and severity of droughts and flooding.
- Heavier precipitation and more frequent storms could threaten DEP's unfiltered water systems by washing additional nutrients and particles into the reservoirs and increasing pathogen levels.
- Both droughts and sea level rise could cause salt fronts to encroach upon the Hudson and Delaware Rivers and threaten the water supply of neighboring jurisdictions and New York City's emergency supply.
- More frequent heat waves could increase water demand.
- Warmer weather could both reduce snowpack, which would decrease the amount of water stored in the watershed, and extend the growing season, which would increase the uptake of water by vegetation and thus reduce flows into reservoirs.
- Impacts to stream ecology from warmer weather may lead to more pressure for New York City to make additional reservoir releases for ecological management purposes.

DRAINAGE AND WASTEWATER MANAGEMENT SYSTEMS

- More frequent intense rainfalls could cause more flooding of streets and basements and overwhelm the capacities of sewers and treatment facilities.
- More frequent coastal storms could cause more damage to critical infrastructure.
- Rising seas could cause backups in the sewers and wastewater treatment facilities.
- Increased temperature of harbor waters could affect aquatic life.

Because modifying its infrastructure is both time-consuming and expensive, DEP must identify potential risks to, and anticipate potential needs of, its infrastructure well into the future. To identify the adjustments that are most cost-effective and likely to minimize climate change impacts, the potential range of risks and the probability of their occurrence must be quantified.

DEP's Progress

DEP has performed a preliminary study of climate change and its potential impacts on New York City's systems for water supply, stormwater management, and wastewater treatment. Task Force members have conducted extensive interviews with system operators to catalog known and projected system vulnerabilities. In addition, a detailed plan for further study and quantification of impacts has been outlined.

DEP's Priorities

To further advance this task, DEP will:

- Conduct a phased, integrated modeling project to quantify and provide a more comprehensive understanding of the potential impacts of climate change on drinking water quality, supply and demand.
- Conduct an integrated modeling, inundation and flood mapping, and cost/benefit analysis project to quantify and provide a more comprehensive understanding of the potential impacts of climate change on drainage, wastewater treatment processes and infrastructure, and harbor water quality.
- Establish a uniform Department-wide system for documenting and reporting the occurrence, levels, and impacts of flooding and other extreme weather events on DEP's systems in the watershed and in the City.
- Identify additional data and monitoring stations needed to track global and regional climate changes.

See Chapter 2 for a full discussion of the potential impacts of climate change on New York City's drinking water, drainage, and wastewater systems and the actions that DEP is taking to further study and quantify the impacts. The potential impacts and the actions are also summarized in Chapters 5 and 6 of the Report.

TASK 3 Determine and Implement Appropriate Adaptations to DEP's Water Systems

The Challenge

DEP is continually making substantial investments in its infrastructure, which is designed and built to last for decades. Indeed, the Department's current 10-year capital program is approximately $20 billion. DEP's infrastructure, as well as its operations, programs, and policies, has been designed on the assumption that future climate and sea level changes will follow historical patterns. But as global warming alters the regional climate, these critical assumptions will become less dependable predictors of risk. Therefore, in order to minimize the impacts of climate change on its water systems, DEP must modify the assumptions on which its current planning and investments are based.

Adjusting DEP's systems will be challenging because the extent of climate change is uncertain, yet the requirements of engineering are very precise. In addition, with millions of customers, thousands of miles of tunnels and pipes, and hundreds of facilities, DEP's systems are not only vital, but also vast. DEP will thus need to work to balance the need to swiftly adjust its infrastructure with the need to make prudent decisions and capital investments.

DEP's Progress

DEP is committed to taking climate change into account in all strategic and capital planning. To achieve this goal, the Department has pushed to ensure that its planners, engineers, operators, and managers are cognizant of and considering the potential risks that climate change may pose to the City's infrastructure. DEP has begun to plan for climate change and implement strategies for adapting its systems at the earliest possible time with the goal of minimizing future service disruptions and financial demands on water and sewer ratepayers.

Most of DEP's ongoing programs and system upgrades can and will be built to improve system resiliency to future climate conditions. However, a more comprehensive effort is needed to build and maintain flexible systems capable of withstanding global climate change. DEP has made a formidable start in identifying many possible strategies for adapting its infrastructure to changes in climate conditions. The Department has identified priority actions that can be initiated immediately, as well as alternative adaptation strategies that, concurrently with DEP's work to refine climate projections and quantify climate change impacts, need to be further evaluated including their cost effectiveness.

In addition, as part of PlaNYC, DEP has worked with Mayor Bloomberg's office over the past year to identify system improvements that will help guarantee through at least 2030 continued delivery of an adequate supply of high-quality drinking water to upstate and in-City customers, reduce street flooding in the City, and improve harbor water quality. The City has committed to these actions primarily to meet regulatory requirements, address the aging of the City's infrastructure, anticipate a growing population, and achieve PlaNYC's goal of opening 90% of the City's waterways for recreation. However, these actions, which include measures to maintain and deliver an adequate amount of high-quality drinking water, reduce water demand, and implement stormwater Best Management Practices, will also considerably improve DEP's ability to provide water services under climate change scenarios that may compromise the water systems.

DEP's Priorities

To further advance this task, DEP will:

- Add climate change as a factor in DEP's Risk Prioritization, which is used to prioritize projects and allocate funding by assessing the probability and severity of infrastructure failure and the associated costs, in order to ensure that additional risks due to climate change are reflected in the Department's capital planning.
- Identify and evaluate potential adaptation strategies based on the findings of each phase of DEP's integrated modeling project to study the impacts of climate change on the water supply system.
- Identify and evaluate a range of adaptation strategies based on the findings of DEP's project to identify the magnitude and location of climate change impacts on drainage, wastewater management facilities, and harbor water quality, and develop a long-term, phased strategy for implementing the adaptation measures. Most immediately, DEP will evaluate flood protection measures for the three Water Pollution Control Plants (WPCPs) that will soon undergo rehabilitation, Rockaway, Hunts Point, and Tallman Island.

See Chapter 3 for a full discussion of potential adaptation strategies for New York City's water systems, the ongoing DEP programs and PlaNYC initiatives on which the Department will build to address climate change, and the actions that DEP is taking to determine and implement appropriate adjustments to the water systems. The potential adaptations and actions are also summarized in Chapters 5 and 6 of the Report.

TASK 4 Inventory and Manage Greenhouse Gas Emissions

The Challenge

In order for New York City to assist in the global effort to slow the pace of climate change, PlaNYC set an ambitious target of reducing the City government's GHG emissions by 30% below 2006 levels by 2017. A City-wide emissions inventory conducted by Mayor Bloomberg's Office calculated that, in 2006, DEP's water supply, stormwater, and wastewater management facilities accounted for 17% of total City of New York government emissions. Thus, reductions at DEP facilities should appreciably assist the City in achieving its GHG reduction goal.

DEP owns and operates a large number of very diverse GHG emissions sources, including hundreds of stationary combustion sources at major facilities and a fleet of over 2,000 mobile sources. Thus, systematic integration of GHG emissions management strategies into all aspects of Departmental planning, engineering, and construction will be necessary to effectively reduce DEP's GHG emissions. In order to reduce its carbon footprint DEP will need to maximize, to the extent practical, implementation of energy efficiency practices and use of renewable energy and alternative fuels. Further, through the forests and plantings that DEP manages both in the City's watershed and in its landfill and wetland restoration projects, DEP will be able to reduce its CO_2 emissions through carbon sequestering and absorption.

DEP's Progress

New York City, recognizing the consequences of climate change, has taken early action toward reducing its GHG emissions. In 2001 the City joined ICLEI – Local Governments for Sustainability – Cities for Climate Protection™ (CCP) Campaign and, as discussed above, PlaNYC has set an ambitious GHG emissions reduction target. The PlaNYC 30% reduction target will help guide and structure DEP's own efforts to build more efficient infrastructure and reduce emissions. New York City is also active in four major litigation initiatives aimed at limiting uncontrolled emissions of GHGs nationally; a recent ruling by the U.S. Supreme Court in one of these initiatives, hailed as one of the Court's most significant environmental decisions, could lead to regulation by the U.S. Environmental Protection Agency in this area.

Because a GHG emissions baseline must be established in order to measure emissions reductions, DEP has already completed initial baseline emissions inventories for DEP's energy use during the years 1995, 2004, and 2005. These inventories indicate that approximately 80% to 85%, excluding vehicles, of the Department's GHG emissions from energy consumption stem from WPCPs and sludge dewatering operations; thus DEP's initial focus for emissions management is on its WPCPs. Since 2003, at each of four DEP plants, the New York Power Authority has installed eight fuel cells powered by anaerobic digester gas (ADG) that otherwise would have been flared into the atmosphere. ADG is a by-product of the wastewater treatment process with very high methane content and global warming potential. Over the last four years, the fuel cells have consumed a total of 253 million cubic feet of ADG and generated 18.7 million kilowatt hours of clean power.

DEP's Priorities

To further advance this task, DEP will:

- Complete a comprehensive emissions inventory and a process for yearly updates. The first priority will be the 14 WPCPs (DEP's largest emitters), and the second-level priority will be DEP's vehicle fleet.
- Develop a Department-wide GHG management plan with facility-specific management plans that are integrated with the capital improvement program. DEP will first increase equipment efficiency during the planned upgrade of the Rockaway WPCP and use the improvements as a pilot for the development of GHG management plans for other facilities.
- Examine all current and pending construction contracts to see where energy can be used more efficiently. Most immediately, DEP will install more energy-efficient equipment during the planned replacement of boilers at the Port Richmond WPCP and generators at the 26th Ward WPCP.
- Reduce methane leaks from sewage processing equipment and expand the use of ADG for on-site energy production at the WPCPs.

See Chapter 4 for a broader discussion of GHG emissions and management in the City of New York and at DEP, New York City's ongoing legal efforts to ensure emissions reductions nationally, and the actions that DEP is taking to inventory and manage its GHG emissions. The actions are also summarized in Chapter 6 of the Report.

TASK 5 Improve Communication and Tracking Mechanisms

The Challenge

The success of Tasks 1 through 4 will depend on effective program management, and this in turn will require effective communication and measurement of performance. Extensive internal coordination as well as collaboration with other agencies and stakeholders will be necessary. Furthermore, performance benchmarks and key indicators for tracking and quantifying progress must be developed to enable project managers and other DEP staff to quickly identify and address obstacles or problems as they arise and provide DEP with a strong sense of tangible improvement and progress. A well-orchestrated approach to climate change will increase the efficiency of DEP's operations, guarantee a swift response to potential climate shifts, and enhance the oversight and management of key projects.

DEP's Progress to Date

Over the past four years, DEP's Climate Change Program and agency-wide Climate Change Task Force have built a strong foundation of knowledge about climate change science and projections, impacts, adaptations, and GHG mitigation in relation to the mission of the Department. This knowledge has allowed DEP to develop this Action Plan for holistic incorporation of climate change projections within the Department's long-term strategic and capital planning processes.

Through partnerships with scientists at Columbia University and other institutions, external collaboration with colleagues both within the United States and abroad, participation in conferences and workshops, membership with the Climate and Lake Impacts Program in Europe (CLIME) project, and presentations of the work of the Task Force to other agencies, DEP has begun a long-term endeavor to share knowledge and spur innovation.

DEP's Priorities

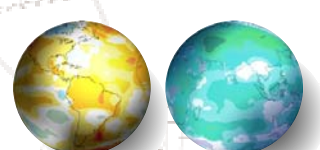
- Develop a plan for the continued success of DEP's Climate Change Program. The first two steps will be to:
  - Establish a senior-level steering committee to focus climate change efforts and permanently institutionalize the mission of DEP's Climate Change Program.
  - Establish a Climate Change Office within DEP's Bureau of Environmental Planning and Analysis. This Office will support the engineering and operating Bureaus by coordinating internal climate change activities and external outreach with other agencies and stakeholders, working to make climate change science more relevant and useful to DEP's policymakers and engineers, and serving as the central repository at DEP for climate change data.
- Develop a climate change intranet site to promote uniform data usage throughout all Bureaus, improve intra-Department information sharing, and enhance DEP's decision-making capabilities.
- Develop a reporting mechanism that sets performance benchmarks and establishes key indicators for tracking and quantifying progress.
- Participate in the new intergovernmental New York City Climate Change Task Force and the new Inter-agency Best Management Practices Task Force, both announced by Mayor Bloomberg as part of PlaNYC, in order to share and gain ideas, guidance, and logistical support from other Departments and stakeholders.
- Foster relationships with other water organizations, including the Water Utilities Climate Change Steering Committee sponsored by the San Francisco Public Utilities Commission, in order to exchange ideas, challenges, policies, and science; pool resources; and formulate research agendas that engage scientists and practitioners for shared problem-solving.

The actions that DEP is taking to improve communications and tracking mechanisms are summarized in Chapter 6 of the Report.

ES3 | Conclusion

This Report signifies a critical transition from analysis to action. By discussing in depth DEP's work to date and its Action Plan for addressing the challenge of climate change, the Report provides the Department and its operational and regulatory Bureaus with a point of reference for advancing its long-term strategic and capital planning with the added perspective of climate change. DEP is committed to this ongoing and evolving process because it will assist the Department in achieving its ultimate goal of providing high-quality water services to the people of New York City for decades to come.

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM



Climate Change Science, Observations, and Projections

1

In order to base Departmental climate change planning on the most current and sound science available, in 2003 DEP began working with the Columbia University Center for Climate Systems Research, the Earth Institute and the NASA Goddard Institute of Space Studies at Columbia University (Columbia University). In addition to developing a suite of customized regional climate change projections for the Department's planning and engineering, Columbia University also significantly enhanced DEP's understanding of climate change science, historical climate trends, Global Climate Models and future greenhouse gas (GHG) emissions scenarios. Columbia University has advised DEP of uncertainties related to model projections and the efforts being made to improve those projections, and outlined various methods for scaling global projections to regional levels. This Chapter outlines these topics and establishes priority actions for further refining DEP's understanding of regional climate projections to allow for their use in project and program planning. DEP actions to work with climate scientists to improve regional climate change projections are also summarized in tabular form in Chapter 6 of the Report.

Image courtesy of NASA Johnson Space Center

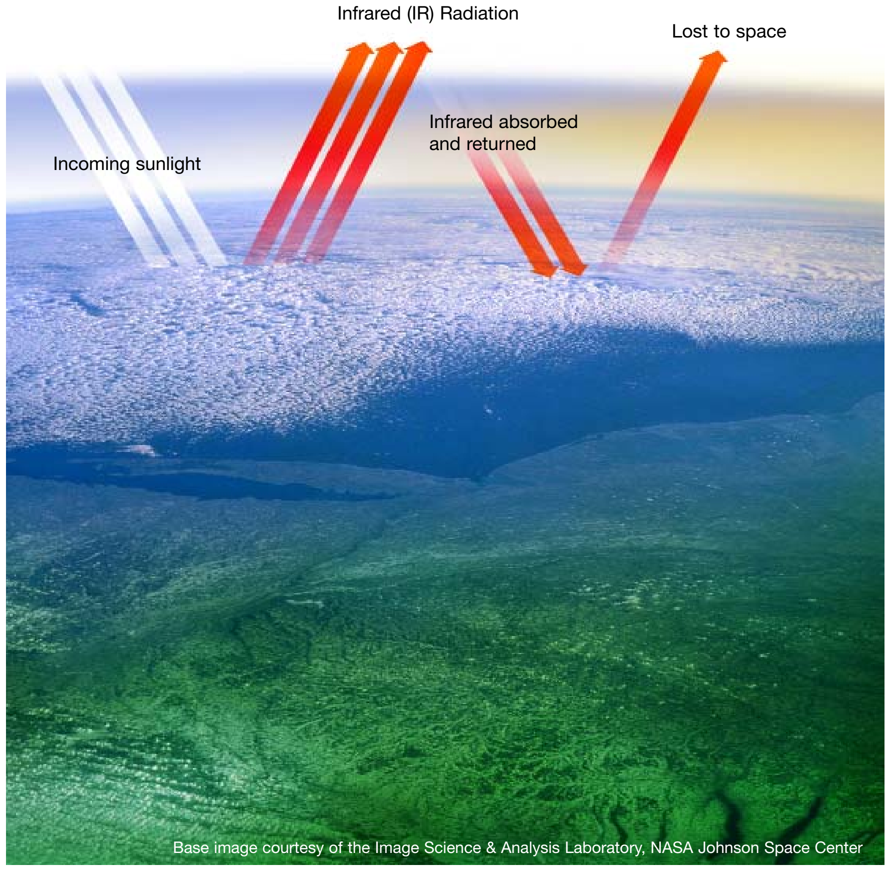
Human activity now produces GHGs at a rate of 70 million tons per day. New York City emits nearly 0.25% of the world's total greenhouse gases.

NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

1.1 Science of Climate Change

The climate of the Earth is naturally variable. The energy of the sun, which heats the Earth's surface and warms the atmosphere, varies in intensity because of changes in both the distance between the Earth and the sun and the tilt of the Earth's axis and wobble, which vary in regular cycles of approximately 100,000 years and 23,000 years, respectively. The heating of the Earth's surface and atmosphere are regulated by a number of other natural variables, including cloud formation, volcanic eruptions, land and sea ice, vegetation and ocean circulation. The natural oscillation of these factors causes the Earth's temperature to fluctuate cyclically and has resulted in ice ages and glacial retreats over the geologic past. During the most recent ice age, 18,000 years ago, global average temperatures were an estimated 6ºF to 9ºF cooler than today (NECIA, 2006), and sea levels were 400 feet lower (Shackleton, 1988). Approximately 10,000 years ago, the climate had warmed by natural processes and the glaciers had retreated.

Figure 1.1
Elements of Earth's Energy Balance



Despite this natural variability, human impacts have demonstrably affected climate patterns over the last 200 years. Since the dawn of the industrial age, human activities have produced greenhouse gases (GHGs), which have altered the natural atmospheric composition and led to noticeable and increasingly alarming warming trends. Naturally occurring GHGs, such as water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), play a critical role in determining the Earth's temperature. Thermal energy from the sun passes through the atmosphere towards the surface of the Earth, most of which is absorbed and heats the Earth (Figure 1.1). The Earth's surface then emits heat in the form of infrared radiation back to the atmosphere, some of which is lost to space and some of which remains in the atmosphere. The GHGs in the atmosphere redirect some of this infrared radiation back to the Earth, which has an additional warming effect and helps maintain the planet's habitability. However, as human activity alters naturally occurring GHG levels, more of the reflected energy is absorbed and redirected toward Earth, dramatically increasing planetary temperature. Human activity now produces GHGs at a rate of 70 million tons per day. (DEP's own GHG emissions are detailed in Chapter 4.)

GHG-induced planetary warming causes many climatic and hydrologic changes. As atmospheric temperatures increase, ice sheets melt, and as oceanic temperatures increase, ocean waters expand. These climatic responses cause sea level rise and change oceanic circulations. Warmer air is able to absorb more moisture, and changing oceanic circulations alter precipitation patterns, causing the hydrological cycle to become more erratic.

Not all climate changes in the Earth's history have been smooth or gradual; some periods have been marked by abrupt climate change. Anthropogenic activity is likely to push atmospheric concentrations of CO_2 and global average temperatures to heights not reached in at least the last 650,000 years, the period for which detailed records are available from Antarctic ice cores (IPCC, 2007). Although the timescales are likely to be very long for high-impact climate change scenarios, such as melting of the ice sheets, abrupt climate change remains a possibility in addition to the more gradual changes that have been observed to date.

Human activities have produced greenhouse gases, which have altered the natural atmospheric composition and led to noticeable and increasingly alarming warming trends.

1.2 | Global and Regional Climate Trends

Historical Global Climate Trends

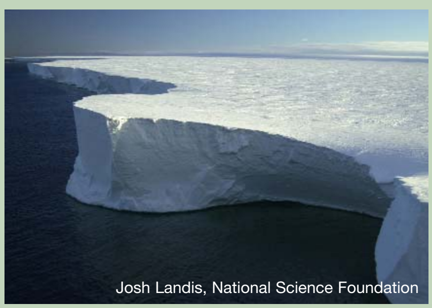
Since the end of the last ice age until recently, atmospheric GHG concentrations have been relatively stable. A 10,000-year-long global trend in the atmospheric concentration of CO_2, the most common GHG, shows an initial moderate decline before increasing slowly until approximately 1800 AD when, due to use of fossil fuels and other factors, CO_2 concentration started to increase sharply (Figure 1.2).

The trends for other GHGs such as CH_4 and N_2O show a very similar pattern. Global temperature increases were consistent with this pronounced increase in atmospheric GHGs since the mid-19th century. (Figure 1.3).

GHG increases are also linked to other observed changes in the climate system. Mountain glaciers and snow cover have declined on average in both hemispheres. Long-term precipitation trends from 1900 to 2005 have been observed in many regions: increases in eastern parts of North and South America, northern parts of Europe and parts of Asia; and decreases in the Sahara, other lower latitude regions, and southern Africa.

Intergovernmental Panel on Climate Change

In 1988, the World Meteorological Organization and the United Nations Environmental Programme established the Intergovernmental Panel on Climate Change (IPCC). IPCC members include hundreds of climate scientists and researchers from around the world who assess peer-reviewed scientific papers on climate change topics. The IPCC's role is to assess on a comprehensive, objective, and transparent basis the scientific, technical, and socioeconomic information relevant to understanding the scientific basis of human-induced climate change, observed climate changes and trends, projected future climate changes, its potential impacts, and options for adaptation and mitigation. The IPCC is in the process of releasing its fourth assessment report. A portion that was released in February 2007 concluded:

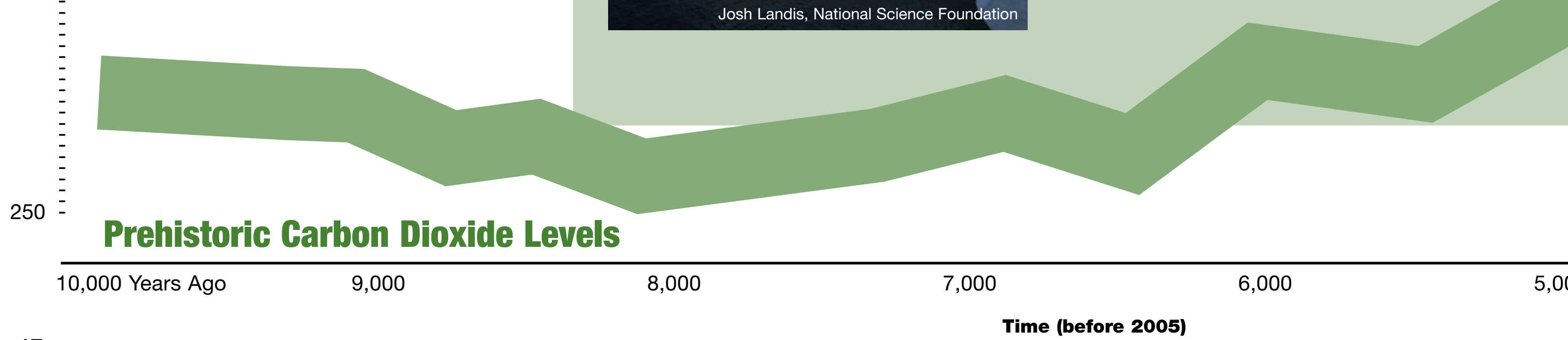


- **Warming of the climate system is unequivocal**
- **Global atmospheric concentrations of greenhouse gases have increased markedly due to human activities since 1750 and currently far exceed pre-industrial values over the last 650,000 years**
- **Most of the observed increase in glob ally-averaged temperatures since the mid-20th century is very likely greater than 90% probability) due to the observed increase in anthropogenic greenhouse gas concentrations**
- **Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850), and the linear warming trend over the last 50 years is nearly twice that for the last 100 years**

The IPCC discounted the probability that the recent observations were caused by natural climate processes alone as less than 5%.

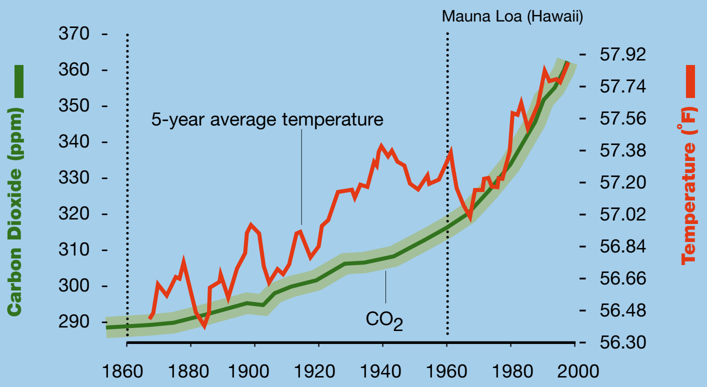
Figure 1.2
Changes in Carbon Dioxide from 10,000 Years Ago to Present CO_2 (2005)

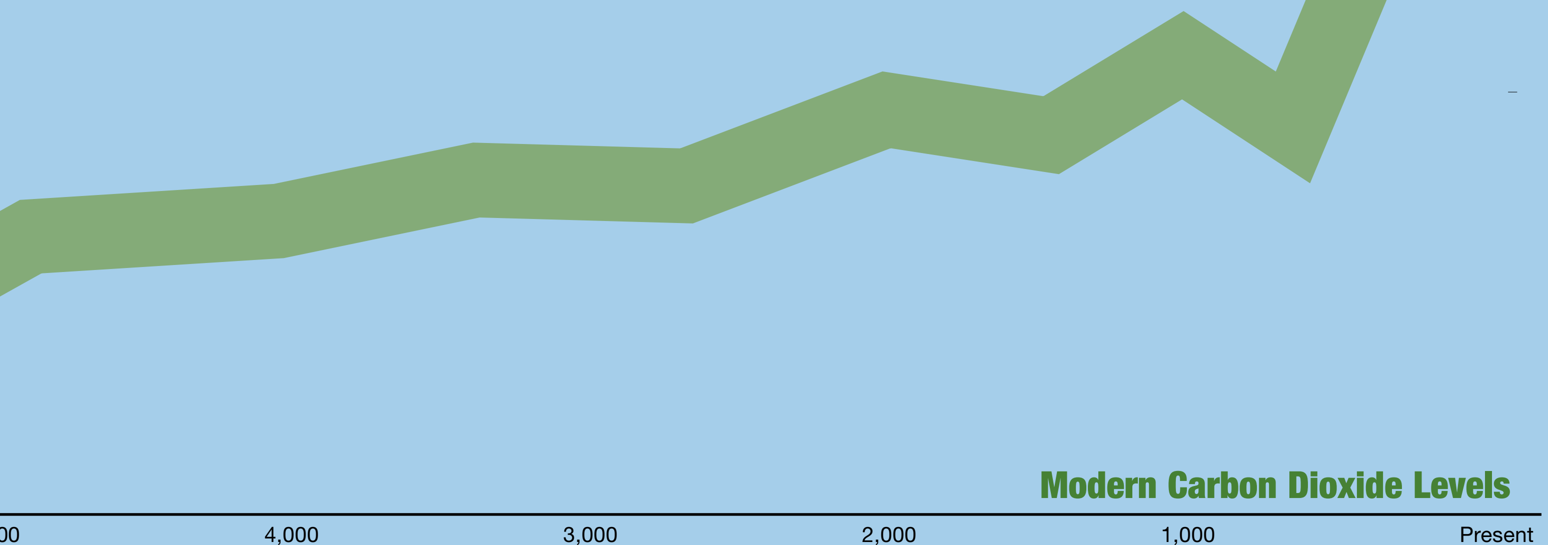
Pre-1950s data from air samples extracted from ice cores and post-1950s data from direct measurements. (IPCC, 2007)



More intense and longer droughts have been observed over wider areas of the tropics and subtropics since the 1970s. Heavy precipitation has increased in frequency over most land areas, consistent with increased atmospheric water vapor. Temperature extremes, hotter days, hotter nights, and heat waves have become more persistent, and tropical cyclones have become more intense since about 1970 (IPCC, 2007). These global trends indicate the dramatic repercussions of human GHG emissions on climate variability.

Figure 1.3
Carbon Dioxide and Global Temperature Trends, 1850-2000
Pre-1950s data from air samples extracted from ice cores and post-1950s data from direct measurements (U.S. OSTP, 2000)





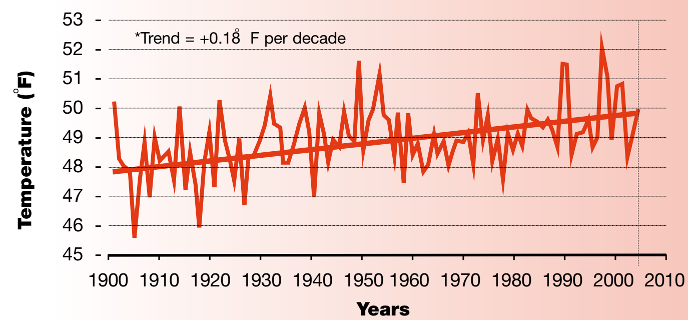
Historical Regional Climate Trends

Data demonstrate that climate trends in the NYC region have been consistent with the global increase in GHGs and the associated range of climatic and hydrologic shifts in air temperature, precipitation and sea level.

Air Temperature

From 1900 to 2005 the annual average observed temperature in the NYC region has increased approximately 1.9ºF, a statistically significant trend (Figure 1.4). Four of the warmest years during the period occurred during the last eight years of the record. This regional increase exceeds the global increase, which may be due in part to the urban heat island effect in New York City and to New York's mid-latitude location (Rosenzweig et al., 2006). Warming is occurring most rapidly in winter (Rosenzweig and Solecki, 2001).

Figure 1.4
Long-Term Annual Observed Temperature Trend in the NYC Watershed Region 1900-2005 (CCSR, 2007)

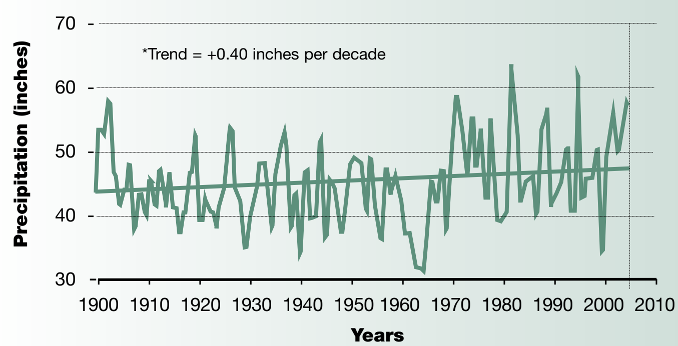


Source: CCSR. Observations were from NCDC Historical Climate Network.
From Five New York State Weather Stations: NYC Central Park, Port Jervis, Yorktown Heights, Mohonk Lake, Maryland.
* = significant at the 95% confidence interval.

Precipitation

From 1900 to 2005 the average annual observed precipitation in the NYC region increased 4.2 inches, an approximately 9.9% increase (Figure 1.5). Because variability of annual precipitation is large, this increase is not statistically significant. However, the variability of annual precipitation has increased somewhat during the latter 40-year portion of this record.

Figure 1.5
Long-Term Annual Observed Precipitation Trend in the NYC Watershed Region 1900-2005 (CCSR, 2007)

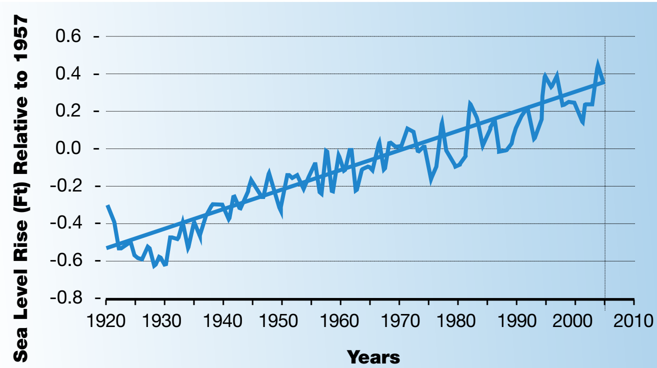


Source: CCSR. Observations were from NCDC Historical Climate Network.
From Five New York State Weather Stations: NYC Central Park, Port Jervis, Yorktown Heights, Mohonk Lake, Maryland.
* = significant at the 95% confidence interval.

Sea Level

From 1920 to 2005 the observed annual mean sea level at the Battery in New York City increased approximately 0.85 feet (Figure 1.6). This is equivalent to approximately one foot in 100 years. In addition to the climate-related factors of thermal expansion of the oceans and ice melt, regional geologic subsidence has also contributed to this increase.

Figure 1.6
The Battery Annual Mean Sea Level Rise, 1920-2005 (Columbia Center for Climate Systems Research, HydroQual, 2007)



1.3 Global and Regional Climate Projections

Some of the most important tools used by climate scientists to project changes in the Earth's climate are General Circulation Models (GCMs, also know as Global Climate Models).

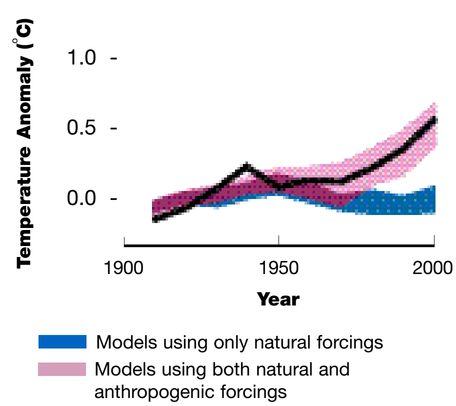
Global Climate Models (GCMs)

GCMs are mathematical representations of the behavior of the Earth's climate system throughout time. They divide the Earth's atmosphere and the ocean into multiple layers and the Earth's surface into thousands of grid boxes defined by latitude and longitude (Figure 1.7). Grid boxes vary in size from 100 to 350 miles on a side with atmospheric and oceanic grid boxes subdivided vertically into many cells. These climate models calculate and solve multiple equations for horizontal and vertical winds, moisture, temperature and pressure; contain subcomponents for radiation, dynamics, clouds, land surface, vegetation, carbon cycle, and atmospheric chemistry; and are scalable by timeframe.

GCM simulations utilize historical GHG levels and natural influences as inputs, and their outputs are validated against historical records. Existing models have effectively replicated observed warming trends from the 20th century. A comparison of observed and calculated global surface temperatures based on a large number of simulations using a variety of internationally available GCMs shows that simulations that include both natural and anthropogenic components compare favorably with observed data, while those using only natural forces do not (Figure 1.8). This affirms that GHG-producing human activities are responsible for much of the current warming.

Figure 1.7
Schematic Representation of Global Climate Model Spatial Segmentation (ACIA, 2004, Level M)

Figure 1.8
Comparison of Observed and Calculated Global Surface Temperature Using GCMs with Natural and Anthropogenic Forces (IPCC, 2007)

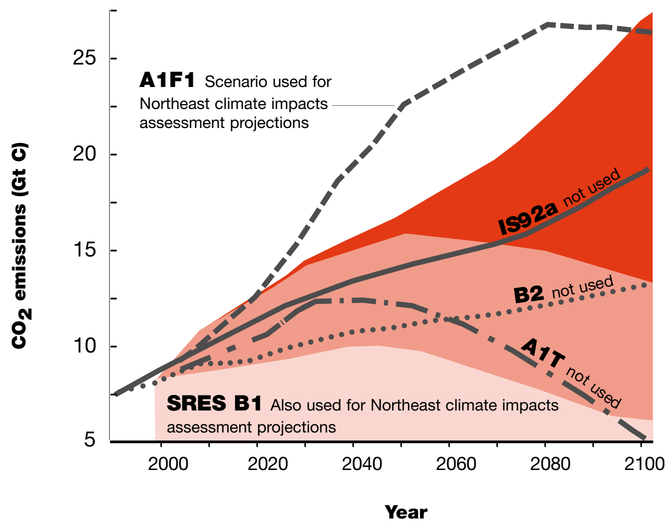


The IPCC endorses GCMs as indicators of future climate trends and changes; however, despite continued improvements, even calibrated models have a level of uncertainty. Therefore, the IPCC recommends the use of several models to develop a plausible range of projected climate outcomes for the future.

Because projection of future climate conditions is dependent upon the future concentrations of GHGs in the atmosphere, the IPCC also recommends running the models with a range of potential future levels of atmospheric GHGs to forecast future temperature, precipitation, sea level and other climate conditions. The IPCC issued a Special Report on Emissions Scenarios (SRES) in 2000 which projects scenarios of future GHG concentrations due to anthropogenic forces (Figure 1.9).

The SRES emissions scenarios are based upon the many factors that will determine the future level of GHGs in the atmosphere: population growth, economic development, technological innovation, energy consumption, land-use, agricultural development, and environmental policy.

Figure 1.9
Anthropogenic Emissions of CO_2 in SRES Emissions Scenarios (IPCC, 2001)



Scenarios used for NYCDEP projections

SRES B1	PRODUCES THE LEAST AMOUNT OF GHG BY 2100
SRES A1B	PRODUCES AN INTERMEDIATE GHG INCREASE
SRES A2	PRODUCES THE MOST GHG BY 2100

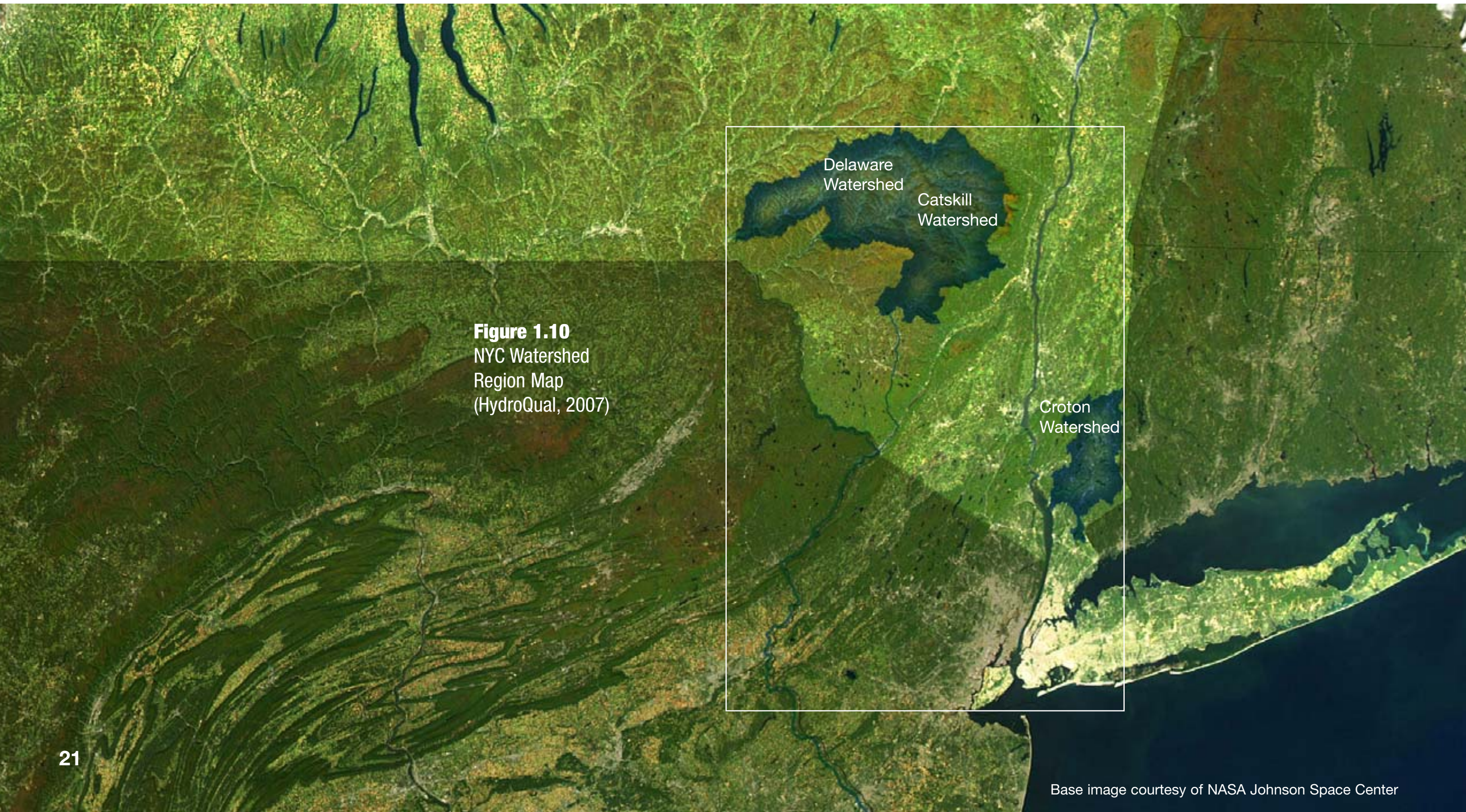


Figure 1.10
NYC Watershed Region Map (HydroQual, 2007)

Base image courtesy of NASA Johnson Space Center

NYC Watershed Region Projections

Columbia University has obtained GCM data for the NYC Watershed Region, which, as defined for these climate projections, spans 40.5 N to 42.5 N and 73.5 W to 75.5 W and includes both the NYC metropolitan area and the upstate watersheds (Figure 1.10). To obtain regional projections Columbia University selected the following five available GCMs for application from the 22 models recognized by the IPCC:

1. GFDL CM2.1
Geophysical Fluid
Dynamics Laboratory (Princeton, NJ)

2. GISS ModelE
NASA/Goddard Institute
for Space Studies (New York, NY)

3. MPI ECHAM5
Max Planck Institute (Hamburg, Germany)

4. NCAR CCSM3.0
National Center for Atmospheric Research (Boulder, CO)

5. UKMO HadCM3
United Kingdom Meteorological Office (Devon, UK)

Three of the seven SRES emissions scenarios depicted in Figure 1.9 were used for model calculations: B1, A1B, and A2 (Table 1.1). These three scenarios were chosen because they span a range of possible futures and are used by most modeling centers. The B1 scenario produces the least amount of GHG increase over the course of the 21st century, while the A2 scenario leads to the most GHG increase by 2100. A1B produces an intermediate GHG increase by 2100, although over the next several decades it actually produces more GHGs than A2, since it initially allows GHGs to increase at 1% each year, which is close to the recent observed rate of increase (IPCC, 2000).

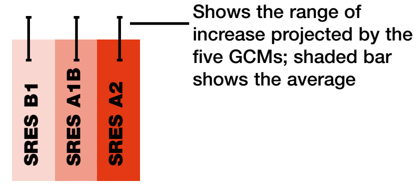
To project a range of potential future temperature and precipitation scenarios for the NYC Watershed Region, Columbia University had to interpolate the five GCMs' run results, each with the three emissions scenarios, for a total of fifteen projections for three different decades: the 2020s, 2050s and 2080s. Due to the differing characteristics of the models, only three of the five GCMs were run in conjunction with the three emissions scenarios to produce sea level projections for the same three decades. The interpolation was necessary because the grid boxes of the various GCMs are spatially larger than the NYC Watershed Region; Columbia University interpolated all results to the local region using a scientifically-accepted method (Cressman, 1959).

SRES Emissions Scenarios

The SRES emissions scenarios are based upon the many factors that will determine the future level of GHGs in the atmosphere: population growth, economic development, technological innovation, energy consumption, land-use, agricultural development, and environmental policy.

Table 1.1
Characteristics of IPCC SRES Emissions Scenarios (Columbia University Center for Climate Systems Research, 2006)

	SRES B1	SRES A1B	SRES A2
PPM CO_2 in 2100	550	720	850
Population Growth	Low	Low	High
GDP Growth	High	Very high	Medium
Energy Use	Low	Very high	High
Land-Use Changes	High	Low	Medium/High
Resource Availability	Low	Medium	Low
Pace of Technological Change	Medium	Rapid	Slow

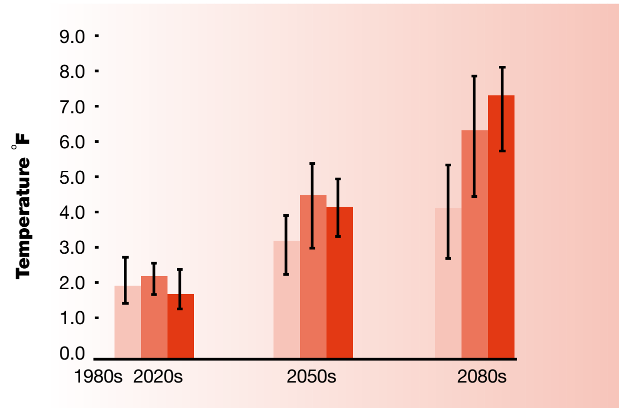


SRES Emission Scenarios and Range of GCM Projections

Air Temperature

The average regional temperature increase for the 15 scenarios over the base period (1970 - 1999) is 2.0°F for the 2020s, 4.0°F for the 2050s, and 5.9°F for the 2080s (Figure 1.11). Although there is a fair amount of variability across the GCMs, they all show a future progression of warming temperatures in all seasons. Seasonal projections from Columbia University show summer increases slightly greater than winter increases. These projections are for the larger NYC Watershed Region. Temperatures in the City might exceed these projections because of the urban heat island effect. The projected temperature increases for the NYC Watershed Region exceed globally averaged changes, indicating that the New York City region might be especially sensitive to the effects of climate change.

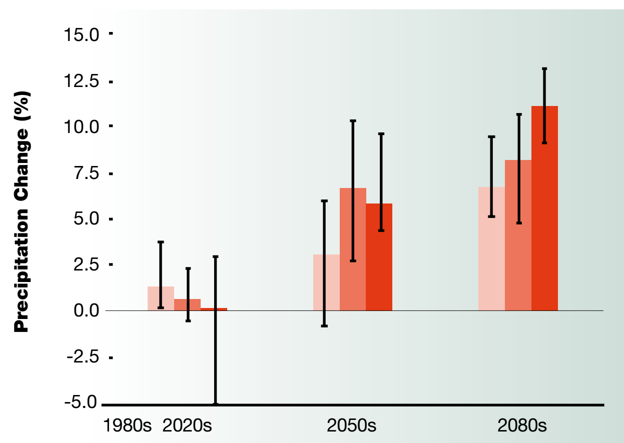
Figure 1.11
Modeled Annual Temperature Changes For the NYC Watershed Region Relative to the 1980s (Columbia Center for Climate Systems Research, 2006)



Precipitation

The average regional precipitation increase for the 15 scenarios over the base period (1970 - 1999) is 0.7% for the 2020s, 5.7% for the 2050s, and 8.6% for the 2080s (Figure 1.12). There is more variability across the models for projected change in precipitation than for temperature. Especially in the 2020s, the models forecast a range of wetter to drier conditions. By the 2050s, however, most projections show increased precipitation for the region. Seasonal projections from Columbia University show precipitation increases may be greater during the winter than in summer in the 2050s and even more so in the 2080s. The synergistic effect of parallel increases in temperature and precipitation are not yet fully evaluated; it remains unclear how much of the increased precipitation will fall as snow, or how snowpack and thaw in the NYC Watershed Region will be affected.

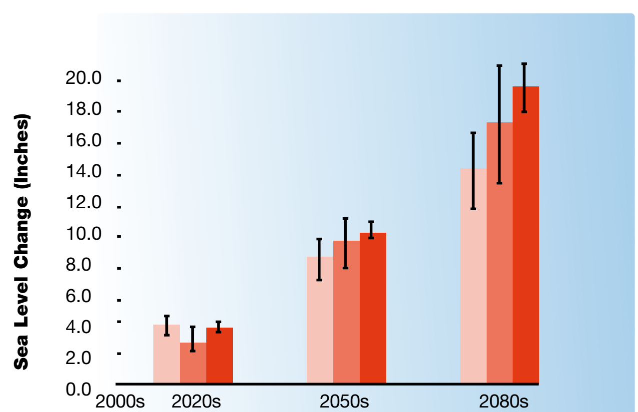
Figure 1.12
Modeled Annual Precipitation Changes For the NYC Watershed Region Relative to the 1980s (Columbia Center for Climate Systems Research, 2006)



Sea Level

The average projected rise in sea level for the 9 scenarios over the base period (1970 - 1999) is 3.2 inches for the 2020s, 9.0 inches for the 2050s, and 16.5 inches for the 2080s (Figure 1.13). There is somewhat less variability across the GCMs for sea level than for air temperature and precipitation; however, these projections do not account for recent research that suggests that the rate of ice melt is accelerating more quickly than most sea level projections have indicated to date. A new study by the National Snow and Ice Data Center found that the area of Arctic sea ice in September, the month when it shrinks the most, has decreased at an average rate of 7.8% per decade since 1953, yet computer climate simulations have used an average ice loss rate of 2.5% per decade for this period (Stroeve, 2007). DEP's long-term planning should include the risk of

Figure 1.13
Modeled Regional Sea Level Rise Relative to the 2000s (Columbia University Center for Climate Systems Research, 2006)



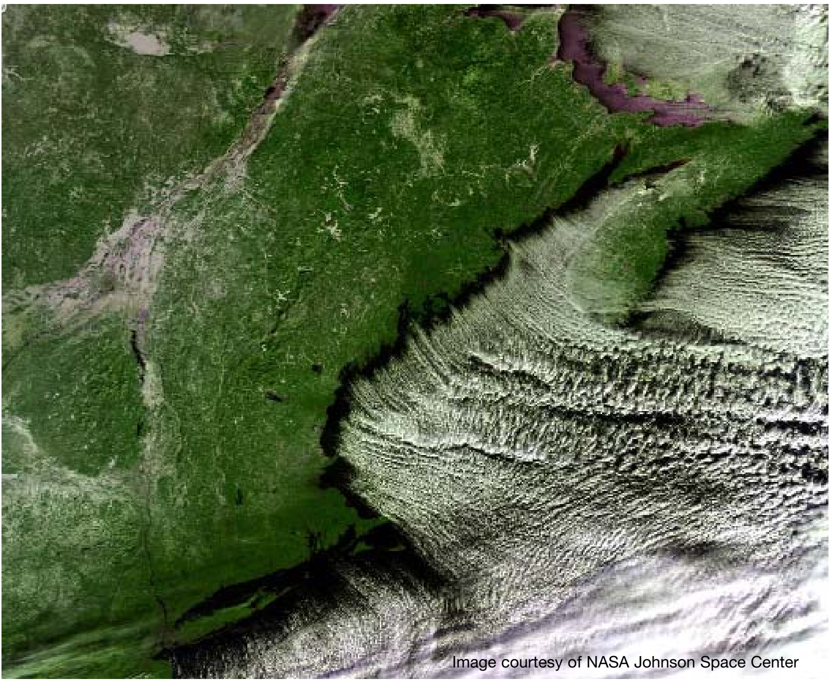


Image courtesy of NASA Johnson Space Center

Extreme Events

In planning for climate change it is also important to consider the increased likelihood of severe and extreme weather events, such as storms, coastal and inland flooding, drought, and heat waves. These events are not as well modeled in current GCMs as are long-term trends in temperature, precipitation and sea level, so forecasts are more uncertain. Nevertheless, because of rising sea levels and the intensification of the hydrologic cycle due to rising temperatures, it is expected that many types of extreme events will occur more frequently (IPCC, 2007). Recent scientific studies have shown a strong correlation between powerful hurricanes and ocean temperature in the North Atlantic (Mann & Emanuel, 2006). New York City and its watershed, particularly because of NYC's coastal geography, may experience more frequent and intense storms in the future as the atmosphere and ocean continue to warm. This is an active area of scientific research that will become more refined and precise over time, though existing data enables the formulation of some broad global projections (Table 1.2).

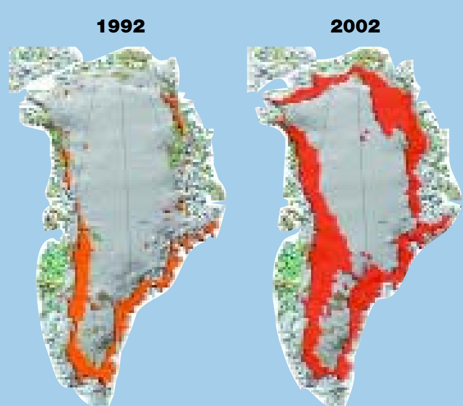
Table 1.2
Recent Global Trends and Anticipated Changes in Potentially Severe and Extreme Events During the 21st Century (IPCC, 2007)

Virtually certain > 99% probability of occurrence
Very likely > 90%
Likely > 66%

Phenomenon and Direction of Trend	Likelihood that Trend Occurred in Late 20th Century (typically post 1960)	Likelihood of Future Trends Based on Projections for 21st Century using SRES Scenarios
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain
Warm spells / heat waves. Frequency increases over most land areas	Likely	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970s	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Likely

Greenland Ice Sheet

This map shows the inland expansion of the summer melt zone of the surface ice in Greenland between 1992 and 2002. If the Antarctic Ice Sheet or the Greenland Ice Sheet were to melt, global mean sea level could rise on the order of 17 feet and 23 feet, respectively. Scientists have conjectured that this would occur over millennia, but recent data suggest that melting is occurring more quickly than previously anticipated.



Source: Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulde (2007).

Flooding

Flooding due to rainfall is likely to increase because of the expected increase in the intensity of rainfall events.

Mean values of climate change are of great importance in planning as are extreme events: storms, coastal and inland flooding, droughts, and heat waves. As indicated by IPCC (2007), there is currently large uncertainty about future changes in extreme events, and climate modeling of extreme events is an emerging science.

It is therefore anticipated that scientific understanding of extreme events will continue to evolve. As new data become available from GCM simulations associated with the next IPCC report in approximately 3-4 years, scientific understanding is likely to improve, since these GCMs will feature more advanced physics, higher spatial (and possibly temporal) resolution (critical for modeling extreme events), and more variables will be stored with longer temporal coverage. Therefore, the current model projections offer the best guidance for future changes in extreme events. While it may be premature to use the precise quantification of changes in extreme events to guide policy, the general direction of many changes, such as a tendency for more heat waves, enhanced coastal flooding, and an intensified hydrological cycle, can be viewed with high confidence, as described by IPCC (2007).

A range of other extreme events is expected to become more severe with global climate change. Heat waves are also almost certain to increase in the region. As mean temperature increases, extreme heat is expected to increase in frequency, intensity, and duration. Even relatively small changes in heat statistics can have large societal impacts, given the severe stresses imposed by heat waves in the current climate. Flooding due to rainfall is likely to increase because of the expected increase in the intensity of rainfall events. Droughts may become more frequent in the region, because as temperatures rise, evaporation rates will increase; droughts may become more common even with increased precipitation.

As the mean sea level increases, smaller storms are able to produce the amounts of flooding previously associated with larger storms.

Further, changes in the intra-annual distribution of rainfall could also contribute to droughts and floods in the region. While evaporation is a relatively steady process, precipitation is highly variable, spatially and temporally. If, as much research suggests (Karl and Knight, 1998 for example), precipitation becomes concentrated in intense events, this could contribute to increased duration and frequency of both floods and the dry intervals between rainfall events.

Coastal flooding is almost certain to become a more serious problem due to increasing sea level. As a result, the recurrence interval for coastal floods at each level of inundation is expected to decrease as sea levels rise. Therefore, any increase in storm frequency or intensity would further contribute to higher incidence of coastal flooding.

1.4 Model Uncertainty and Validation

Quantitatively Comparing Data with Historical Hindcast Simulations

As with all forecasting, some level of uncertainty in climate change projections is unavoidable. Uncertainties in GCM projections stem from the difficulty of understanding and expressing the physics of the weather and climate systems, grid sizes, topography, and the amount of future GHG emissions. Given the uncertainties, an approach that considers the range, frequency and general confidence of various levels of change is more appropriate than basing decisions on mean changes. Columbia University used multiple GCMs and GHG emissions scenarios to produce a range of projections (Table 1.3). For the three climate variables, considering only the modeling projections from the 15 model-emission scenarios framework created by Columbia University, it is most probable that the increase in sea level will be within the GCM-projected range shown, followed by air temperature then precipitation increases, based on the modeling probabilities associated with the various ranges.

Columbia University validated the temperature and precipitation projections for the NYC Watershed Region by quantitatively comparing data from historical hindcast simulations of the GCMs to historical observed data. This process is undertaken to gain assurance as to the appropriateness of the models for projecting future climate scenarios. The differences in hindcast values and observed values are not part of the process of developing future scenarios, which are based on assumptions about future GHG emissions and on generated future climates that are different from the present climate. Rather, the forecasting procedure applies the difference between the GCM projections and the hindcast values for the base period to the observed average values for the base period (1970-1999).

The calculated GCM ensemble hindcast average temperature is 2ºF less than the observed 30-year average for the period 1970 to 1999, just outside of one standard deviation of the measurements.

Melting Glaciers

When meltwater seeps through cracks in the ice sheet, it may accelerate melting and, in some areas, allow the ice to slide more easily over the bedrock below, speeding the movement of the ice sheet to the sea.

Table 1.3

Model-Based Probability of Change[1] in Climate-Related Characteristics in the NYC Watershed Region

	Air Temperature[2]		Precipitation[2]		Sea Level Rise[3]	
Decadal Average	**Range (°F)**	**Model-Based Probability (%)**	**Range (%)**	**Model-Based Probability (%)**	**Range (Inches)**	**Model-Based Probability (%)**
2020s	1.0 to 3.0	100	0 to 2.5	60	2 to 6	100
2050s	3.0 to 5.0	80	2.5 to 7.5	64	6 to 12	100
2080s	5.0 to 8.5	67	7.5 to 15.0	74	12 to 22	89

[1] Model-based probability that the projected increase will be within the range shown across selected GCMs and three emissions scenarios.

[2] Relative to the 1970-1999 base period from five GCMs.

[3] Relative to the 1970-1999 base period from three GCMs. Percentages rounded to nearest integer.

Source: Columbia University Center for Climate Systems Research (2006).

For precipitation it is approximately 0.2 inches/month (5.4%) greater than the 30-year average, and within one standard deviation of the measurements (Table 1.4). These are considered strong performance comparisons, but even these minor inaccuracies should be considered in the application of GCM projections in those cases where forecasted changes are on the same order as these variances. Modeled sea level rise can not be validated through comparing model hindcasts to observed sea level because sea level rise is not a direct GCM output. IPCC experts determine global sea level projections based on the historical relationship between observed sea level rise and observed temperature increase over the 20th century (IPCC 2001, 2007 and Rahmstorf, 2007).

Regional projections for sea level rise at the Battery in NYC are based on three additional factors:

- **Change in land height (primarily due to Glacial Isostatic Adjustment, which is causing land subsidence in the NYC region)**
- **Change in global mean sea level (projected based on a linear fit with GCM projections of global temperature change, as described above)**
- **Regional distribution of sea surface height, which is a function of ocean temperature, surface wind, salinity, current velocity, and atmospheric pressure**

Standard techniques were also used to assess the statistical significance of the projected changes in mean temperature, precipitation, and sea level. Analysis shows that all regional temperature projections are significantly different statistically from the historical base period; that is, in each case there is less than a 2.5% chance that future warming of that magnitude would occur by chance alone. Similarly, 7 of the 15 projected precipitation changes for the 2050s and 14 of the 15 projected precipitation changes for the 2080s are significantly different statistically.

The precipitation projections for the 2020s are not yet distinguishable from natural variability (although increases are projected in 11 of the 15 models, the trend is not statistically significant at the 2.5% level). The sea level rise projections are all statistically significant at the 95% level; that is, given sea level variability over the 20th century, there is less than a 5% chance that the projected level of rising would occur by chance alone (i.e., without global warming).

Table 1.4
Model Validation for the NYC Watershed Region Annual Temperature and Precipitation Hindcast Projections for 1970-1999

	Observed Data (± Standard Deviation)	Average of Model Hindcasts	Model Hindcast Range
Temperature (°F)	48.0 ± 1.0	46.0	43.5 - 48.5
Precipitation (inches/mo)	3.7 ± 0.5	3.9	3.2 - 4.5

* Model results based on five GCMs.
* Sea level rise projections are not validated through hindcasting.
Source: Columbia University Center for Climate Systems Research (2006).

"Although there is certainty that many climate changes will be experienced, there is uncertainty as to the magnitude and timescale of these changes."

Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

1.5 Scientific Uncertainty and the DEP

Despite documented changes in historical climate records and great advances in climate science, uncertainties remain. For instance, although there is broad agreement that the global climate is warming and that sea level is rising, precipitation trends are not as clear. An analysis that compared the most recent 50 years of rainfall records in the New York City metropolitan area to those from the preceding 50 years showed a very small change to date in short-term rainfall intensity and duration relationships (Vieux & Associates, Inc., 2006).

Similarly, although there is certainty that many climate changes will be experienced, there is uncertainty as to the magnitude and timescale of these changes. In addition, projections for how the climate system will change globally are currently more certain than projections for particular regions. Some changes that are projected to occur in much of the world may be experienced to a greater or lesser degree in New York.

Much of the data generated by scientific studies is not yet sufficiently detailed and site-specific for infrastructure planning. DEP's current infrastructure planning and design practices rely on data that is much more precise than that which can be readily extrapolated from GCM projections. For instance, the precipitation projections that have been developed to date for DEP are daily and monthly averages, and the smallest time interval that can be calculated by GCMs is 3 hours, yet the existing sewer system is designed according to the amount of precipitation that falls in much shorter time intervals, 5 minutes in some cases.

DEP needs to find ways to bridge the gap between broad and evolving global climate science and site-specific infrastructure engineering planning and design. Important first steps have been taken, but more are needed to quantify both potential impacts and risks at a level of detail sufficient for the development of planning strategies.

1.6 DEP Actions to Reduce Uncertainty in Regional Climate Change Trends and Projections

To enhance climate change projections for New York City and its Watershed Region, DEP will:

ACTION 1

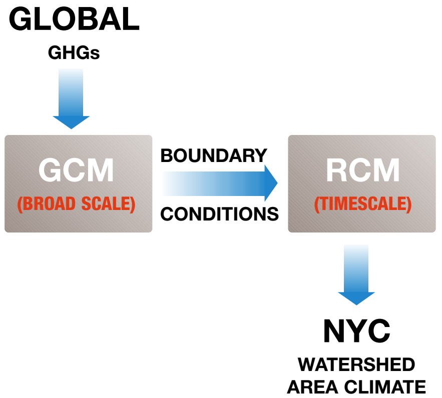
Work with the scientific community and other governmental and non-governmental organizations to develop more refined regional climate change projections.

ASSEMBLE A COMPREHENSIVE SUITE OF REGIONAL CLIMATE PROJECTIONS

Columbia University has provided DEP with comprehensive sets of climate data for the New York City Watershed Region. The datasets include daily temperature, precipitation, solar radiation, wind, humidity and other variables. The data will be used as a basis to provide DEP with the ability to identify the range of potential impacts using its various watershed, sewershed, and harbor water quality modeling tools.

APPLY A REGIONAL CLIMATE MODEL TO NEW YORK CITY AND ITS WATERSHEDS

Under the direction of Columbia University, the University of Connecticut is applying a Regional Climate Model (RCM) that runs on smaller spatial and time scales and includes localized topographic features important for finer scale monthly temperature and precipitation projections. This technology is promising but still in a developmental stage. Results from this research will be shared and discussed by the Department with other utilities and regional authorities to facilitate a collaborative approach toward understanding the impacts of climate change at a local scale.



ACTION 2

Work with regulatory and other agencies on the PlaNYC initiative to update the existing 100-year flood elevations using current sea level data, and develop agreed-upon estimates of future 100-year flood elevations, sea level rise, storm intensity, and maximum probable flood using climate change projections.

Using historical data and climate change projections, DEP will work with other agencies and regional authorities to advance the PlaNYC initiative of updating the current 100-year flood elevations using current sea level data. The current elevations, which are used by DEP for flood protection criteria in facilities planning, are based on coastal engineering work conducted by regional authorities approximately 25 years ago. DEP will also work with other agencies and authorities to use climate change projections to develop estimates of future 100-year flood elevations, sea level rise, storm intensity, and maximum probable flood so that the factors used for safety and design are standardized City-wide.

ACTION 3

Identify additional data and monitoring stations needed to track global and regional climate changes.

As projected climate change impacts are long-term in nature, DEP will institutionalize a monitoring program across all planning and operational Bureaus to track change over time. This will help DEP advance projects and programs along a time schedule that is consistent with the projected climate changes. For factors such as temperature and sea level rise, data that can be appropriate as indicators generally already exist and are routinely collected from regional weather stations, tide gauges, and other monitoring locations. However, DEP must identify the other key indicators that will be needed to effectively monitor and analyze changes and implement appropriate adaptations.

NYCDEP Watershed Meteorological Station

ACTION 4

Track developments in climate change science, improvements in global climate models, and emerging estimates of changes in the severity, duration, and frequency of weather events.

Climate change projections are dependent on a range of complex mathematical GCMs that will continue to be improved over time. DEP is particularly interested in advancements in regional climate modeling, an area of research that is not yet as well developed as global climate modeling. DEP will continue to track climate change science in order to keep abreast of evolving climate change issues and progress by the world scientific community. This will allow DEP to determine when advances in climate science and models merit the development of new regional projections to keep DEP's engineering and design processes as scientifically current as possible.

In addition, DEP will closely monitor qualitative and quantitative estimates of changes in the severity, atmospheric energy, duration, and return frequency of extreme events and discuss these estimates with other City and regional collaborators. At this time, changes in extreme events, such as hurricanes, are not well-modeled and projected.

However, because New York City is at-risk to hurricanes and other extreme events, and climate change may increase the frequency and severity of these extreme and potentially catastrophic events, DEP will benefit from any developments that are made in this area of research.

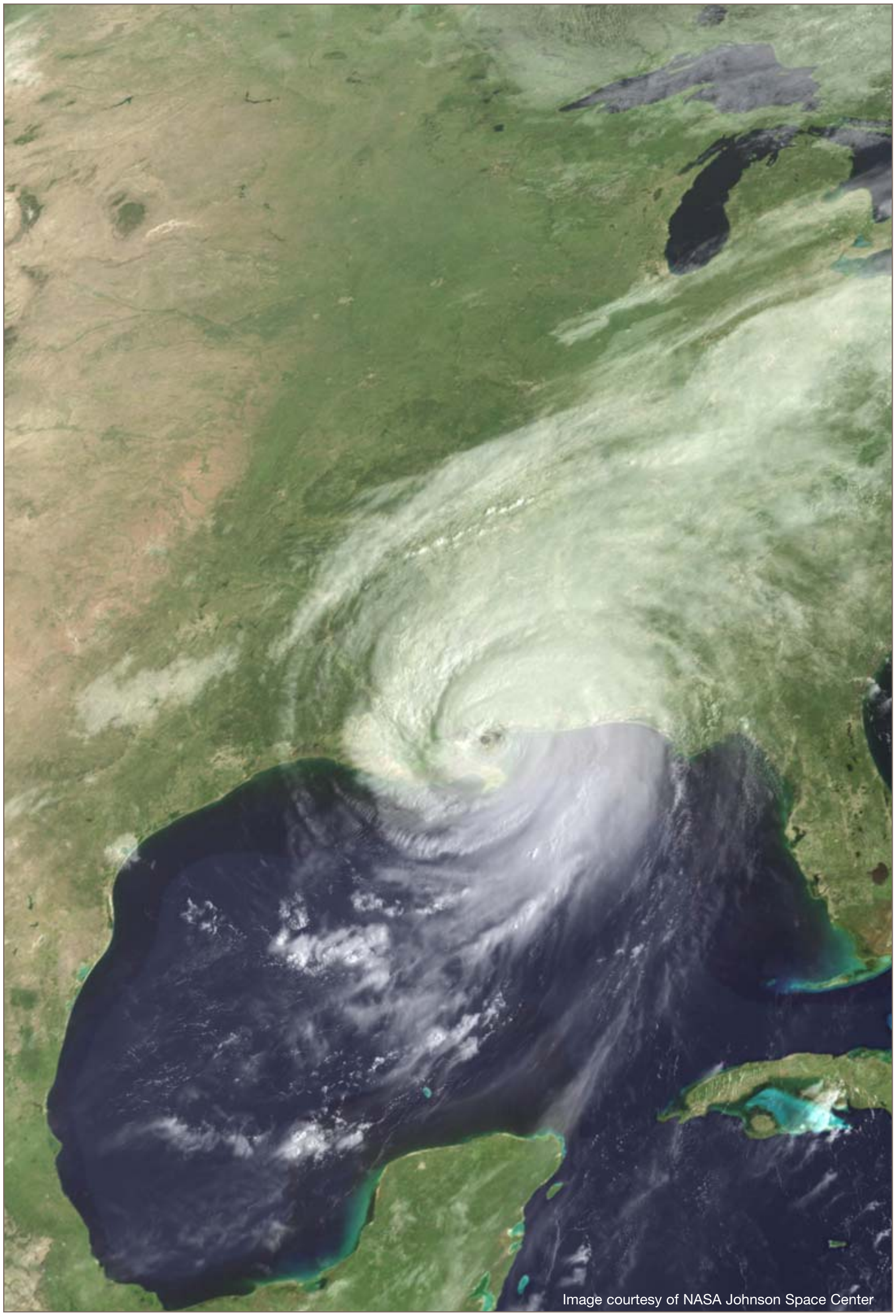
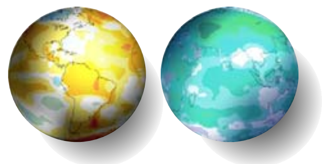


Image courtesy of NASA Johnson Space Center

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM



Potential Climate Change Impacts on DEP

2

DEP's heightened awareness of climate change issues over the past four years has led to extensive discussions about how regional changes in temperature, precipitation, sea level, and frequency of extreme weather events will impact New York City's water supply, drainage and wastewater management systems. Impacts could be significant - new climate and sea level extremes could be experienced that the systems are not designed to accommodate. DEP's existing awareness of system vulnerabilities, from observing the effects of past climate variability and extreme weather events, has guided the Department's initial assessment of how climate change could impact DEP and its water systems.

Impacts could be significant - new climate and sea level extremes could be experienced that the systems are not designed to accommodate.

This chapter examines the potential impacts of climate change on the City's water systems identified to date by DEP and details the actions that DEP will take to further define and quantify the impacts. Quantification is essential, because it will allow DEP to weigh the environmental and financial costs of climate change impacts against the costs and benefits of various strategies for adapting its systems to future climate conditions. The results of such analyses will allow DEP to implement the adaptations that will most effectively and efficiently minimize the impacts of climate change and fulfill its mission of delivering drinking water to New Yorkers and effectively managing and stormwater and wastewater. The potential impacts as well as DEP's actions to further define these impacts are also summarized in Chapters 5 and 6.

Ashokan Reservoir; photo courtesy of SUNY Cortland

Approximately 90% of the City's water supply is from the Catskill and Delaware systems.

2.1 Potential Impacts to the Water Supply System

Drinking water supply issues for the City of New York fall into three broad categories:

- **Quantity: Will we consistently have enough water?**
- **Quality: Will water quality be threatened?**
- **Demand: Will we use more water?**

Sources of New York City's Drinking Water

New York City's drinking water originates from a 1,972 square mile watershed approximately 125 miles north of the City that provides approximately 1.1 billion gallons per day of safe drinking water to 8.2 million residents of New York City and an additional 1 million people in eight upstate counties each day. The surface system is comprised of a network of 19 reservoirs and three controlled lakes throughout the Croton watershed east of the Hudson River, and the Catskill and Delaware watersheds west of the Hudson.

New York City's development of these watersheds, authorized by State legislation and effected between the mid-1800s and the mid-1900s entirely with City (ratepayer) funds, allows the City to impound and take water from various streams within eight upstate counties. The Water Supply Act of 1905 and its subsequent statutes, which authorized construction of much of the City's water supply system, allow for certain municipalities and water districts in designated upstate counties where water supply facilities are located to take prescribed amounts of water from the City's system.

In addition, a U.S. Supreme Court Decree in 1954 limits how much water the City can divert from the Delaware watershed, and imposes certain additional requirements for the maintenance of flow in the Delaware River. Finally, various resolutions adopted by the Delaware River Basin Commission (DRBC) and regulations adopted by New York State require the City to make certain specified reservoir releases for fisheries protection and recreational use.

The City's drinking water originates from a 1,972 square mile watershed approximately 125 miles north of the City that provides approximately 1.1 billion gallons per day of safe drinking water.

Approximately 90% of the City's water supply is from the Catskill and Delaware systems. The water quality from these systems meets criteria set by the U.S. Environmental Protection Agency under the Surface Water Treatment Rule. This allows the Catskill and Delaware systems supplies to be unfiltered under a series of Filtration Avoidance Determinations. The Croton system, approximately 10% of the City's supply, will be filtered upon completion of a treatment plant in late 2011. The quantity and quality of the Catskill and Delaware systems are largely determined by the hydrology and ecology of their watersheds.

The quantity and quality of the Catskill and Delaware systems are largely determined by the hydrology and ecology of their watersheds.

In addition to the surface supply systems, New York also obtains less than 1% of its daily water needs from its Brooklyn-Queens Aquifer. This is a groundwater system in southeastern Queens.

Potential Water Quantity Changes

CLIMATE CHANGE, ECOLOGICAL CHANGE, AND DROUGHT

Most of the GCM models examined by DEP indicate that New York City and its watersheds will experience higher annual rainfall by the 2050s. In addition, current climate science suggests that the rainfall events experienced now may become larger and more intense, with a longer interval between the rainfall events during this century. Climate change may also affect the length of the growing season and the ecology of the watershed (Table 2.1).

These changes could affect evapotranspiration and, thus, reservoir inflows. Longer growing seasons could increase plant uptake, reducing soil moisture and reducing the availability of groundwater and surface flows to resupply reservoirs. Also, it is observed by DEP operators that water inflows to the City's reservoirs decrease abruptly at leaf-out, i.e., during the onset of the spring growing season. Because of these potential ecological changes, New York could experience more frequent and intense droughts. A Drought Watch is declared when there is less than a 50% probability that either the Catskill or Delaware reservoir system(s) will be filled by the following June 1st. This probability factor is based on historical records of reservoir refill dating back to 1927. Going forward, this may not be an accurate predictor of future droughts.

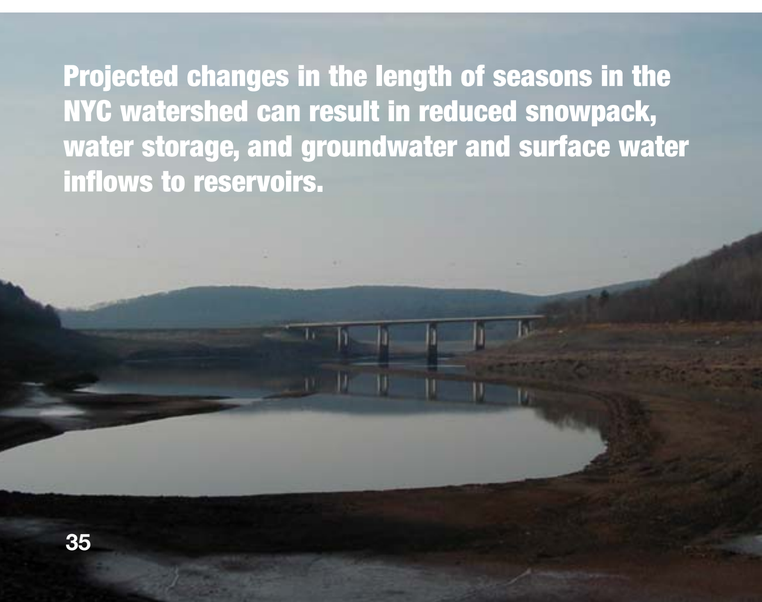
Further compounding the water supply quantity issue is that during the winter, warmer temperatures may result in more precipitation falling as rain, with less falling as snow. Thus, there will likely be less storage of water in the form of snowpack, and therefore reduced inflows to reservoirs during the spring thawing season.

Table 2.1
Projected Changes (in days) in Key Indicators Related to Plant Growth in the Northeast as Simulated for Lower[1] and Higher[2] Emissions Scenarios

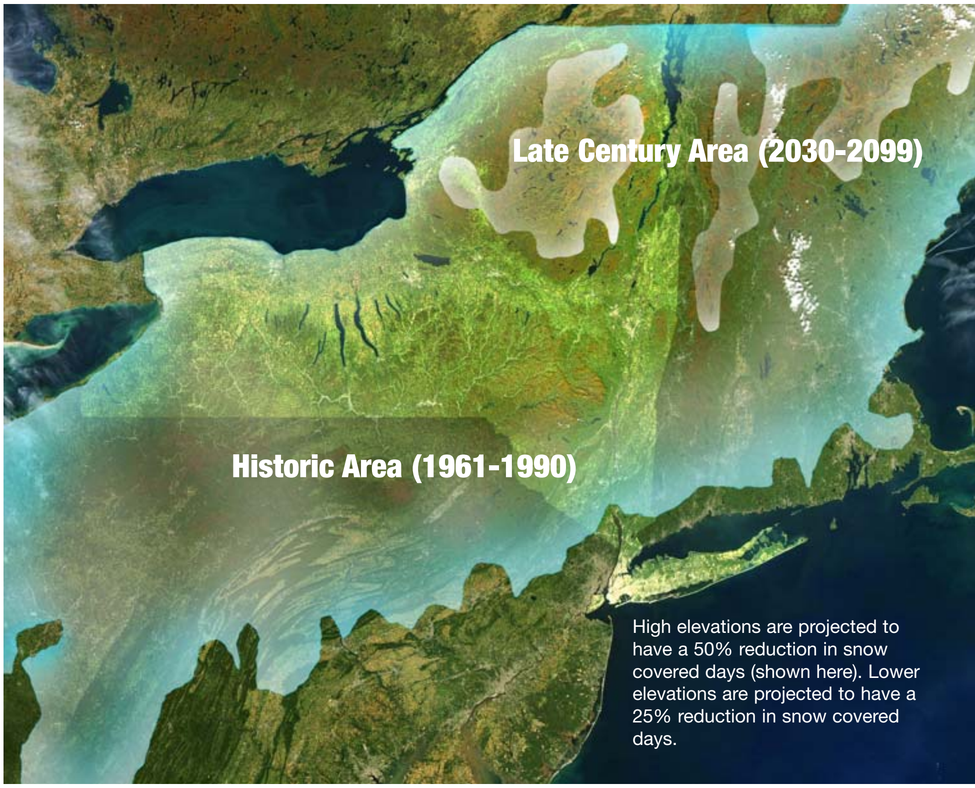
	2035 - 2064		2070 - 2099	
	Lower Emissions	Higher Emissions	Lower Emissions	Higher Emissions
Onset of Summer	-6	-11	-9	-21
End of Summer	+10	+16	+12	+23
First Frost (Fall)	+1	+16	+6	+20
Last Frost (Spring)	-8	-14	-16	-23
Length of Growing Season	+12	+27	+29	+43
First Leaf (Spring)	-3	-5	-7	-15
First Bloom (Spring)	-4	-6	-6	-15

(1) Special Report on Emissions Scenarios (SRES) B1 (B1 also used for DEP projections - see Chapter 1)
(2) SRES A1F1 (higher than A2, which was the high scenario for DEP projections - see Chapter 1)

Source: The Northeast Climate Impacts Assessment, 2006.



Peak snowmelt in the Catskills is already shifting earlier in the year, with a recent study showing that during the period 1952-2005 it shifted from early April to late March, which was consistent with other study findings including a decreasing trend in April runoff and an increasing trend in maximum March air temperature (Burns, Klaus & McHale, 2007).



Projected reduction in snow cover area with greater than 30 days of snow on ground.

REDUCED STORAGE DUE TO FLOOD MITIGATION AND STREAMFLOW AUGMENTATION

In addition to the potential for diminished inflows to the City's water system, the likelihood of these and other climate impacts affecting other jurisdictions in the region may result in calls for the City to maintain voids in its reservoirs. Due to recent record rainfall events within the Catskill and Delaware watersheds, some have called on the City to maintain sizable voids in its reservoirs throughout the year to provide storage capacity in anticipation of storm events. The City's reservoirs were not designed as flood control structures, but they do attenuate these events. The lowering of reservoir levels to provide storage capacity in anticipation of snow melt and/or large storms may be of some value for mitigating or attenuating flooding events. In turn, however, this may reduce the statistical probability that water resources will be available to the City, especially if drought events increase or become more prolonged. Given the uncertainty of whether and when water released can be recaptured, maintaining voids throughout the year would significantly affect the ability of the City water supply system to meet the demands placed on it. The Department will have to carefully monitor and work with local and state officials to ensure that any programs implemented in the future to enhance the flood attenuation capabilities of the reservoirs do not impact water supply reliability. Warmer temperatures may also lead to impacts on fish life in watershed streams. Warmer stream water results in lower dissolved oxygen levels, and dissolved oxygen is a key determinant affecting fish life. Impacts to stream ecology might lead to more pressure for the City to make additional stream releases for environmental purposes, which would further compromise the availability of drinking water.

ENCROACHMENT OF SALT FRONTS

Regional drought and sea level rise could also impact the City's water supplies, both directly and indirectly. While DEP does not currently have a permit to use it, the Chelsea Pump Station on the upper Hudson River has provided an emergency supply of treated water to the City in the past. More frequent droughts and sea level rise could move the salt front up the Hudson closer to the Chelsea intake and lessen the potential viability of that emergency supply source.

Drought, sea level rise and the movement of salt fronts could also threaten other nearby Hudson River users, as well as Delaware River users downstream of the City's Delaware watershed. If sufficiently severe, these climate impacts could affect the amount of water New York City is allowed to take from the Delaware watershed and the amount of releases by the City needed in the Delaware to keep the salt front from advancing upstream. This potential threat could be increased if water sources for those other jurisdictions are significantly impacted by climate change, and New York City actions are perceived as contributory to the problem or solution. Though many New York State communities using Hudson River water do not currently use New York City water, climate change issues could increase pressure to have the relatively larger supplies under the City's jurisdiction used for emergency or even routine use elsewhere.

Steve Adamec, NYCDEP

Chelsea Pump Station on the Hudson River for emergency water supply.

Potential Water Quality Changes

A series of programs under the umbrella of the Watershed Protection Program, which includes wastewater treatment plant upgrades, stormwater controls, best management practices, and many other initiatives, has successfully protected the quality of the City's surface water supply and allowed the City to continue to enjoy high quality unfiltered water from its Catskill and Delaware watersheds. Because climate change poses a threat to water quality, successful continuation of DEP's Watershed Protection Program is essential. The main water quality concerns include:

CHANGES IN PRECIPITATION PATTERNS

- Changes in precipitation patterns, particularly the potential for larger and more intense storms, which could cause more erosion and increased turbidity, more debris in reservoirs (e.g., downed trees, leaves), increased loadings of pathogenic bacteria and the parasites *Cryptosporidium* and *Giardia*, more phosphorus and eutrophication in reservoirs, stimulation of blooms of blue-green algae which can cause changes in water color and taste, and increased disinfection by-product precursors that can react during disinfection to form substances harmful to human health in high concentrations

CHANGES IN ECOLOGY OF THE WATERSHED

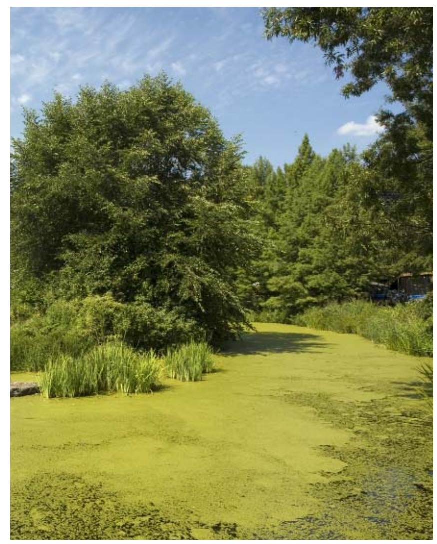
- Changes in the ecology of the watersheds, plant life, wildlife and insects, due to both temperature increases and precipitation levels and patterns may affect water quality in ways that are not presently understood

INCREASED WATER TEMPERATURE

- Increased water temperature in streams and reservoirs could change temperature stratification, reduce dissolved oxygen, increase algae growth which can lead to changes in water color and taste, elevate concentrations of unionized ammonia, and potentially lead to the introduction of new invasive species

- Increased water temperature in reservoirs also increases the settling of turbidity causing better quality warmer surface waters in reservoirs to be sent toward distribution which could affect downstream coldwater fisheries habitats

- Increased temperature can also alter the migration habits of waterfowl, such as Canada geese, which can have a major influence on fecal coliform levels in reservoirs (DEP currently conducts a Waterfowl Management Program to discourage the presence of geese, ducks and gulls near water intake areas)



These potential changes could stress water quality, which would require additional efforts to maintain the City's filtration avoidance status, or, alernatively, large costs for filtering the water from the Catskill and Delaware systems.

Runoff and Reservoir Turbidity

Runoff into reservoirs from extreme weather events can significantly affect the levels of turbidity, which is a measurement of cloudiness of water. Although turbidity has no health impacts, it can hinder the effectiveness of disinfection and provide a medium for microbial growth. Therefore, high turbidity levels can lead to water quality violations in an unfiltered water supply system.

The turbidity levels increase and persist much longer for the larger storm events. In the case of an April 2005 runoff event, resulting from a storm with a 25-year return period, extremely high turbidity levels above 100 Nephelometric Turbidity Units (NTU) were recorded for more than 100 days (5 NTUs is the limit under the Safe Drinking Water Act). Typically, turbidity values currently range between 0.5 and 1.5 NTU.


NYCDEP

Schoharie Reservoir after Hurricane Floyd. Turbidity is an issue particularly in the Catskill watershed, where the slopes are steep and there is a lot of clay soil.

Extreme weather events that erode streambeds, streambanks and sedimentary deposits can transport glacial clays into the water supply and affect turbidity levels. When such peak turbidity levels occur, DEP has treated as much as 600 mgd in the Catskill Aqueduct with alum and sodium hydroxide to reduce turbidity levels by precipitating clay particles. In order to reduce the need for chemical treatment related to extreme weather events, DEP has conducted a study of structural and non-structural alternatives to control turbidity leaving the Schoharie Reservoir. Further, the Department has implemented a Stream Management Program in the Catskill Watershed to reduce streambed and streambank erosion and has also implemented Best Management Practices to reduce turbidity in runoff at key locations near intakes.

Potential Water Demand Changes

On the demand side, though climate change concerns appear less complicated, impacts may be significant. After several decades of water usage above the system's safe yield of 1,290 million gallons a day (mgd), the City reduced demand signif-

Safe Yield

Safe yield is the maximum sustainable annual withdrawal from a water supply system over a period of years that will not deplete the supply during a drought with some specified probability of occurrence.

icantly through an extensive water conservation program, such that it is now operating below this critical indicator level. In-City demand fell from 1,206 to 1,069 mgd over the past decade, while demand from communities outside the City that use City water fell from 123 to 117 mgd. DEP projects that future demand in the City could be 1,237 mgd by 2030. Although future development and population increase within the City is expected to be large, with an additional million people by 2030, the mandated use of low water use fixtures is anticipated to have a significant effect in moderating overall demand. However, these projections do not account for changes in upstate demand or other likely impacts of climate change.

Climate change is likely to exaggerate seasonal and peak periods rather than annual average usage. Temperature effects associated with seasonal and peak usage are well documented. Hot periods exceeding 90ºF, particularly if lasting more than three consecutive days, are known to cause high demand flows from legal and illegal hydrant usage within the City. In less urbanized areas, where lawn watering and irrigation use is prevalent, temperature increases lead to increased seasonal and peak outdoor water usage. High temperatures also promote the use of central air conditioning systems, which use water to operate their evaporative cooling towers. With temperatures potentially rising by 3.0ºF to 5.0ºF by the 2050s and 5.0ºF to 8.5ºF by the 2080s, more days above 90ºF will be experienced, and seasonal and peak demands will likely increase.

Within the City, while annual average demand is currently about 1,069 mgd, peak demand flows can rise to over 2,000 mgd during heat waves and hydrant-opening episodes. For example, on August 2, 2006, which was the third successive day with temperatures in the 90s and humidity over 70%, the daily flow was 1,560 mgd, and peak flow reached 2,020 mgd. When peak flows are over 2,000 mgd during heat waves, the ability of the existing aqueducts to refill the City's main distribution reservoir is strained. As a result, water levels go down during the daytime hours of excessive peak demand, decreasing water pressures throughout the system. This impairs fire fighting, leads to low pressure complaints from upper floors of buildings without pumping capabilities and increases sediment re-suspension within water mains. Pressure effects are more pronounced in certain outlying areas of the City (Queens and Staten Island) as well as high elevation areas (Washington Heights in Manhattan).

Outside the City, climate-induced demand issues, in general, may be more oriented to the summer season. Longer dry periods between rainfall events and more frequent

NYCDEP, Scott Foster

Open Fire Hydrant

Both permitted and illegal fire hydrant openings occur during sustained periods of hot weather.

extreme heat conditions may lead to additional outdoor water usage over extended periods of time, thus having more of an effect on total demand. Since more water is used per capita for landscaping upstate than in the City, average daily use per capita during the summer season will likely increase more upstate than in the City. Out-of-City water users are subject to additional usage charges if per capita upstate usage is greater than that of City users; however, these surcharges may not be sufficient to adequately limit increases in future demand. The City has limited power to influence upstate water demand, prices, and conservation policies.

DEP's Watershed Management Models

DEP's watershed management models simulate water quality and quantity in the NYC Water Supply system, driven by climate data. DEP is preparing to run these models with future climate projections from global and regional climate models. The climate variables applied to the watershed and reservoir models, including precipitation, maximum and minimum temperature, wind speed, solar radiation, and humidity, are all climate model outputs.

The DEP models include: GWLF (Generalized Watershed Loading Function) watershed models that predict streamflow, runoff, sediment, and nutrient loadings from a watershed to provide assessments such as the probability of high nutrient loading concentration in summer; a 1D reservoir model that outputs daily water column average phosphate, nitrogen particulates, and ultimately chlorophyll; a 2D reservoir model which is used to model turbidity transport; and OASIS, a model which is used to manage operations such as movement of water through the reservoir system.

Image courtesy of NASA

2.2 Potential Impacts to the Drainage and Wastewater Systems

Climate change concerns relating to the drainage and wastewater systems fall into three broad categories:

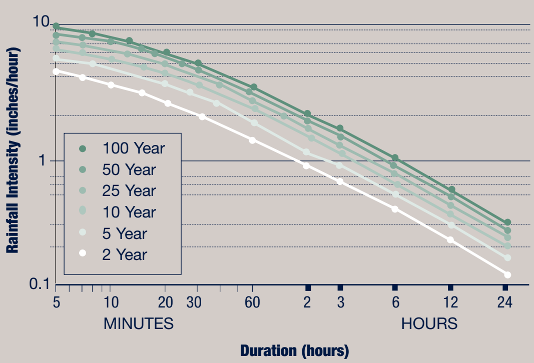
1. **Flooding: Will there be more flooding incidents?**
2. **Regulatory Standards: Will the ability to meet wastewater treatment requirements be impacted?**
3. **Ecology: Will there be water quality impacts to receiving waters?**

Designing New York City Sewers

The City's storm and combined storm sewers are designed to convey surface stormwater runoff from rainfall events of varying intensities and durations. The methodology used to design sewers for runoff conveyance is based on precipitation intensity-duration-frequency (IDF) curves.

These diagrams are constructed from observed rainfall data of varying durations, from 5 minutes to 24 hours. The data are analyzed and arrayed graphically as precipitation intensity (inches/hour) as a function of rainfall duration (minutes or hours). Statistical procedures are used to develop a series of curves for various return periods (probabilities of occurrence).

Rainfall Intensity and Duration
New York, NY 1903-1951



The standard design criterion in New York City is to use the intensity-duration values based on a storm with a 5-year return period (e.g., 1.75 inches/hour for a one hour storm). The sewer design flow is then determined by application of an equation using a runoff coefficient, a rainfall intensity determined from an equation derived from the IDF analysis, and the contributory drainage area (NYCEPA, 1973). The design of combined sewers includes allowance for the sanitary flows.

The IDF curve currently used by New York City is based on historical data from 1903-1951. With climate change, the intensity and duration of a storm with a 5-year return period is likely to increase, therefore the current curve may not be adequate for designing infrastructure that is to last decades. However, recent studies using rainfall records from 1948-2002 (Vieux, 2006) have shown that the intensity and duration relationships actually decreased somewhat during that period.

New York City Drainage and Wastewater Treatment Systems

The City's drainage and wastewater system is extensive. It consists of about 6,600 miles of sewers, 130,000 catch basins, almost 100 pumping stations, and 14 WPCPs. Approximately 40% of the sewered area is drained by separate storm and sanitary sewers. The storm sewers collect runoff from rainfall events for conveyance to nearby waterways and the sanitary sewers carry sewage to the WPCPs. The remainder of the City's sewered area is served by combined sewers, which convey both sewage and stormwater runoff in a single pipe. During larger rainfall events, regulating devices in the sewer system divert excess combined sewage to receiving waters through combined sewer overflow (CSO) outfalls in order not to exceed the capacity of WPCPs. The City has several CSO storage facilities in various stages of operation, construction and planning, and various other measures have or are being implemented to reduce CSO discharges.

Water Pollution Control Plants

1. Bowery Bay
2. Hunts Point
3. Tallman Island
4. Wards Island
5. Newtown Creek
6. North River
7. Oakwood Beach
8. Port Richmond
9. Red Hook
10. 26th Ward
11. Coney Island
12. Jamaica
13. Owls Head
14. Rockaway

Flooding Incidents

The City is vulnerable to two main types of flooding events: inland flooding from excessive rainfall and coastal inundation from storm-induced high tides. For rainfall events, the City's drainage and wastewater collection system, whether storm or combined sewers, has been designed to various sizing criteria based on historical patterns and intensities of precipitation. If rainfall becomes more intense as a result of climate change, particularly during short time intervals of 5 to 15 minutes when the rate of rainfall can be extremely high, the capacity of portions of the sewer system could be exceeded (sewer flood), leading to street and basement flooding. In addition, for low-lying areas of the sewer system near the coastline, high tidal conditions can inhibit the discharge of runoff in the sewer system causing backups and resulting in localized street and basement flooding. As sea level rises due to climate change, such backups could become more widespread and severe.

For coastal inundation, more frequent and severe shoreline flooding will occur as sea level rises and, if storms become more intense, the flooding will be worsened. Storms such as Nor'easters and hurricanes that produce severe high tides and wave action and inundate low-lying coastal areas can cause physical damage to public and private property.

Nor'easters and hurricanes can also worsen inland flooding when seawater enters catch basins and manholes located near the shoreline. DEP's WPCPs and some pump stations are located along the shoreline so that gravity can drain the sewer system and treated wastewater can be discharged to the harbor. However, due to the infrastructure's location in the flood plain, it is vulnerable to direct coastal inundation with saline waters, which could submerge and damage critical equipment, particularly electric motors and pumps. In addition to the financial cost of damage, the future reliability of operations could be compromised. Outfalls, retaining walls, docks, piers and other structures are also subject to damage.

In addition, the wetlands in and around New York City, which have shrunk by almost 90% over the past century, continue to be lost due to storm damage, development, and other factors (Bloomberg, 2007). The loss of wetlands is a concern due to their natural role in conveying, filtering and storing stormwater and their ability to attenuate coastal storm surge.

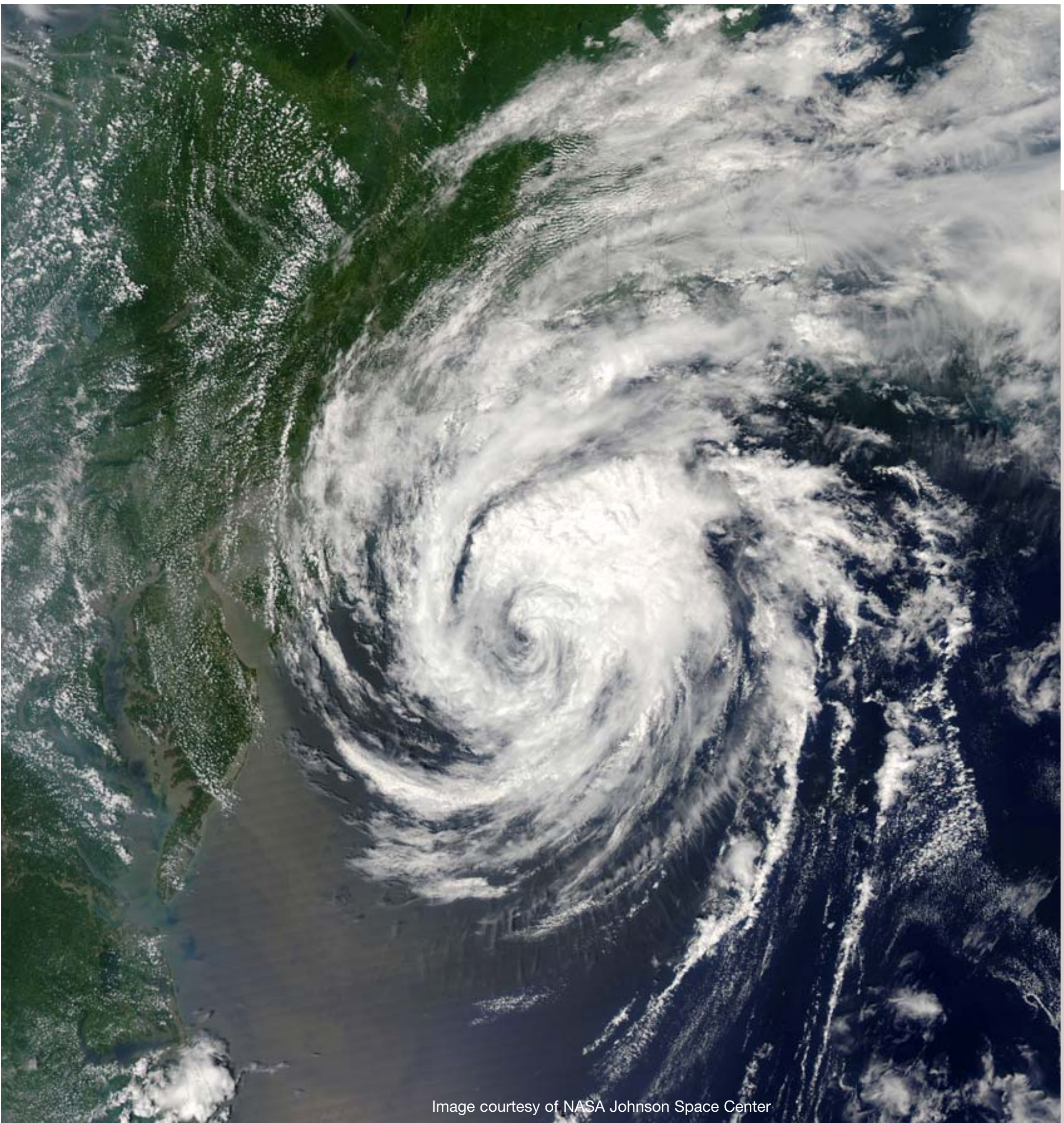


Image courtesy of NASA Johnson Space Center

DEP's Sewershed Discharge and Harbor Water Quality Models

By using rainfall records as input to estimate wastewater discharges and pollutant loads to receiving waters from CSOs and stormwater runoff, DEP's primary landside sewer system model, InfoWorks, allows planners and engineers to predict the environmental impact following a rainfall event. DEP's harbor water quality models, the System-Wide Eutrophication Model (SWEM) and the New York Harbor Pathogens Model (PATH), compute circulation, stratification, and water quality within New York Harbor, Long Island Sound and the "New York Bight." SWEM computes the effect of various potentially polluting discharges on the harbor's dissolved oxygen resources, and PATH computes the harbor's pathogenic indicator bacteria. SWEM and PATH are influenced by freshwater boundary inflows, tidally driven surface water boundary elevations, and meteorological forces, including wind, solar radiation, ambient air temperature, precipitation, and relative humidity, many of the variables that will be altered by climate change. In an upcoming study, DEP will run these models for a range of potential future climate-related conditions to assist the Department in quantifying the impacts of future rainfall, wind, ambient air temperature, and sea level conditions on runoff loading and harbor water quality.

Potential Impacts to Wastewater Treatment

Sea level rise represents a threat to the hydraulic capacity of WPCP outfalls. These outfalls have been designed to discharge peak influent flow to the harbor under conditions of historic high tide, and that capability is part of discharge permit requirements. Some plants are already known to be approaching their hydraulic outfall limits because, during very high tides, peak flows can be difficult to discharge. Addressing this potential impact may require effluent pumping and additional power consumption.

Sea level rise and coastal inundation may cause temporary increases in the salinity of influent to the WPCPs, which is regulated and can upset biological treatment processes and lead to corrosion of equipment. Sea water intrusion could also cause quantity concerns. Most combined sewer outfalls have tide gates to prevent the inflow of seawater directly from outfall sewers, backward to regulators, and then to treatment plants. Due to climate change, DEP may need to install tide gates at more outfalls to prevent inflows, and DEP may need to check and repair its existing tide gates more frequently.

The inability of sewers to discharge to receiving waters due to higher tidal levels during storm events could cause combined sewage to back up in the collection system, which could force more of it to the treatment plants. For the most significant storms, this could result in inundation of the WPCPs' influent wet wells, thus necessitating the throttling of flows in order to protect the plants from flooding and prevent disruptions to the treatment process. Some temporary street flooding in vulnerable areas could also result. The need to improve the reliability of throttling facilities and instrumentation related to WPCP operations could increase in order to handle significant rainfall events under conditions of higher tides. Also, pressure could increase for treatment facilities to take in more CSO flow, necessitating expansion of treatment plants, which are currently very space constrained.

Aeration Tanks at the Hunts Point WPCP

Treatment facilities may also be directly impacted by rising temperature. Treatment processes rely on biological and chemical reactions, some of which are temperature related. Rising temperatures could have beneficial effects by improving biological actions in some parts of the treatment process (for instance, less power may be required to heat digesters). Although it is anticipated that any adverse impacts would be minor, rising temperatures may reduce dissolved oxygen levels and transfer rates in wastewater, resulting in the need for more aeration equipment such as blowers and, therefore, for additional power.

An additional challenge is that electricity demand increases significantly during hot weather events, therefore increasing the likelihood of power outages and the need to use backup power at DEP facilities (NYCOEM, 2007). Backup power maintains essential plant operations but sensitive treatment processes such as biological nutrient removal (BNR) could be disrupted. The BNR process can take two to three weeks to recover following an extended power outage. In the interim, off-quality effluents could be discharged to harbor receiving waters and affect water quality by some amount.

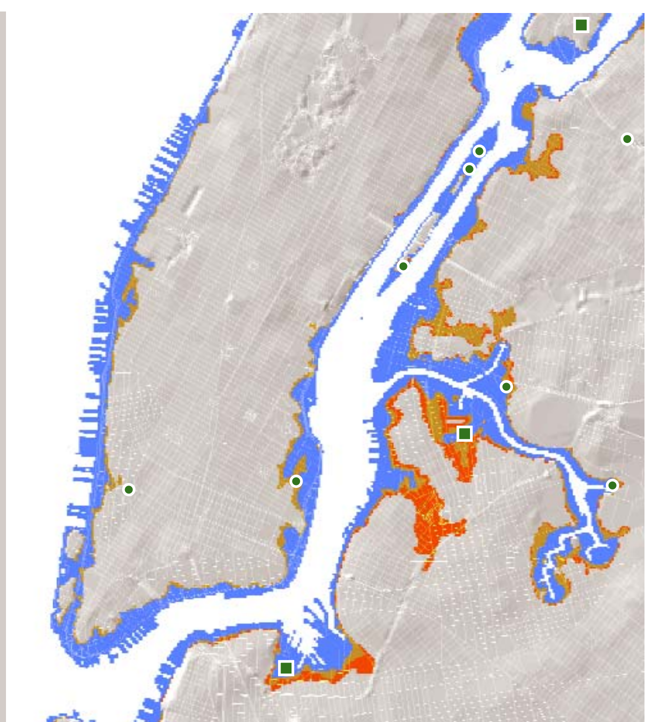
Comparing Inundation with Current and Projected (2080s) Sea Level Estimates

CASE STUDY: 100-YEAR STORM

- Projected Inundation Zone Estimates (current sea level)
- Projected Additional Inundated Area IPCC B1 (13.8 inch sea level rise)
- Projected Incremental Additional Inundated Area IPCC A1B (16.7 inch sea level rise)
- Water Pollution Control Plant
- Pump Station

Storm Surge Data Source: FEMA Flood Insurance Study, 2/15/91
Sea level rise estimates based upon Goddard Institute of Space Studies Atmospheric-Ocean Model using International Panel on Climate Change greenhouse gas emission scenarios for 2080s.

Mapping by HydroQual

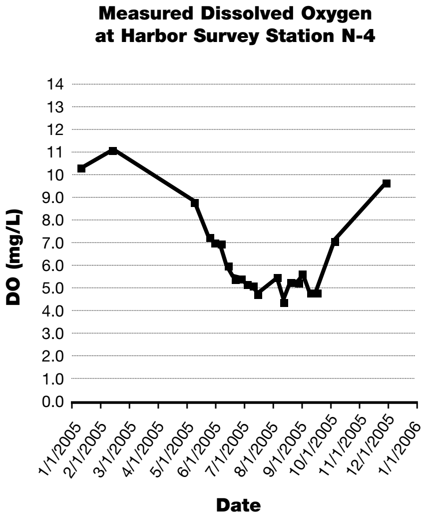


Potential Water Quality Impacts to Receiving Waters

The waters to which DEP's drainage and wastewater management systems discharge include New York Harbor and nearby western Long Island Sound, which form an estuary (a body of water that is affected by the tidal interchange of saline ocean water and the fresh water of the Hudson River and other tributary rivers and streams). The salt content and elevation of the harbor are constantly changing from the daily and seasonal influence of tides, temperature, and precipitation. While sea level rise will likely move saline ocean waters farther upstream, the range of salinity concentrations within most of the harbor will likely remain similar to that currently experienced, although the average salt concentration at any given geographical point could increase somewhat. Sea level rise will increase water depth somewhat, and changes in precipitation patterns could result in more or less fresh water inputs from time to time. The possible ecological changes resulting from these potential climate-induced changes to the water in the harbor are not yet understood and require further study.

New York Harbor and Long Island Sound water quality may be directly impacted by temperature change. Warm waters hold less dissolved oxygen than cold waters hold, and increased thermal temperature stratification restricts the ability of atmospheric oxygen to be transferred to lower layers of the water column. Dissolved oxygen in receiving waters is a key water quality parameter regulated by State water quality standards. Low dissolved oxygen levels represent a threat to marine life, and levels must be maintained above key thresholds, depending upon the water body's use classification established by the State. A significant portion of DEP's water pollution control programs are driven by treatment requirements established to maintain compliance with dissolved oxygen standards. In the summer, receiving waters are at a low point in the annual cycle of dissolved oxygen levels, so treatment requirements are set to meet these summer lows.

Temperature rise could, therefore, potentially lead to more stringent treatment requirements. Several of the City's WPCPs already have advanced treatment requirements to remove nitrogen from wastewaters because of nitrogen's fertilizing of algae that, in turn, increases demand for oxygen in the lower layers of marine waters. State and federal regulators are currently investigating the need for more such controls. The need for even further advanced treatment requirements for nitrogen would present great challenges to DEP because of space, power and overall cost concerns.



Another water quality concern is combined sewer overflows. If precipitation patterns change such that the same or more annual rainfall is experienced through fewer but larger storms, then there is the potential that DEP will need to manage more combined sewage in order to prevent additional CSOs and the impacts to the quality of the receiving waters. It is also possible, however, that longer dry periods between storms could reduce the overall number of CSO events, therefore possibly providing better intermittent harbor water quality.

Inundation Mapping

In order to develop maps that illustrate how much inundation areas within New York City may increase in size during future storm events, HydroQual developed a high resolution digital elevation model of the New York City topography, NYCDem, using data derived from aerial photogrammetry conducted during the 2001-2002 fly-overs for the New York City base map, NYCMap.

The Stony Brook University Storm Surge Model was used to project shoreline sea water elevations produced by historic storms, and FEMA estimates were used for 100 and 500-year storm surges. Three sea level scenarios were considered: current mean sea level, as well as current mean sea level with a 13.8 inch rise and a 16.7 inch rise (the average rise projected for the 2080s by 3 GCMs for IPCC emission scenario B1 and A1B, respectively).

Coney Island Beach

On the positive side, climate change could result in improved bathing water quality compliance. Warmer harbor waters can result in faster die-off of pathogenic organisms, which are key determinants in swimming water quality.

Discharges from WPCPs will continue to need disinfection as they do currently, and effluent from the plants will still need to meet the same residual chlorine requirement. However, the effectiveness of the pathogenic reduction in both the wastewater and receiving water should be enhanced by the higher temperatures.


P. Simmons, HydroQual

2.3 | Other Impacts to DEP

In addition to water supply, drainage, and wastewater issues, a number of other DEP facilities may be impacted by climate change. More intense storms and flooding in the upstate watershed could damage DEP offices, garages and other support facilities. In addition, there may be a need in the future to review dam safety criteria, as today's dams are designed for the Maximum Probable Flood based on past climate data. In the City, the vulnerability of the Department's WPCPs, pumping stations, and sewer systems to sea level rise and coastal inundation from storms has been noted. In addition, flooding events in the City from more intense rainfall could impact office buildings, field offices, repair yards, inland pumping stations, water tunnel shafts and similar facilities, as well as cause construction delays. Structural damage may also result from storms and hurricanes with increased intensity, and increased temperature could affect the durability of structures, shortening their useful life, and increase the operating cost for repair and energy needs.

In addition to the physical and environmental impacts, the fiscal impacts of climate change on water and sewer ratepayers and the Department could be significant. Climate change may cause considerable damage, and system recovery after extreme events could be very costly. In addition, the costs to managing these potential climate changes could be substantial.

Therefore, the Department needs to proceed with addressing the issue rapidly enough to minimize impacts and sustain the Department's consistently strong bond ratings, but not so quickly that DEP's funds are spent on unnecessary measures. In many instances, it is unlikely that authorization would be given to spend funds on addressing a problem that is not yet very well defined, for which there is significant uncertainty that it will in fact materialize, or for which the predicted impacts are very far in the future. Thus, understanding the extent and timing of potential impacts and critical system vulnerabilities to climate change is crucial for effective and responsible planning and decision making.

2.4 DEP Actions to Enhance its Understanding of the Potential Impacts of Climate Change on DEP

To quantify, better understand, and monitor the impacts of climate change on DEP and its water supply, stormwater, and wastewater management systems, DEP will:

ACTION 1

Conduct a phased integrated modeling project to quantify and provide a comprehensive understanding of the potential impacts of climate change on drinking water quality, supply, and demand.

Working with Columbia University, DEP has developed a plan for a modeling project that will integrate climate change projections with the Department's watershed management models, including its water quality, quantity, and system operations models, in order to quantify and provide a comprehensive understanding of the potential impacts of future climate change scenarios on the City's water supply system. The modeling will aim to determine the extent to which changes in temperature, precipitation, extreme events, and other climate changes will impact the following key elements:

- Water quantity
- Probabilities of refill and drawdown (which are drought indicators)
- Probability and quantity of spill
- Water quality at key system locations to assess compliance with applicable regulatory and operational water quality standards
- Water demand

The project will have two phases:

Phase I

Phase I will use a series of sensitivity analyses to 1) test how DEP's water supply system may be impacted by a range of climate change projections, and 2) identify the key climate influences or concerns that DEP should closely track. DEP's watershed management models will be run with climate projection data in order to simulate a range of future water supply, quality, and demand under various future climate conditions.

Phase I will focus on the Catskill-Delaware watershed. The possible water supply impacts due to potential changes such as increased evapotranspiration due to warmer temperatures and longer growing seasons, and changes in precipitation, snowpack, and runoff will be studied. Relevant pressures and rules of the system, including reservoir release requirements to maintain downstream ecological flows, plus a range of future water demand estimates, will be taken into account. The potential water quality impacts due to such factors as possible pollutant loading and atmospheric changes will be studied for "indicator" reservoirs (Schoharie Reservoir in the Catskill system and Cannonsville Reservoir in the Delaware system).

Phase II

Phase II tasks will be structured according to the findings from Phase I and will utilize model enhancements and more refined climate projections. Phase II may also study how the salt front in the Hudson and/or Delaware Rivers may be impacted by climate-induced changes in flow and sea level. Alternative operating procedures will be modeled to determine how operational changes may be used as a tool to optimize quantity and quality and understand the limits in the resilience of the system. The review of operating procedures will take into consideration how regulations may change in the future. For example, how diversions from reservoirs may be altered or increased for ecological flow requirements to maintain healthy fisheries.

The results of this effort will support the recommendations for prioritizing proactive strategies that will maintain watershed operations at acceptable levels in a changing climatic regime.

ACTION 2

Conduct a project to quantify and provide a more comprehensive understanding of the potential impacts of climate change on drainage, wastewater treatment processes and infrastructure, and harbor water quality.

DEP will initiate a multi-year project to identify system vulnerabilities, and quantify the range of potential impacts of current extreme weather events and future sea level rise, coastal flooding, and precipitation changes on the Department's in-City infrastructure and its ability to drain storm water and treat wastewater. This will be achieved by running the Department's sewershed discharge and harbor water quality models with climate change data, assessing past trends, performing sensitivity tests, developing inundation maps, and performing cost/benefit analyses.

As part of this project, DEP will:

- Identify, tabulate, and centralize the elevations of outfalls and the critical flood elevations (the lowest point where flooding occurs and may worsen) at DEP facilities in particularly flood prone areas; identify and map the current and potential range of future sea levels and 100-year flood inundation areas at the various infrastructure components; and compare the elevations of the outfalls and the critical flood elevations with the updated sea levels and inundation areas to identify the areas of the system that are flood-prone and/or susceptible to sediment deposition and sewer capacity reductions.

- Attempt to estimate how the intensity and frequency of rainfall will change within short durations in order to assess the impacts of climate change on urban drainage (the amount of rain that falls within 5 or 15 minutes is one factor that guides sewer sizing). Climate models are currently unable to project the amount of rainfall within a period of time shorter than three hours. Thus, a methodology will need to be developed to extrapolate data from the climate models. This will likely require collaboration with other utilities that have been developing or plan to develop such estimates. However, it is possible that this will prove to be unachievable until further developments are made in climate science.

- Evaluate to what extent street and basement flooding and CSOs will be exacerbated by climate change due to changes in rainfall intensity, duration, and frequency.

- Estimate the probability that various costs may be incurred due to potential damage to DEP's in-City infrastructure.

- Estimate changes in groundwater levels due to sea level rise and changing precipitation patterns and the potential for greater infiltration or inflow of groundwater into the wastewater conveyance system.

- Estimate potential changes in harbor water quality indicators.

The findings will guide the development of a long-term plan for gradually implementing system management that will better enable DEP to provide drainage and wastewater services in the face of climate change, while making the systems more resilient to current weather extremes.

ACTION 3

Establish a uniform Department-wide system for documenting and reporting the occurrence, levels, and impacts of flooding and other extreme weather incidents on DEP's systems in the watershed and in the City.

This will allow DEP to determine the degree to which the potential impacts to DEP operations and programs identified in this Report and in future studies are occurring, as well as to detect impacts that have not yet been identified.

ACTION 4

Conduct additional and more detailed interviews with system operators, and catalog all known system vulnerabilities.

This will allow DEP to supplement existing in-house knowledge about current system vulnerabilities with a more targeted focus once potential future climate change challenges are better defined.

ACTION 5

Track published studies and identify opportunities for collaborating with researchers on future studies that will enhance DEP's understanding of the potential impacts of climate change on DEP's water systems.

DEP is not able to study all of the potential impacts of climate change that may require systemic or operational modifications, particularly those that are not fully understood by the global scientific community, such as the ecological impacts of climate change. Tracking scientific advances in the understanding of climate change impacts may reveal data gaps and additional monitoring needs for future DEP studies. Examples of topics that may require additional study in the future include:

- Ecological changes to the watershed
- Effects of sea level rise and precipitation changes on the potential for salt water intrusion into groundwater within the City, particularly in areas targeted for increased groundwater utilization as part of auxiliary supplies
- Impacts to dams and other facilities that contribute to the impoundment and transmission of water, the hydrological changes that would be necessary to cause damage, and the probability that damage would occur based on various climate change projections and factors
- Ecological changes resulting from climate-induced changes to the water environment in New York Harbor

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM

Potential Adaptation Strategies For DEP

3

Raising Departmental awareness of climate change issues was the first step in what will be a decades-long process of adjusting New York City's water supply, drainage, and wastewater management systems to climate change. DEP now understands that climate change must be a priority factor in all future strategic and capital planning efforts in order for the City's vital water systems to function under and be resilient to a range of potential future climate conditions. In its consideration of potential climate change impacts, DEP has made a formidable start in identifying strategies for adapting its infrastructure, operations, programs and policies to climate change. DEP is considering these adjustments early, with the goal of minimizing future service disruptions and financial demands on the water system's ratepayers due to climate change impacts.

Many ongoing DEP projects and PlaNYC initiatives for addressing current climate extremes, environmental regulations, aging infrastructure, and population growth are also adapting DEP's systems for climate change. Though these projects will improve system resiliency to future climate conditions, a more comprehensive effort is needed to truly build water systems for the future. This Chapter examines many of the potential adaptation strategies identified by DEP to date, the projects that DEP is implementing to confront other challenges that are also effective climate change adaptations, as well as actions that DEP will take to implement or further study various adaptation strategies. The potential adaptation strategies and DEP actions to study and implement adaptations are also summarized in Chapters 5 and 6.

NYC Watershed Region

NYC Watershed Region spans approximately 40.5 N to 42.5 N and 73.5 W to 75.5 W and includes both the NYC metropolitan area and the upstate watersheds.

Base image courtesy of NASA Johnson Space Center

3.1 Potential Water Supply Adaptation Strategies

DEP has identified adaptation strategies for helping to mitigate the three categories of climate change impacts to the water supply system examined in Chapter 2:

- **Decreased quantity of water supply**
- **Decreased quality of water supply**
- **Increased demand**

Maintaining Water Supply

DEP is currently assessing various projects for their potential to prevent future water supply and demand imbalances due to non-climate-related factors. Such projects could also potentially assist in the prevention of water shortages due to climate change. For instance, because its infrastructure is aging, DEP is studying a range of measures that could be implemented to ensure the Department's ability to provide an adequate amount of water to the City and upstate communities while its aqueducts are taken out of service for inspection or repair.

Managing shared water resources in a potentially more volatile future climate will likely require watershed-wide strategies to fully address the issue.

The actions that could help protect the City from major shortages due to planned system outages include implementing a range of demand-reducing conservation measures, developing or enhancing alternative auxiliary sources such as groundwater, backing up systems by creating regional interconnections with pipes between New York City and New Jersey, Connecticut, or Long Island, and using reservoir models and other tools to balance flows and releases in order to optimize system operation and provide increased resiliency. This existing planning effort complements climate change-related water quantity concerns, as the imbalance between demand and supply due to planned system outages will likely be larger in scale than the quantity imbalances that might be manifested due to climate change.

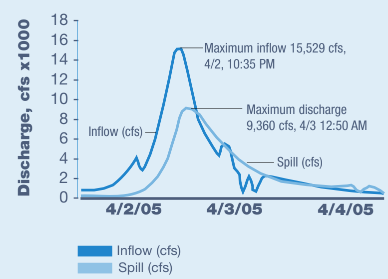
The actions that will increase water supply dependability during system outages will make the water supply system more resilient overall to challenges, such as drought and intense rain events. However, managing shared regional water resources in a potentially more volatile future climate will likely require watershed-wide strategies to fully address the issue.

For example, although the City's water supply reservoirs were not designed as flood control structures, and the City is not obligated to engage in flood control, the City has agreed to undertake certain measures for making controlled releases to help attenuate flooding as an accommodation to other parties. To more comprehensively address the potential flooding impacts of climate change however, a broad basin-wide flood mitigation strategy would be necessary. In addition, if future studies show that the Maximum Probable Flood will become more severe due to climate change, DEP will need to work with other agencies to examine whether additional dam stabilization efforts may be necessary to ensure public health and safety.

Flood Dampening

Watershed reservoirs were designed to ensure a safe and reliable supply of water for the City. They were not designed as flood control structures, and the City has no duty to engage in flood control. Nonetheless, the City's reservoirs confer a benefit on local communities, in terms of flood mitigation, simply by virtue of their existence. As this figure demonstrates, even when full, the City's reservoirs slow the rate at which water cascades downstream, thus reducing inundation areas during storm events. In this example, during an April 2005 storm, the City's Rondout Reservoir reduced the peak flow below the reservoir by approximately 60%.

**Rondout Reservoir,
Runoff vs. Spill Discharge
Storm Event April 2-4, 2005**



Some parties have called for the City to release water from its reservoirs to provide storage capacity and, thus, additional flood dampening in anticipation of storm events. Given the uncertainty of whether and when the amount of water released can be recaptured, such releases create concerns about the ability of the City's water supply system to meet the demands placed upon it, especially if droughts become more frequent.




BMPs
Several types of stormwater best management practices (BMPs) are used throughout the watershed to control erosion and facilitate the infiltration of runoff to reduce the sediment load to the reserviors, such as riprap-lined swales and pervious berms pictured above.

Maintaining Water Quality

Large and intense storms, and the associated runoff and flooding, are existing threats to water quality, particularly to the unfiltered waters from the Catskill and Delaware watersheds. Due to its rigorous watershed protection and planning, DEP has been able to confront these challenges very effectively. However, larger and more intense storms due to climate change may affect the level or frequency of water quality challenges. Since existing water quality protection measures depend heavily on natural systems, temperature and precipitation changes and the consequent effects on local ecology will bring a new dimension to DEP's management of the City's water supply. The ongoing Watershed Protection Program approved by EPA under the City's series of Filtration Avoidance Determinations (FADs), which includes land acquisition, land use, forest management, and numerous other programs, also serves as an adaptation for mitigating climate change impacts and will continue to guide DEP's goal of continued filtration avoidance.

Alternative strategies of dealing with water quality impacts due to climate change divide along structural and non-structural lines. One structural strategy is relying more heavily on the filtered Croton system during turbidity events. The non-structural strategy of bolstering the watershed protection program to account for potential larger storms and ecological changes will necessitate further research and study with experts and institutions in the fields of agriculture and forest ecology. DEP currently consults with Cornell University and others on such matters, and these relationships and programs of study may need to be increased to make technical assessments of the efficacy of natural systems to continue to meet water quality standards when they are stressed by more intense climatic events. Alternatively, the application of the coagulant alum (aluminum sulfate) is an operational strategy that has been used for decades to separate out particles that are suspended after a storm event in the water transported through the Catskill Aqueduct.

Although this improves drinking water quality, it does require dredging part of the Kensico Reservoir in order to remove the alum sediments that settle at the bottom.

Desalination Options

In January of 2007, United Water New York announced plans to construct a desalination facility that will treat water from the Hudson River for its customers in Rockland County (United Water, 2007). The Vice President of the utility company stated: "The Hudson River gives us a drought tolerant water supply that is eminently expandable."

The desalination option is also being investigated in Australia to relieve recurrent water shortages and the threat of salinization of water supplies. This planning illustrates that some locales believe desalination to be a feasible alternative and may be a particularly desirable option for ensuring a reliable water supply in the face of potential climate changes.

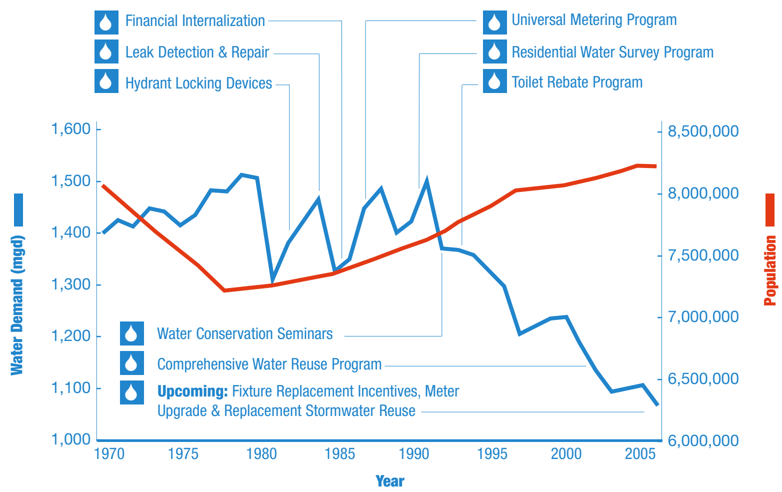
Reducing Water Demand

Climate change concerns can also exacerbate supply-demand imbalances. Particularly during short-term, peak demand periods, such imbalances may require additional measures for controlling the events that cause water pressure problems in the City distribution system. Climate change presents an additional reason to complete, or accelerate, structural improvements to the aqueduct system that could reduce pressure problems associated with an inability to refill Hillview Reservoir for peak daily demands. The Department's Kensico-City Tunnel Project (KCT), although motivated by reliability concerns over being able to take either the Delaware or Catskill Aqueducts south of Kensico Reservoir out of service for repair, could also help to alleviate low system pressure events by sizing to the KCT to convey volumes greater than can be currently delivered to Hillview Reservoir. For projects in the early planning stages, such as the KCT, DEP must consider the full range of climate changes projected to be experienced.

Alternatively, peak demand problems caused by climate change could be addressed by more small-scale approaches such as installation of better hydrant-locking mechanisms, use of more spray caps, provision of more public swimming pools and spray stations in City parks, better enforcement of illegal hydrant openings, agreements with upstate users of City water to impose conservation measures, and in-City conservation measures that reduce overall demand. These are all measures that can be considered in a programmatic way to manage this peak demand issue. Also, additional roof-top water tanks could assist individual buildings in tolerating multiple-day drops in water pressure, which can prevent water tanks from being refilled.

Water Supply Conservation Programs: Supply vs. Population

NYC population and water demand changes from 1970 to 2006. Water conservation programs reduced water demand even during periods of population expansion.



NYCDEP Water Demand and NYCDCP Adjusted Population Data

PlaNYC Water Supply Initiatives with Adaptation Benefits

On April 22, 2007, Mayor Michael Bloomberg announced PlaNYC, a far-ranging plan to ensure sustainable and environmentally conscious development of New York City to the year 2030. PlaNYC initiatives are primarily being implemented to address environmental regulations, aging infrastructure, and a growing population. However, many of the actions have the potential advantage of making DEP's water supply system more resilient and robust, thus serving as system adaptations for ensuring drinking water quality and quantity in the face of climate change:

PlaNYC DEP actions that will support drinking water quality as the climate changes:

- Enhance the Watershed Protection Program in order to maintain a Filtration Avoidance Determination for the Catskill and Delaware Water Supplies, with efforts such as a $300 million investment in land acquisitions in the watershed over the next ten years.
- Construct the Catskill/Delaware Ultraviolet Light Disinfection Facility to neutralize potential disease-causing organisms from the City's upstate watershed west of the Hudson River.
- Construct the Croton Filtration Plant to safeguard the Croton system.

PlaNYC actions that will support an adequate water supply as the climate changes:

- Launch an effort to reduce City-wide water consumption by 60 mgd by 2012 through rebate programs for toilets, urinals and high-efficiency washing machines in laundromats. Evaluate extending this effort to include water-efficient industrial equipment, water-saving dishwashers and ice machines for the food service industry; water audits, early leak detection, and gray water reuse and recycling.
- Maximize water supply from existing facilities such as the groundwater system in Jamaica, Queens, which is currently underutilized, and the New Croton Aqueduct, which is being improved to maximize the reliable delivery of water from the Croton system. Expanding the use of the groundwater system will also lower the water table and thus reduce localized flooding in the City.
- Establish a connection between the New Croton and Delaware Aqueducts to provide an alternative means for delivering water from the Croton and Delaware systems to the City during an emergency.
- Evaluate new water sources and projects that could help the City to meet a shortfall during a prolonged shutdown of the Delaware Aqueduct for repair, including demand-reduction programs, system diversification through desalination or storage of surface water in aquifers, and operational modifications.
- Continue to modernize in-City distribution by completing Water Tunnel No. 3, completing a backup tunnel to Staten Island, and accelerating the replacement of old water mains from 60 miles annually to 80 miles annually.

Source: Bloomberg (2007)

3.2 Potential Drainage and Wastewater Adaptation Strategies

DEP has identified adaptation strategies for minimizing the three categories of climate change impacts to the drainage and wastewater management systems examined in Chapter 2:

- **More frequent flooding of basements, streets, and coastal areas**
- **Challenged ability to meet wastewater treatment requirements**
- **Water quality impacts to receiving waters**

Projections of the increased frequency of intense storms and the magnitude of sea level rise are essential in developing critical risk-based policy analysis and decision making.

Minimizing Flooding

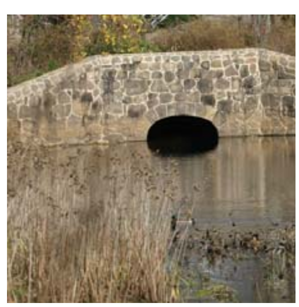
STREET, BASEMENT, SEWER FLOODING

Street, basement, and sewer flooding will potentially be more frequent because the intensity of storms is projected to be greater, and sea level rise will reduce the hydraulic capacity of existing outfalls to discharge.

Sewer systems and drainage designs are a precise business. Pipe grades and elevations are set so flow is driven by gravity, and street topography and property elevations are important design details. Equally important considerations in the design process are storm intensity and frequency criteria and land use characteristics that determine the amount and timing of runoff that reaches the sewers. The New York City system was designed to minimize standing water on roadways and streets, is mostly gravity based, and has been built out over hundreds of years. The sunk-cost investment in the City's sewer systems is enormous, and there is almost no flexibility to modify existing piping, either in size or slope, without digging up entire areas tributary to each outfall, and replacing such entire systems with new and larger pipes. In addition to the cost and disruption, the time to effect such changes would be extremely long, additional space would be required within the maze of subsurface utilities below streets, and pumping might be needed in some instances to convey storm and wastewater flows. However, some change in the system will likely be necessary to prevent unreasonable levels and frequency of street and basement flooding.

Green Drainage Corridors

The Staten Island Bluebelt is DEP's award-winning, ecologically sound and cost-effective stormwater management system for approximately one third of Staten Island's land area. The program preserves natural drainage corridors, called Bluebelts, including streams, ponds, and other wetland areas. Preservation of these wetland systems allows them to perform their functions of conveying, storing, and filtering stormwater, while providing community open spaces and diverse wildlife habitats. The Bluebelt program saves tens of millions of dollars in infrastructure costs, when compared to providing conventional storm sewers for the same land area.



Identified alternatives include:

- Augmentation of the capacity of the existing collection system using conventional, structural methods such as:
    - Increasing the size of sewer pipes in select areas where installation of new pipes is planned or where there is space within City rights-of-way not overcrowded with utility infrastructure
    - Constructing supplemental "high level storm sewers" where there is space within City rights-of-way and favorable topographic conditions
    - Pumping of stormwater or combined sewer flows and WPCP discharges
    - Increasing wet weather pumping and treatment capacities at WPCPs, where feasible
- Management of increased flows by more frequently cleaning sewers and maintaining catch basins in flood-prone areas
- Continued development of methods that use and enhance natural landscape and drainage features for runoff control such as the concept of the Bluebelt on Staten Island
- Implementation of stormwater controls at the source in order to decentralize key management processes
- Promotion of the use of green roof technology to reduce and reuse stormwater for ecologically productive purposes (as well as to reduce energy needs for cooling top floors of buildings and to collectively moderate the urban heat island effect)

The Jamaica Bay Watershed Protection Plan

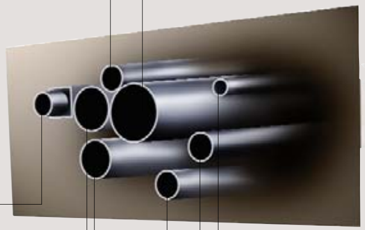
Jamaica Bay is one of the largest tidal wetlands in New York State. It remains ecologically rich, with at least 325 bird species and 91 fish species. However, its watershed is one of the most densely populated regions in the country with approximately 1.7 million people living or working within the watershed boundaries. The water quality of the Bay has deteriorated over the last 150 years due to dredging and changes in bathymetry; the introduction of WPCP and CSO discharges; the hardening of shorelines; and the replacement of most of the natural features within the Bay's watershed with impervious surfaces. Rainwater, which was once filtered by soil and vegetation, now runs off to the Bay carrying pollutants found within urban areas.

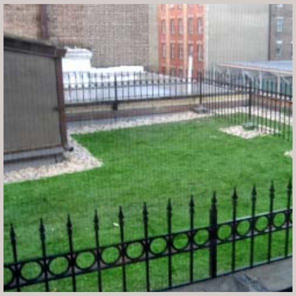
Even with DEP's tremendous ongoing efforts to improve water quality in the Bay, more needs to be done. Under Local Law 71, passed by the NYC Council and signed by Mayor Bloomberg in July 2005, DEP has developed a Jamaica Bay Watershed Protection Plan. The goal is to develop strategies to protect and restore the Bay's water quality and to improve and sustain its ecological integrity. To achieve this goal, in coordination with PlaNYC initiatives, numerous BMPs for managing stormwater at its source and capturing runoff from streets are being evaluated and will soon be implemented as a pilot project. In addition to mitigating the additional stormwater runoff and CSOs that could be triggered by climate change, these initiatives will also improve the health of the Bay's wetlands and, therefore, their ability to act as a buffer to storm surge as storms become more intense.

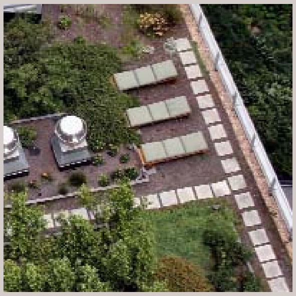
Flood Relief

One adaptation for minimizing street and basement flooding impacts is increasing the size of sewer pipes. This schematic cross section of a New York City street illustrates one of the many challenges this adaptation would present as space within City rights-of-way is very limited.

Street Cross Section







Photos courtesy of Ed Clerico, Solaire and Shinjinee Pathak, Columbia University.

Green Roofs

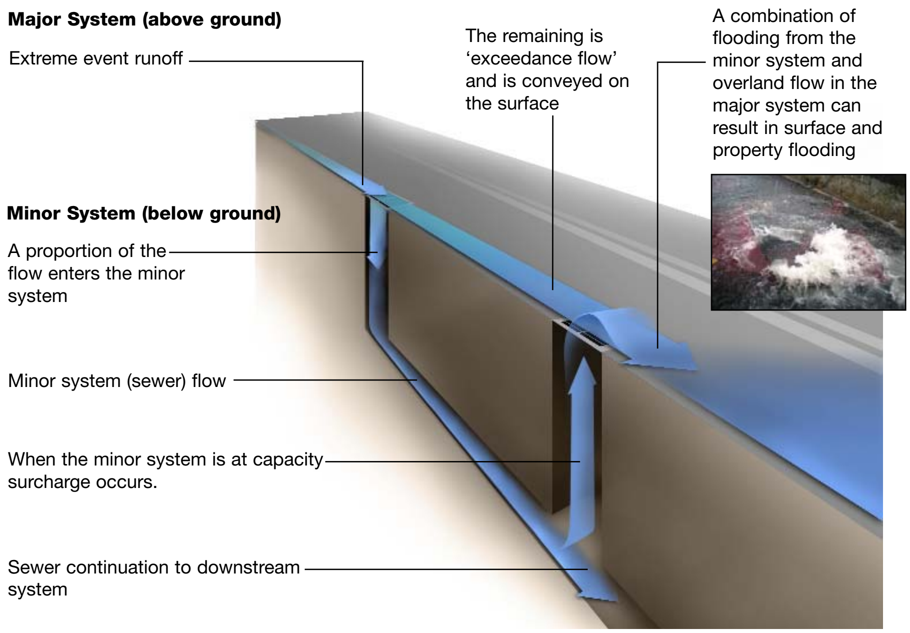
In addition to reducing some amount of stormwater runoff, green roofs collectively moderate the urban heat island effect (Rosenzweig, 2006). Intensive green roofs tend to require irrigation and are designed to address aesthetic considerations, in the style of roof gardens. Extensive green roofs, on the other hand, are generally designed to require little or no irrigation and to optimize stormwater retention as opposed to aesthetics.

Because there are many barriers to a number of the adaptation alternatives listed previously, DEP will need to think outside the box and examine drainage and treatment methods currently used or being considered in other regions such as in the Netherlands, which is almost entirely at or below sea level, or in the United Kingdom, which is at the forefront of adaptation planning. For example, an alternative drainage strategy could involve designating roadways for above-ground conveyance of waters during extreme events. This approach manages flooding in a controlled manner that minimizes damage but does not eliminate flood waters to the same extent as has been attempted by past engineering strategies. Such an approach is now a planning requirement for new developments in England, because their studies have indicated that the conventional underground conveyance approach is not affordable or sustainable for the most extreme events. It remains to be seen whether a very dense urban area such as New York City will be able to allow some roadways or open space areas to be purposely inundated on a periodic basis as an acceptable way of dealing with flooding from more frequent high-intensity storms. However, this and other innovative approaches need to be studied as alternatives to conventional structural solutions.

Designing For Exceedance

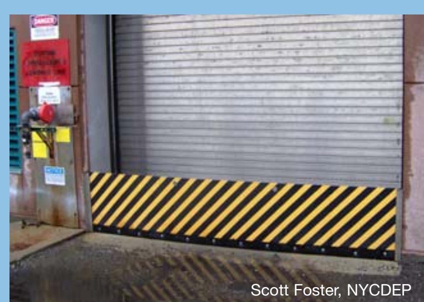
A potential adaptation strategy for accommodating increased runoff from more intense storms is to design above-ground conveyance pathways for sewer system exceedances. This approach, which is being applied in the United Kingdom for new developments, aims to minimize runoff on roads and other default pathways that are not designed to accommodate the flow. Instead, features on the surface such as swales, pathways, or roads are designed to control flooding by functioning during storm events as conveyance systems for the run-off that exceeds the capacity of the sewer system.

Interaction Between the Minor and Major System During an Extreme Event



COASTAL FLOODING

Coastal flooding due to sea level rise and storm effects on tide height and wave action may be even more difficult to address. New York City has 578 miles of coastal shoreline, and the metropolitan area of New York Harbor has significant additional shoreline. "How much sea level rise" and "what intensity of storm, hurricane, and tide and wave action should be planned for" are key risk based policy decisions that will determine which alternative solutions would most effectively minimize coastal flooding.The larger the magnitude of event (such as the worst-case scenario of a Category 4 hurricane moving north-north westerly and making landfall during high tide near Atlantic City, New Jersey, which would amplify the effect of storm surge through the "New York Bight"), the more appropriate regional approaches to this problem may be. Should studies of potential coastal damage reveal that coastal flooding events result in damage assessments far lower than the cost of protective measures,



Tallman Island WPCP Local Barrier during April 2007 Nor'Easter.

then more modest local protection strategies such as flood walls at key facilities or areas may be more appropriate. The range of possible approaches to coastal flooding may include:

- Raising elevations of key site-specific facilities above projected flood heights and construction of watertight doors and windows to protect critical equipment and control rooms
- Consideration of submersible pumps rather than wet/dry well pumps
- Having additional backup emergency management equipment in reserve so that the time to bring facilities on-line post-storm is minimized

"How much sea level rise" and "what intensity of storm, hurricane, and tide and wave action should be planned for" are key risk based policy decisions that will determine which alternative solutions would most effectively minimize coastal flooding.

Storm Surge Barriers

In 2002, the State University of New York at Stony Brook conducted research with sponsorship from New York State Sea Grant and DEP to investigate the feasibility of storm surge barriers to protect most of New York City from the effects of storm surge. The Storm Surge Research Group developed a coupled hydrodynamic and atmospheric model to simulate storm surge and evaluate the effectiveness of barriers at multiple seaward access points of New York Harbor. Two historical storms were evaluated, Hurricane Floyd and the December 1992 Nor'easter, and the barriers were shown to be operationally effective. Such an approach would be a regional adaptation strategy requiring approval of multiple governing agencies. How to protect areas not within the confines of the barriers would need to be addressed.

STORM SURGE BARRIER

Hurricane Floyd, 1999. Image produced by Hal Pierce, Laboratory for Atmospheres, NASA Goddard Space Flight Center

- Development of local protective barriers such as dunes, riprap, or sea walls
- Construction of large, multiple barriers such as tidal gates that would span openings to New York Harbor and provide regional protection
- Gradual retreat from the most at-risk areas or different use of these areas, such as for park land that could flood with minimal damage

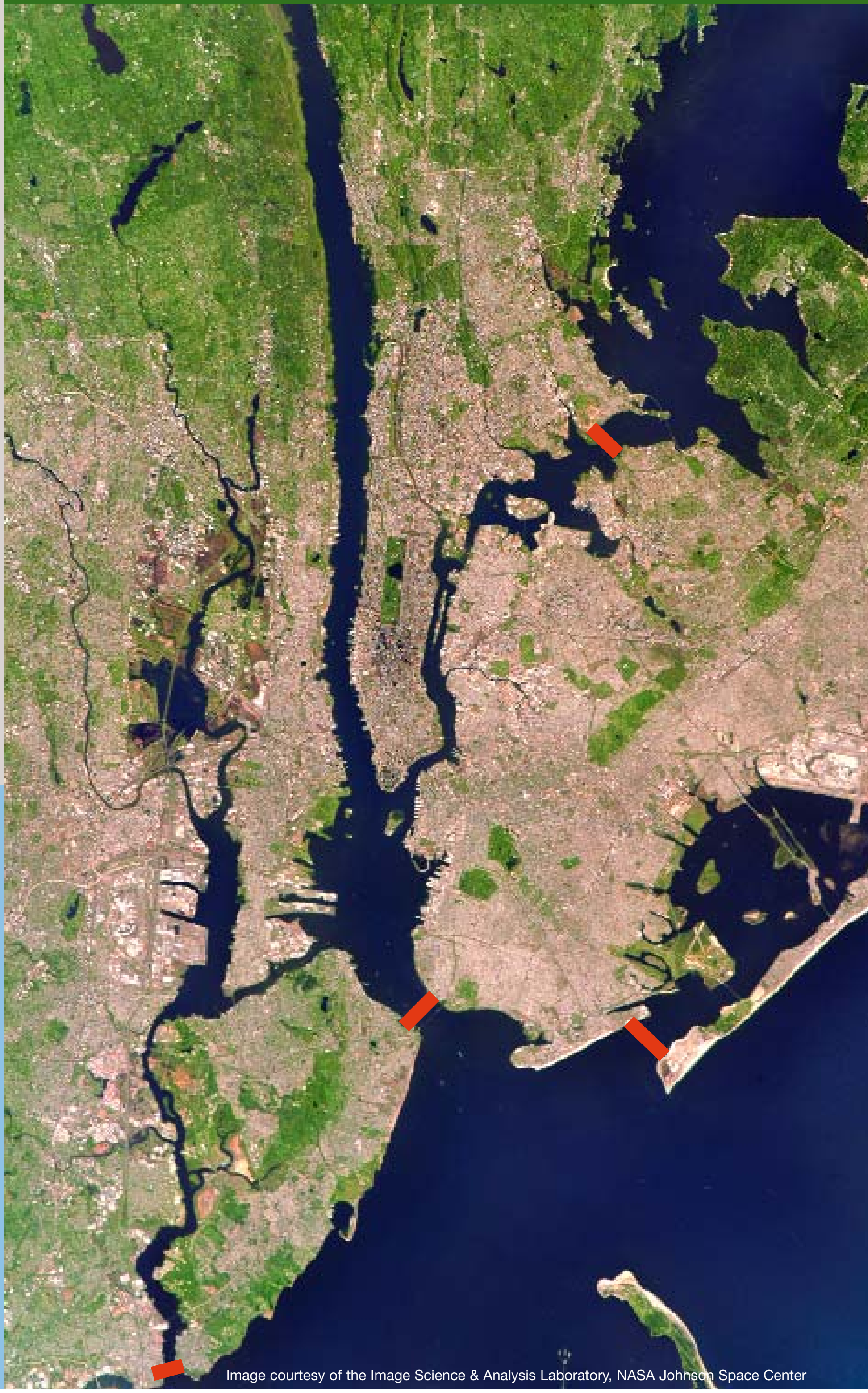


Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

Raising elevations of key site-specific facilities, or portions thereof, may be an appropriate strategy for some DEP facilities such as WPCPs or pump stations that lie in areas susceptible to coastal inundation. Raising key electrical equipment to higher elevations may be called for as a fairly low-cost protective measure that may be warranted without much further study if performed in conjunction with other remedial work on such systems.

Local protective barriers around entire facilities such as WPCPs may be warranted in the future, based on current and projected storm surge levels and estimated facility damage and extent of service outages. However, more study of site-specific facilities and noted parameters of surge and cost is warranted before such investments are committed.

Constructing storm surge barriers in New York Harbor has been considered in the past based on storm protection and water quality considerations. Such facilities transcend just protecting DEP facilities, they are targeted instead at large portions of the multi-state metropolitan areas that border New York Harbor. In addition to the large cost and controversial environmental considerations associated with this type of project, it is not clear what agency, other than the U.S. Army Corps of Engineers, or possibly the Port Authority of New York and New Jersey, would have jurisdiction over the construction and operation of such barriers.


Phil Simmons, HydroQual

Sea level rise may warrant modifications to existing shoreline protective structures such as bulkheads and seawalls.

Maintaining Ability to Meet Wastewater Treatment Requirements

Wastewater treatment processes can be impacted by all projected climate changes: temperature, precipitation, sea level rise, and inundation from increased storm surge. Temperature affects biodegradation kinetics and process requirements, and power disruptions from heat-related outages place demands on backup systems. Precipitation increases result in more flow and pollutant loadings to WPCPs and CSO control facilities and compromise the capacities of the WPCP digesters. Sea level rise may reduce the hydraulic capacity at WPCPs to pass peak design flows and may result in sea water entering the sewer system and WPCPs through faulty tide gates. Possible adaptation strategies for improving DEP's ability to maintain wastewater treatment requirements as the climate changes include:

- Regulatory relief of water quality criteria and attainment requirements for severe and extreme weather conditions
- Increased WPCP blower capacities or redundancy equipment for critical high temperature events
- Increased backup power capacity; scheduled interceptor and catch basin cleaning to reduce grit and sediment loads to WPCPs during rainfall events
- Improvements in capacity and operations of WPCP main sewage pump and screening capacity and operation to avoid failures during wet weather
- Relocation of vulnerable equipment above critical flood elevations; raising the height above the high water line of waste water treatment tanks, channels, and wet wells to prevent floodwaters from over-topping and entering the wastewater treatment process; and construction of watertight doors and windows to protect critical equipment and control rooms
- Revision of design criteria so that they address sea level rise
- Provision for effluent pumping to overcome sea level induced reductions in outfall capacity

Minimizing Water Quality Impacts to Receiving Waters

Receiving water quality in New York Harbor and western Long Island Sound can be adversely affected by temperature increases which affect thermal stratification, reduce dissolved oxygen concentrations, and increase ammonia toxicity which affects aquatic life. Increased annual precipitation and changes in rainfall intensity can create additional stormwater and combined sewage to manage in order to prevent additional runoff and CSOs to surrounding waters and the associated adverse impacts to recreational water quality.

Potential adaptation strategies for managing these risks include:

- In-stream aeration for critical water bodies that may be vulnerable to dissolved oxygen or stratification impacts, as has been done with DEP's destratification facility in Shellbank Basin, Queens
- Further upgrades to WPCP treatment processes to expand wet weather capacity and improve effluent quality
- Enlargement or supplementation of existing CSO control facilities
- Management of CSOs through best management practices such as on-site collection and reuse of stormwater

PlaNYC

Pilot Promising BMPs

☑ Investigate low-impact development strategies on individual tax lots, such as design guidelines for off-street parking lots, bioinfiltration BMPs, such as rain gardens, on-site stormwater reuse techniques, such as rain barrels, and possible incentive programs

☑ Create vegetated ditches (swales) along highways

☑ For five years pilot a property tax incentive to offset 35% of the installation cost of extensive green roofs

☑ In Hendrix Creek, a tributary to Jamaica Bay near the 26th Ward WPCP, reintroduce 20 cubic meters of ribbed mussel beds to test mollusks' ability to improve the water quality of tributaries around combined sewer overflow outfalls

☑ In the Jamaica Bay Watershed, pilot vegetation and infiltration techniques for treating and capturing stormwater from large parking lots

PlaNYC Harbor Water Quality Improvement Initiatives with Adaptation Benefits

Many of the PlaNYC actions being implemented to achieve the City's goal of opening 90% of its waterways for recreation also serve as system adaptations for mitigating the potential impacts of climate change on harbor water quality as shown below:

- Develop and implement comprehensive Long-Term Control Plans for all New York City drainage areas
- Expand wet weather capacity at the Newtown Creek and 26th Ward WPCPs, which will reduce CSO discharges during rainstorms
- Capture some benefits of New York City's open space plan, which will expand the amount of green, permeable surfaces across the City and reduce stormwater runoff
- Expand the Staten Island Bluebelt program
- Convert certain combined sewers into High Level Storm Sewers (HLSS), and integrate HLSS into major new developments, especially on the waterfront
- Develop a comprehensive policy for protecting and managing the remaining wetlands in the City
- Expand, track, and analyze new BMPs for runoff and CSO control
    - Develop an interagency approach to stormwater control to maximize stormwater capture at its source
    - Identify locations with the New York City Department of Parks and Recreation for stormwater management in the Bronx River Watershed
    - Partner with the New York City Department of Transportation to incorporate BMP designs into the reconstruction of the Belt Parkway bridges
    - Identify City property for opportunities to convert impervious pavement to porous pavement

Source: Bloomberg (2007)

Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

3.3 Uncertainty and Planning for System Adaptations

The first step towards efficiently implementing adaptation strategies is to reduce uncertainties about climate change scenarios and the magnitude and timing of impacts on the Department's operations and programs (see Chapters 1 and 2 for the DEP's comprehensive plans for reducing those uncertainties and responding to the range of potential impacts to the extent feasible). Responsible adaptation will require striking a balance between (a) waiting until the changes are well understood or evident before deciding whether to implement an adaptation project, thus risking being unprepared for change; and (b) proceeding immediately with costly system adaptations, despite uncertainties in climate science, that may prove unnecessary or inadequate. The Department's goal is to strike this balance responsibly.

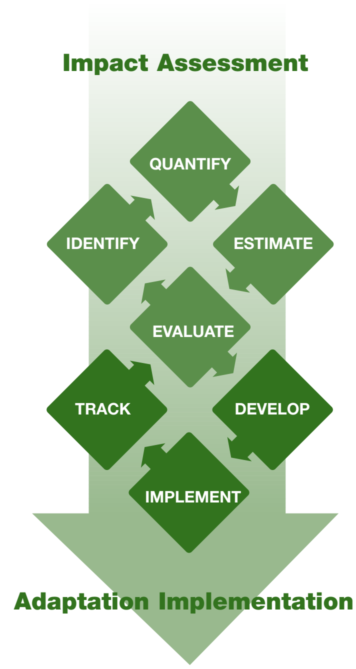
Because there are risks associated with taking no action because of the uncertainties about the future, system adjustments must proceed concurrently with ongoing studies to better define potential impacts. Therefore, the Department is proceeding immediately with the implementation of select adaptations that will also serve to increase the reliability of the systems under current climate conditions, will not involve large expenditures or cause large impacts on the Department or the public, and/or are in response to the most likely impacts.

At the same time, DEP will be undertaking detailed assessments of other adaptation strategies that will consider cost, the space needed for their construction, the time required for planning and construction, and the energy that each would require. As uncertainty will diminish over time, DEP's ability to select the most effective adaptation strategies and the time frame for their implementation will only improve.

The Adaptation Process

A series of coordinated and iterative technical and management steps are needed in order to best formulate specific strategies for addressing climate change impacts:

1. **Identify a climate change impact to DEP's water supply, drainage, or wastewater management systems**
2. **Quantify the impact using DEP watershed, sewershed, or harbor water quality models as well as other tools**
3. **Evaluate the likelihood that the impact will occur**
4. **Estimate the timeframe for when the impact will become significant**
5. **Identify various types of adaptation strategies to overcome or minimize impact**
6. **Quantify the cost and effective lifetime of each adaptation strategy**
7. **Evaluate risks associated with proceeding or not proceeding with the implementation of the adaptations: compare the estimated impacts, the likelihood of occurrence, and the economic, engineering, and environmental aspects of the strategies**
8. **Develop a financial model that will sustain climate change investment**
9. **Develop indicators that would trigger the need to start implementation of the adaptations**
10. **Implement and monitor the success of adaptations**
11. **Track advances in climate modeling, and periodically reevaluate the need for additional adaptations**



3.4 DEP Actions to Determine and Implement System Adaptations

In addition to implementing and building upon the Department's numerous ongoing programs and PlaNYC initiatives that will help to mitigate the impacts of climate change on DEP's water systems, the Department will initiate the following actions in direct response to the work of its Climate Change Program:

ACTION 1

Add climate change as a factor in DEP's Risk Prioritization project.

The Department's ongoing Risk Prioritization project is used to rank projects and allocate funding by assessing the probability and severity of failure of various infrastructure components and their associated costs. Adding climate change as a factor to this process will ensure that additional risks due to climate change are reflected in the Department's capital planning and that the timely implementation of necessary system modifications is feasible

ACTION 2

DEP will identify and evaluate potential adaptation strategies based on the findings of each phase of DEP's integrated water supply and watershed modeling project to study the impacts of climate change on the water supply system.

A wide range of adaptation strategies will be considered, such as additional best management practices (BMPs), i.e., a device, practice, or method used to manage stormwater runoff, modifications to the level of storm that BMPs are designed to withstand, additional treatment, and diversification or increased capacity of the supply system. Comprehensive recommendations will then be made about adjustments needed immediately and in the future to mitigate climate change impacts on water supply system operations and infrastructure.

ACTION 3

DEP will assess the cost, environmental impact, and engineering feasibility of a range of adaptation strategies for mitigating the impacts of climate change on drainage, wastewater management facilities, and harbor water quality, which are to be identified by DEP's impact assessment project for vulnerable areas; and develop a long-term, phased strategy for monitoring impacts and implementing adaptation measures City-wide. As part of this project, DEP will:

- Review and update flood protection design criteria.
- Recommend modifications to DEP's current stormwater management programs (such as facility plans, Long Term CSO Control Plans, and the Jamaica Bay Watershed Protection Plan) in order to address the potential exacerbation of street and basement flooding and CSOs.
- Weigh the costs and benefits of additional structural and non-structural measures that may be necessary to prevent or greatly mitigate: 1) damage to specific DEP infrastructure components (e.g., flood walls, changes to the level of storm and surge for which DEP plans), 2) flooding problems throughout the drainage system (e.g., BMPs, changes to drainage level of service and design criteria for outfall elevations), and 3) harbor water quality impacts that could result from climate impacts on the drainage and wastewater treatment systems (e.g., BMPs, reintroduction of mollusk habitat).
- Recommend an adaptation plan that includes cost estimates, conceptual designs; estimated implementation time frames and schedules that prioritize measures and integrate implementation with the capital planning process and current planning initiatives to the extent practicable, as well as processes for monitoring and evaluating the effectiveness of adaptations.
- Identify "indicators" that DEP should track that may trigger the planning or implementation of specific adaptations when identified thresholds of change are crossed.

ACTION 4

Identify equipment at WPCPs and pump stations that are vulnerable to flood damage and integrate flood prevention measures into the capital upgrade cycle.

Most immediately, DEP will evaluate flood protection measures for the Rockaway, Hunts Point, and Tallman Island WPCPs, which will be undergoing rehabilitation, and use these improvements as a template for guiding future upgrades at other facilities. Examples of flood prevention measures will include elevating critical equipment and armoring critical facility components with water tight doors and windows.

ACTION 5

Create a methodology for the City Environmental Quality Review process so that potential climate change impacts are assessed and considered before decisions are made.

ACTION 6

Develop a procedure for providing the resources and equipment needed to functionally operate when water supply, drainage, or wastewater management systems are damaged during an extreme storm event and to rapidly restore full services after the storm recedes.

The New York City Department of Environmental Protection

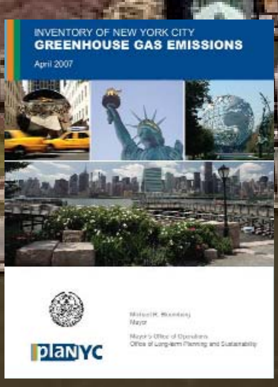
CLIMATE CHANGE PROGRAM

Greenhouse Gas Emissions and Mitigation At DEP

4

Climate change will have significant and adverse effects on the well-being of New Yorkers and the operations at DEP facilities and infrastructure. Climate scientists have warned that even if human-caused greenhouse gas (GHG) emissions were curtailed today, climate changes as a result of previous emissions would nonetheless continue, perhaps for centuries. However, a growing consensus of scientists and policymakers now affirms that prompt action to limit and control further GHG emissions can potentially mitigate the most severe climate change impacts. DEP is committed to the global project of GHG emissions reductions.

This Chapter begins with an overview of the commitments that the City of New York has made to reduce GHG emissions. The sources of GHG emissions within DEP's water supply, drainage, and wastewater management systems are then outlined, and an overview of DEP's work to inventory the emissions from those sources is provided. Possibilities for accounting for carbon sequestration in DEP's GHG emissions inventory are explored, and an overview of the City's efforts to limit uncontrolled GHG emissions nationally by way of litigation is discussed. The Chapter concludes with the actions that DEP will take to further inventory and manage its GHG emissions. DEP's actions to inventory and manage its GHG emissions are also summarized in Chapter 6 of the Report.



New York City recognizes the consequences of climate change and, with the City emitting nearly 0.25% of the world's total greenhouse gases (GHGs), realizes that reducing its carbon footprint could have a tangible impact on global warming (Bloomberg, 2007).

Mayor's Office of Operations, Office of Long-term Planning and Sustainability

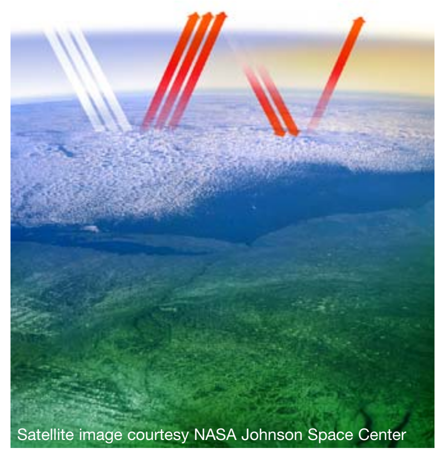
4.1 City of New York Commitments to Greenhouse Gas Emissions Reductions

Although GHG emissions are not currently regulated by the federal government, the City has voluntarily taken early action by committing to reduce GHG emissions. First, in 2001, the City joined ICLEI – Local Governments for Sustainability – Cities for Climate Protection™ (CCP) Campaign. Second, in 2005, New York City Mayor Michael Bloomberg committed to strive to achieve a 7% reduction from 1990 levels in City government GHG emissions by 2012 under the U.S. Conference of Mayors Climate Protection Agreement. Most recently, as one of the goals in PlaNYC, a plan for a sustainable City announced by Mayor Bloomberg in December, 2006, the City set a 30% reduction target in GHG emissions from 2005 base levels by 2030 for City-wide emissions. Furthermore, on April 22, 2007, Mayor Bloomberg released PlaNYC, which includes an ambitious GHG emissions reduction target of 30% below 2006 levels by 2017 for government operations. In addition to reducing its own emissions, New York City is participating with several northeastern states in a number of litigation actions with the goal of achieving national controls for GHG emissions.

DEP is committed to managing and reducing GHG emissions from its facilities and operations to the extent practicable in order to assist the City in achieving its emissions reduction target. In response to a recommendation from DEP's Climate Change Task Force, the Department conducted an initial feasibility study for an agency-wide GHG inventory and management plan (CDM, 2007). DEP's long-term plan is to develop an agency-wide GHG inventory and management plan for all facilities operated by the Department. GHG management will be implemented over the long term, integrated with facility upgrades, equipment replacements, and new facility designs, to ensure that reduction opportunities are not missed. This will increase energy efficiency and reduce GHG emissions in a cost effective manner.

Thinning Upper Atmosphere

Models predict that emissions of carbon dioxide are causing the upper atmosphere to cool and contract and therefore reduce the density of gases in the layer spanning from 60 to 400 miles above the surface - known as the thermosphere. (Photograph taken from the Space Station at roughly 225 miles above the earth.) According to a study by the Naval Research Laboratory, the density of the thermosphere has decreased about 10 percent over the last 35 years. The study validates models of the "greenhouse effect" of increased carbon dioxide release on the dynamics of the atmosphere. (Text and photograph courtesy of NASA.)



Satellite image courtesy NASA Johnson Space Center

Global Warming Potential and Carbon Dioxide Equivalents

Global warming potential (GWP) is the relative heat-trapping strength of a gas compared to carbon dioxide (CO_2) on the basis of its radiative effect. Scientists express the GWP of various gases in "carbon dioxide equivalents" (CO_2e). For example, compared with one kilogram of CO_2 released into the atmosphere today, one kilogram of methane will result in about 21 times more warming, and one kilogram of chlorofluorocarbon-12 will result in 8,500 times more warming.

4.2 DEP Greenhouse Gas Sources

Energy use, predominantly in the form of burning fossil fuels, is by far the largest source of worldwide GHG emissions (WRI, 2005). In the United States, more than 90% of GHG emissions is from energy use, predominantly for electricity, heating, and transportation (WRI, 2005). Waste management disposal accounts for approximately 4% of both world and U.S. GHG emissions (WRI, 2005). However, the great majority of waste management emissions are from landfills, not wastewater treatment facilities. Thus, from a global perspective, wastewater treatment is not a significant cause of GHG emissions.

On a local level, however, wastewater plays a more substantial role. A City-wide GHG emissions inventory conducted by the Mayor's Office calculated that in Fiscal Year 2006 (July 1, 2005 - June 30, 2006), DEP's water supply and wastewater management systems accounted for a significant 17% of total City government emissions (that is, 655,000 metric tons CO_2 equivalent (CO_2e) out of 3,840,000 metric tons CO_2e) (Office of the Mayor, 2007). Included in this calculation are the direct and indirect emissions from energy consumed to run DEP's water supply and wastewater management systems and the direct emissions of methane gas from the wastewater treatment process. As the City's water supply system is almost entirely gravity fed, the great majority of energy consumed by the water and sewage sector was used for wastewater transport and treatment (Office of the Mayor, 2007). Because the water and sewage sector accounts for 17% of total City government emissions, reductions in GHG emissions from DEP's water systems will be studied in order for City government operations to meet the Mayor's 30% reduction target by 2017.

DEP's GHG emissions come from stationary combustion sources (e.g., boilers), electricity and steam generation, mobile combustion sources (e.g., the vehicle fleet and marine sludge vessels), and fugitive emissions (e.g., releases from sludge digestion and equipment leaks). DEP owns and operates a wide variety of facilities throughout a large geographic area extending from New York City to the City's upstate watersheds. The Department's several hundred facilities and other GHG-emitting system components include Water Pollution Control Plants (WPCPs) in the City, wastewater treatment plants in the watershed, combined sewer overflow facilities, water and wastewater pump stations, grit chambers, regulators, water supply distribution shafts, gatehouses, office buildings, the vehicle fleet, marine vessels, and more.

In addition to the GHG emissions from its current facilities, it is anticipated that DEP's emissions will increase due to the energy demands linked to a number of needed water supply and wastewater treatment projects that are planned or under construction.

In addition to the energy needs of these new or upgraded facilities, some strategies for adapting DEP's water systems to mitigate the impacts of climate change could be very energy intensive and increase DEP GHG emissions (such as additional pumping to prevent flooding as the sea level rises). Furthermore, the population of New York City is projected to grow by almost one million by 2030 (NYCDCP, 2006). The water supply and wastewater treatment needs of these additional people will add to DEP's energy use.

Projects that will add to DEP's energy use include:	Status
A new water filtration plant for the Croton Watershed System	Under construction
A new Ultraviolet Light Disinfection Facility for the Catskill/Delaware Watershed System	Site preparation underway; construction in near future
New CSO control facility at Flushing Creek	Presently online
New CSO control facilities at Paerdegat Basin and Alley Creek	Under construction
New CSO control facilities at other locations (in planning phase)	Planning phase
Major upgrades of Newtown Creek, the City's largest WPCP	Under construction
Major upgrades of four East River WPCPs (Wards Island, Bowery Bay, Hunts Point, and Tallman Island) for installation of advanced wastewater treatment	In progress
Major upgrades of two Jamaica Bay WPCPs (26th Ward and Jamaica) for process improvements	Planning underway

4.3 Establishing a DEP Greenhouse Gas Emissions Inventory

A comprehensive and complete baseline inventory of GHG emissions and a tracking system for annual GHG emissions are essential for a successful GHG management program because it will allow DEP to identify opportunities across the Department for GHG reductions and to measure progress in reducing its GHG emissions over the coming years. The process of creating a complete baseline inventory of DEP emissions has been incremental and is still underway.

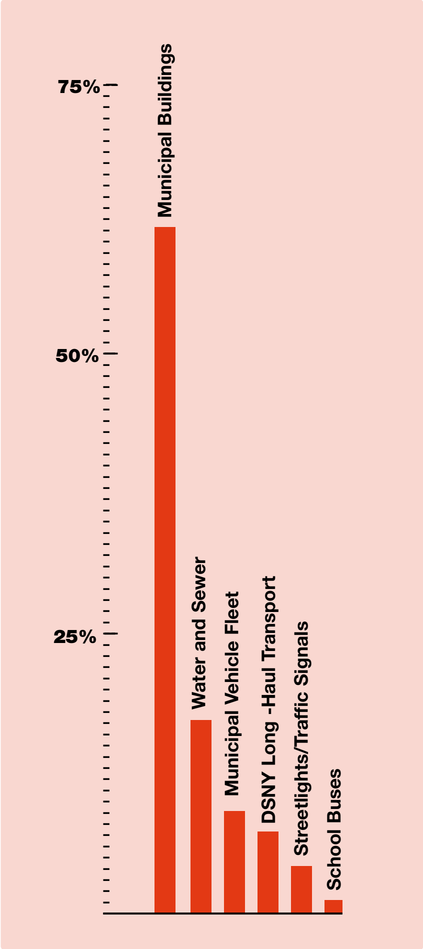
Croton Water Filtration Plant

Croton Water Filtration Plant Under Construction in the Bronx. NYCDEP's energy demand will increase due to necessary water supply and wastewater treatment projects such as this, the New York City UV Disinfection Facility and WPCP improvement projects currently under construction.

Previous DEP Greenhouse Gas Emissions Inventories

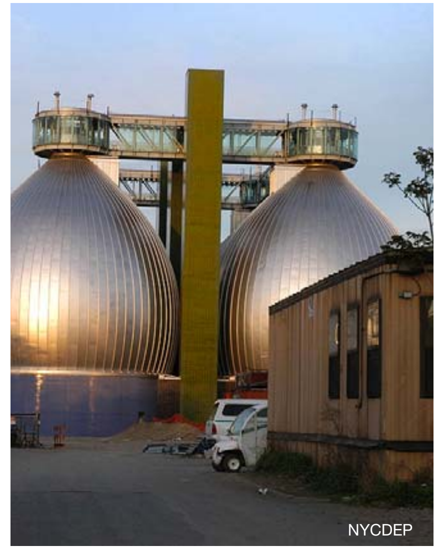
In 2005, DEP completed an initial preliminary emissions inventory for the years 1995 and 2004. It was conducted by Columbia University's Center for Climate Systems Research using the ICLEI Clean Air and Climate Protection Software, and the data was collected and verified in partnership with the Mayor's Office of Environmental Coordination (CCSR, 2005). The initial preliminary inventory was limited to emissions from electric power and natural gas consumption. Because of its limited scope, the inventory did not include some data that proved to be difficult to locate, including electric power and natural gas data for several large City facilities. Even though data were incomplete, the inventory was still highly informative, indicating that about 80% of DEP's GHG emissions, on the basis of electrical power and natural gas consumption alone, was from WPCPs and sludge dewatering operations (CCSR, 2005). This finding highlights: 1) energy efficiency of DEP's water supply system (only about 5% of the water is regularly pumped to maintain the desired pressure and, due to its high quality, it currently receives limited treatment); and, 2) the need for DEP's initial emissions management focus to be on the WPCPs.

In early 2007, DEP completed a follow-up Greenhouse Gas Management Feasibility Study, conducted by the New York Power Authority (NYPA) and CDM - Environmental Management & Planning (CDM) that explored the feasibility of completing a more comprehensive GHG inventory and associated management plan (CDM, 2007). The 2007 Feasibility Study focused on assessing the sources, quality, availability and completeness of GHG emissions data beyond those included in the initial preliminary inventory described above, as well as on identifying objectives, processes and structures for developing an agency-wide GHG management plan that would include facility-specific plans. CDM collected data on DEP GHG emissions sources and carbon sinks for 1995 and 2005 and assessed the current state of the available data. This review found that the 2005 data are much more complete than the 1995 data. Although DEP will keep the 1995 and 2005 data as references, it will likely be even more accurate and efficient for DEP to use a more recent year as the baseline for DEP's eventual GHG management plans (CDM, 2007). Using 2006 as the baseline is most likely, as the 30% reduction target by 2017 for government operations is based on 2006 emissions.



2006 City of New York Government CO_2e Emissions by Sector

One important finding of the 2007 Feasibility Study is that development of a "normalization factor" will be necessary in order to measure DEP's progress in emissions management. A normalization factor (such as gallons of water supplied or treated, or tonnage of water pollutants removed) will allow DEP to take facility expansion and the resulting growth in emissions into account. One single factor may not be appropriate for all facilities, so DEP may elect to use different factors for various types of facilities. Another important finding is that a comprehensive and useful DEP inventory will need to go beyond energy use to include fugitive emissions from Anaerobic Digester Gas (ADG) leakage, which has high methane content, as well as other sources of GHGs. As outlined in Table 4.1, which provides a list of the six GHGs regulated by the international Kyoto Protocol and their common sources, methane (CH_4) has 21 times the Global Warming Potential (GWP) of CO_2. In addition to CO_2 and CH_4, four other GHGs can be critical to include because, although generally emitted in much lower quantities than CO_2 and CH_4, their GWP is very high.



Sludge Digestion Tanks at NYCDEP's Newtown Creek Water Pollution Control Plant, Brooklyn.

Table 4.1
Six Greenhouse Gases and their Global Warming Potential

Greenhouse Gas	Common Sources	DEP Sources	Global Warming Potential
CO_2 - Carbon Dioxide	Fossil fuel combustion, forest clearing, cement production	Flaring of digester gas, fossil fuel combustion at facilities and by vehicles, electric power purchased	**1**
CH_4 - Methane	Landfills, production and distribution of natural gas and petroleum, anaerobic digestion, rice cultivation, fossil fuel combustion	Digester gas leakage at WPCPs, fossil fuel combustion at facilities and by vehicles, electric power purchased	**21**
N_2O - Nitrous Oxide	Fossil fuel combustion, fertilizers, nylon production, manure	Wastewater treatment, fossil fuel combustion at facilities and by vehicles	**310**
HFCs - Hydrofluorocarbons	Refrigeration gases, aluminum smelting, semiconductor manufacturing	Potentially from facilities that repair refrigeration and air conditioning equipment	**120-12,000**
PFCs - Perfluorocarbons	Aluminum production, semiconductor industry	No DEP source	**5,700-11,900**
SF_6 -Sulfur Hexafluoride	Electrical transmissions and distribution systems, circuit breakers, magnesium production	No DEP source	**22,200**

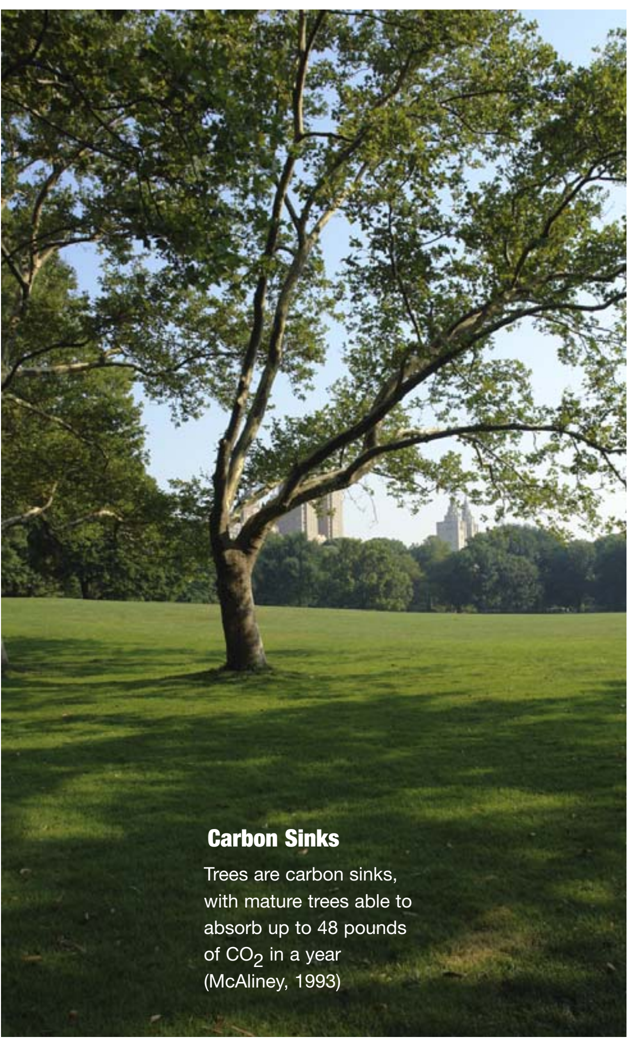
Sources: ICBE (2007), IPCC 1996 Second Assessment Report (1996), CDM (2007)

ADG is a by-product of anaerobic decomposition, a method used at wastewater treatment facilities to digest and stabilize the sludge produced during the different stages of the water purification process. By volume, ADG is typically composed of 65-70% CH_4; 25-30% CO_2; and small amounts of nitrogen (N_2), hydrogen (H_2), and hydrogen sulfide (H_2S) (M&E, 1991). Historically, ADG has been piped to a flare to eliminate odor problems and methane emissions. Flares can prevent the release of ADG gas directly into the atmosphere by transforming it into CO_2. Since ADG has a very high GWP, the use of flares can prevent several thousand tons of CO_2e from being emitted into the air. However, to minimize WPCP fossil fuel dependency, instead of being flared, ADG can be beneficially used by being converted into electric power for on-site boilers and engine generators while generating heat for other plant operations such as digesters.

Flaring Digester Gas

Flaring transforms ADG into CO_2, which eliminates a lot of emissions because of the high GWP of ADG.

The forests in the watershed owned and managed by NYCDEP sequester millions of pounds of carbon each year.



Carbon Sinks

Trees are carbon sinks, with mature trees able to absorb up to 48 pounds of CO_2 in a year (McAliney, 1993)

Building on the findings and recommendations of the Feasibility Study, DEP's next step is to develop a complete and comprehensive GHG emissions baseline. This will identify opportunities across the Department for GHG reduction, and a process for tracking annual emissions in future years so that DEP can measure its progress in GHG emissions reduction.

Accounting for Carbon Sinks

In addition to including the sources of GHG emissions in DEP's baseline inventory, the Department may also be able to include "carbon sinks." Resources or processes that absorb atmospheric carbon can be referred to as "carbon sinks" because they sequester, as opposed to emit, CO_2. The Department owns and maintains considerable resources which act as carbon sinks.

DEP owns tens of thousands of acres in its watersheds to protect drinking water quality, many of which are forested. Under the 1997 Filtration Avoidance Determination for the Catskill/Delaware watershed (FAD), a Land Acquisition and Stewardship Program was established. The primary goal of the program is to ensure that, through fee simple or conservation easement acquisition of undeveloped, environmentally-sensitive watershed land, the watershed continues to be a source of high-quality drinking water (USEPA, 2007). Under the program to date, DEP has acquired or has under contract nearly 80,000 acres of land, the majority considered high quality properties at risk of development (NYCDEP BWS, 2006). DEP has also worked with 620 landowners to develop long-term forestry plans that cover 109,000 acres to be implemented in the coming years (J. Schwartz, May 30, 2007). Under the 2007 FAD, issued by EPA, the City will be required to commit $300 million over the next ten years to acquire even more watershed land and has agreed to solicit at least 50,000 acres annually.

In addition to its protection and management of forests in the watershed, DEP is also planting tens of thousands of trees to create Northeastern coastal woodlands on the former Fountain and Pennsylvania Avenue Landfills in the City. These landfills, located near the Belt Parkway and Jamaica Bay in eastern Brooklyn and a small part of Queens, cover approximately 400 acres and are composed of tens of millions of cubic yards of waste disposed at the site until the landfills were closed in the mid-1980s. In the early 1990s, concerned that rainfall filtering through the uncovered waste deposited at the landfills was having an adverse effect on the water quality of Jamaica Bay, State regulators mandated that New York City act to seal the landfills with impermeable covers. In response, DEP is now involved in a multi-year project to remediate the landfills with an innovative approach that goes beyond the more traditional approach of capping landfills and planting them with lawn grass. DEP is planting coastal woodland/shrubland and grassland species indigenous to the region, including some species that have been extirpated from the area to create coastal woodlands with hiking and walking trails for passive public use. At the end of the planting phase of this project, DEP will have planted over 40,000 trees and shrubs. The coastal woodlands being planted by DEP will not only protect the water quality of Jamaica Bay, provide valuable habitat for wildlife within the City, and create an enormous seed source enabling once-absent species of trees and plants to be disseminated throughout the City, but will also sequester carbon.

Managing DEP-owned forests for maximum carbon sequestration will present opportunities and challenges. A warming atmosphere will extend the growing season, so forests will leaf-out earlier and retain foliage later, therefore, increasing carbon sequestration to some degree. Changes in forest species composition could also result in greater sequestration, if the compositions of forests become more like those of the southeastern U.S. and/or central hardwood forests (e.g., if the sugar maple gives way to black birch and red maple). However, warming may also increase the likelihood of severe damage from insects, pathogens, wind disturbance, and fire, thus causing adverse effects on soils and forest health, thereby precluding carbon sequestration.

The forests owned or managed by DEP in the watershed and the forests that DEP is planting in the City on landfills could potentially be included as a 'carbon sink' in the Department and City government emissions inventories, i.e., as a net emissions reduction for DEP and the City (CDM, 2007). However, this needs to be explored because guidelines for accounting for 'carbon sinks' in GHG inventories are still evolving.

The 40,000 trees and shrubs that DEP is planting on the closed Pennsylvania Avenue Landfill (shown here) and Fountain Avenue Landfill in Brooklyn and Queens will improve the water quality of Jamaica Bay and sequester carbon.

Rick Meyer Associates, NYCDEP

4.4 Establishing a DEP Greenhouse Gas Management Plan

DEP has already made progress in managing its GHG emissions. Since 2003, NYPA, in cooperation with DEP, has installed eight fuel cells at each of four DEP WPCPs in a venture made possible with grants from the New York State Energy Research and Development Authority (NYSERDA) and the U.S. Department of Energy (DOE). These fuel cells, which are owned and operated by NYPA, are powered with the renewable ADG produced at the WPCPs. Since their installation, the fuel cells have consumed a total of 253 million cubic feet of ADG and generated 18.7 million kWh of clean power. A 2005 study estimated digester gas leakage at the four WPCPs using fuel cells with the primary purpose of identifying system improvements necessary for providing a consistent and reliable source of ADG for use by the fuel cells (CDM, 2005). The study concluded that fugitive ADG emissions could be substantial. Therefore, DEP has an opportunity to reduce overall DEP emissions by capturing even more ADG for beneficial use at its WPCPs. DEP's efforts to manage its GHG emissions will go beyond the use of fuel cells. After developing a complete emissions baseline, DEP will create a Department-wide GHG management plan that includes facility-specific management plans with an emphasis on the fourteen WPCPs. Multiple facility-specific management plans are important because they facilitate accurate identification and quantification of GHG emissions and because specific equipment and building energy services are controlled at individual facilities. The 2007 Feasibility Study recommends that the WPCP GHG management plans identify all potential emissions management projects (e.g., fugitive emissions capture, energy efficiency, fuel switching and carbon sinks) and their cost and potential contribution to managing GHG emissions; establish goals and objectives, prioritize projects, and integrate projects into facility operations and management and DEP capital plans; allow for flexibility and responsiveness to changes in operations, budgets, and expenses over time; and provide for personnel training and the involvement of facilities personnel in the implementation of the plans. In addition to developing the facility-specific management plans, DEP will explore opportunities for reducing emissions from its vehicle fleet. Such opportunities may include increasing the use of alternative fuel or high-efficiency passenger vehicles and light trucks, or the possibility of using alternative fuel for DEP's marine vessels and heavy trucks.

In order for DEP to effectively minimize future GHG emissions, the 2007 Feasibility Study concluded that where economical and practical DEP will need to maximize energy efficiency and the use of renewable energy and alternative fuels. DEP should replace inefficient equipment with more highly rated products during normal replacement cycles or sooner; assess potential revisions to some of DEP's design standards and specifications; evaluate equipment efficiency ratings and operation and maintenance protocols; review energy efficiency and use of alternative energy at existing and planned facilities; and maximize the use of fuel cells.

Currently five small hydroelectric facilities within the watershed are operated under contracts with DEP; more such opportunities could be explored.

The Department should explore renewable energy strategies in addition to heat recovery and reuse and use of ADG as an energy source at its WPCPs. For instance, the Gryaab Wastewater Treatment Plant in Gothenburg, Sweden, views organic waste as a resource (GSA, 2007). The plant has reduced costs by accepting more organic waste and using it to produce biogas, which is then upgraded and injected into the City's gas distribution network. There may also be opportunities for harnessing more renewable energy from the water supply system.

When exploring various opportunities for meeting energy demands with renewable energy, in addition to cost and the potential for GHG emissions reductions, the 2007 Feasibility Study recommends that DEP consider energy needs and time of use; reliability of renewable energy sources; ability to provide backup, emergency power during grid outages; financing or incentives available from New York State or other outside sources; visibility and community relations; and risk management and liability.

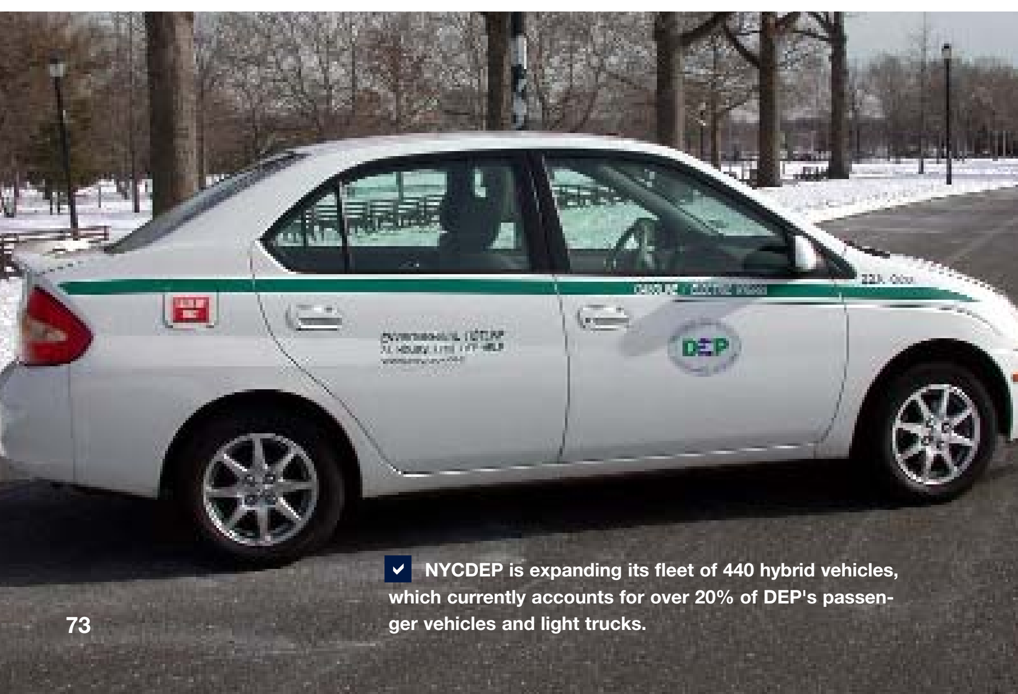
Carbon can be a marketable commodity in the form of a "carbon offset." A carbon offset represents the reduction in GHG emissions from a project undertaken by an organization that meets the criteria of additionality. Additionality is "a criterion for assessing whether a project has resulted in GHG emission reductions or removals in addition to what would have occurred in its absence" (WRI/WBCSD, 2004). Examples of such projects include installing energy-saving light fixtures, adopting fuel-reduction protocols, and permanently protecting forestland for the express purpose of carbon sequestration (CDM, 2007). Because the primary purpose of DEP's current Land Acquisition and Land Management programs in the watershed and landfill planting program in the City is not carbon sequestration, the carbon sequestered through these initiatives is not marketable. However, there may be future opportunities for carbon offset projects at DEP facilities or within the watershed.

DEP's current Ten-Year Capital Strategy budget is approximately $20 billion, the bulk of which is dedicated to upgrades at WPCPs and the construction of new drinking water treatment plants (The City of New York, 2007). These large financial commitments could be further enhanced by fully examining opportunities for energy efficiency and alternatives to fossil fuel energy in order to help lower operating costs and reduce GHG emissions. Opportunities for retrofitting equipment at DEP are ongoing because of the Department's constant infrastructure needs and large capital planning program. However, managing GHG emissions at DEP facilities will be a considerable undertaking due to the large number of diverse facilities (even within the wastewater system) that the Department owns and operates. The fourteen WPCPs, which currently account for the great majority of GHG emissions within the agency-wide emissions profile, all have differing designs, equipment, and ages. Space limitations at WPCPs can preclude installation of additional large infrastructure such as fuel cells.

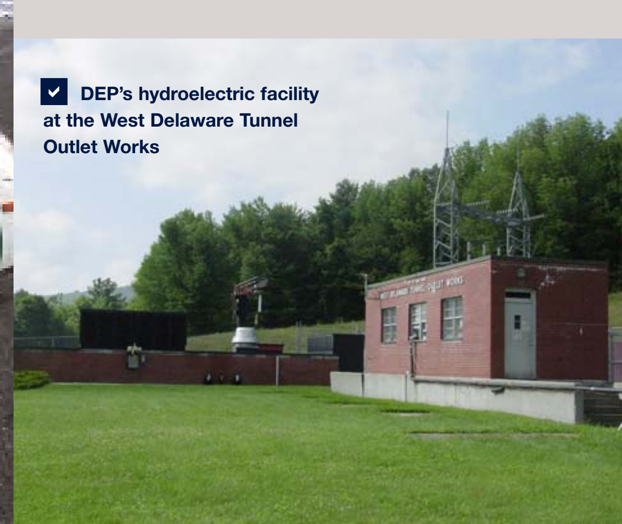
Furthermore, prioritization of infrastructure upgrades and other GHG reduction measures adds a competing demand for capital funds, and the City's current funding structure procures equipment based on up-front costs, not lifetime costs. Thus, the City's Office of Management and Budget will need to be involved in this process. Despite the challenges, DEP is committed to decreasing its GHG emissions.

DEP's new 6th Police Precinct at Eastview in Westchester County, dedicated on December 19th, 2007, has been designed according to U.S Green Building Council Leadership in Energy and Environmental Design (LEED) criteria.

Fuel Cell Operated by the New York Power Authority at NYCDEP Water Pollution Control Plant. Fuel cells at NYCDEP facilities prevent the release of several thousand tons of CO_2e greenhouse gas emissions every year.



NYCDEP is expanding its fleet of 440 hybrid vehicles, which currently accounts for over 20% of DEP's passenger vehicles and light trucks.



DEP's hydroelectric facility at the West Delaware Tunnel Outlet Works

4.5 City of New York Litigation Initiatives to Curb Greenhouse Gas Emissions

In addition to DEP's internal efforts to inventory and ultimately reduce its GHG emissions, the Department, through its Bureau of Legal Affairs, supports New York City's efforts to require the federal government to limit the uncontrolled emissions of GHGs nationally. As United States emissions account for 25% of the global total (NEIC, 2004), significant reductions within the U.S. are necessary to prevent the most extreme climate changes and the associated damage that those changes will cause. The Environmental Law Division of New York City's Law Department leads the City's involvement in four major litigation actions that the City is pursuing with the joint goal of mandatory reductions in national emissions and minimizing the injuries to the City due to global warming.

The first court action that the City joined was *Massachusetts et al. v. Environmental Protection Agency et al.,* a challenge brought in October 2003 by several U.S. states, cities, and environmental non-governmental organizations (NGOs) against the U.S. Environmental Protection Agency (EPA) determination not to regulate motor vehicle emissions of carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons. Reversing the appellate court's decision upholding the EPA determination, in a 5-4 ruling in April 2007, the U.S. Supreme Court sent the determination back to EPA and held "that EPA must ground its reasons for action or inaction in the Federal Clean Air Act," [549 U.S. Code (2007) (slip op., at 32)]. The Court reached this ruling by deciding that the petitioners had the legal right to challenge the EPA's determination, and the federal Clean Air Act authorized EPA to regulate emissions of these GHGs. Hailed as one of the U.S. Supreme Court's most significant environmental decisions, the majority's opinion will ease the ability for the City and others to pursue global warming litigation and could lead to EPA finally regulating in this area.

As a companion to the Massachusetts action, which addressed certain mobile source emissions, the City joined a group of states, cities, and NGOs in bringing *State of New York, et al. v. Environmental Protection Agency, et al.,* a challenge to EPA's failure to regulate GHGs emitted from certain stationary sources - electrical utility steam-generating units. Put on hold until the U.S. Supreme Court decided *Massachusetts*, the *New York* petitioners are now in the process of filing a motion to send the complaint back to the EPA to conduct a rule-making that is in accordance with the U.S. Supreme Court's decision in *Massachusetts*.

The City is also part of a third climate change challenge against the federal government, this time involving the National Highway Traffic Safety Administration (NHTSA). The NHTSA recently promulgated rules to reclassify light trucks for purposes of setting new corporate economy fuel efficiency (CAFE) standards. The reclassification creates incentives to build larger, less fuel-efficient models, thus it has the potential of putting a greater number of larger passenger vehicles on the road, causing a net increase in GHG emissions. Therefore, a group of petitioners including the City has challenged the adequacy of the environmental review that NHTSA conducted for the new rule. DEP has submitted an affidavit that details the City's injuries from and responses to climate change. The matter is pending before the U.S. Court of Appeals for the Ninth Circuit.

In addition to challenging the federal government for its failure to regulate and for its improper environmental review, the City also joined Connecticut and several other states in a public nuisance action against the five largest U.S. power plant emitters of carbon dioxide - responsible for 10% of the United States' emissions - in an attempt to require them to gradually reduce their emissions even in the absence of federally mandated standards. In September 2005, the action was dismissed as a political question not proper for courts to resolve. An appeal before the U.S. Court of Appeals for the Second Circuit is pending. The plaintiffs recently brought the U.S. Supreme Court's *Massachusetts* decision to the attention of the Second Circuit as authority for why the plaintiffs have the legal right to pursue this global warming action, why the matter is not a political question, and why any forthcoming regulation from EPA does not prevent the nuisance action from going forward.

Finally, because of its involvement in these different matters, the City is often invited to submit *amicus curiae* or "friend of the court" briefs in other climate change actions occurring in states and localities throughout the country.

4.6 DEP Actions to Inventory and Reduce Greenhouse Gas Emissions

To inventory and reduce its GHG emissions, DEP will:

ACTION 1

Complete a comprehensive baseline emissions inventory and a process for yearly updates

The inventory and annual reporting and tracking system will allow DEP to identify GHG reduction opportunities and measure the Department's progress in reducing its emissions. The 14 WPCPs will be prioritized because they are DEP's largest emitters; the second-level priority will be DEP's vehicle fleet.

ACTION 2

Develop a Department-wide GHG management plan with facility-specific management plans that are integrated with the capital improvement program

DEP will first focus on the fourteen WPCPs, the Filtration Plant for the Croton water supply system, and the Ultraviolet Light Disinfection Facility for the Catskill/Delaware water supply system. A GHG management plan for a WPCP will first be developed for the Rockaway WPCP. During its planned upgrade of the facility, DEP will increase equipment efficiency and use the improvements as a pilot project for the development of GHG inventories and management plans for DEP facilities.

The facility GHG management plans will develop procedures and new design standards for the incorporation of process improvements, energy efficiency, and renewable energy into facility planning; efforts will focus on the actions with the greatest emissions reduction potential per dollar invested; a plan will be identified for phased implementation; efforts will be coordinated with DEP's capital planning program; and be adaptive to changes in energy pricing and future GHG regulations. Techniques that water utilities in other jurisdictions use to maximize their GHG reductions will be investigated.

ACTION 3

Review current and proposed construction and equipment replacement contracts to identify opportunities for energy efficiency improvements

DEP will install more energy-efficient equipment during the planned replacement of boilers at the Port Richmond WPCP and generators at the 26th Ward WPCP.

ACTION 4

Accelerate the replacement of aging infrastructure with equipment that will minimize GHG emissions when the benefits outweigh the costs

DEP will search for opportunities to proceed with cost-effective infrastructure maintenance utilizing equipment that will reduce GHG emissions.

ACTION 5

Reduce methane leaks from sewage processing equipment and expand the use of ADG for on-site energy production at the WPCPs

As part of this effort, DEP will assess the potential to accelerate contracts to repair ADG leaks and identify all potential beneficial uses of ADG (e.g., for boilers, fuel cells, Stirling engines, and on-site cogeneration of steam and power).

ACTION 6

Continue to support the Bureau of Legal Affairs and the New York City Law Department in their efforts to seek judicial and administrative relief from injuries to the City caused by the uncontrolled emissions of GHGs nationally and the resulting climate change

DEP will continue to support with technical expertise and other activities as appropriate Departmental and City legal initiatives to require the reduction of uncontrolled GHG emissions by large emitters nationally.

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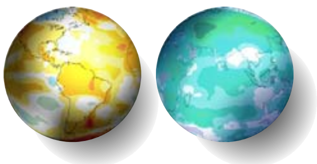

5

Potential Impacts and Adaptations Summary

Summary of Potential Climate Change Effects, Impacts, and Adaptations Identified to Date by DEP's Climate Change Program

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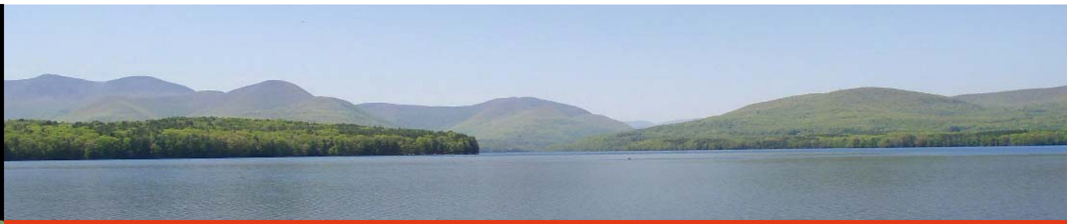
CLIMATE CHANGE PROGRAM

POTENTIAL IMPACTS

WATER SUPPLY



POTENTIAL CLIMATE CHANGE EFFECT	POTENTIAL IMPACT TO DEP
Warmer weather	■ Longer plant growing season increases evapotranspiration, which reduces water supplies ■ Shifting bird migration patterns and populations change fecal contamination of reservoirs
More hot summer days	■ Increased peak and seasonal demands ■ In-City water pressure and delivery problems
Warmer water temperatures in reservoirs	■ Biological and chemical effects on potable water quality
Warmer water temperatures downstream of dams	■ More pressure for increased reservoir releases to maintain fish life in rivers and streams reduces water supply for NYC
Warmer winters, less snowfall and snowpack	■ More runoff in winter, less runoff in spring ■ Concern for lower overall water supplies
More intense rainstorms	■ More turbidity incidents in unfiltered watersheds ■ Increased nutrient loads to reservoirs, increased eutrophication, taste and odor problems, increased levels of disinfection by-product precursors ■ Increased loadings of pathogenic bacteria and parasites such as *Cryptosporidium* and *Giardia*
More extreme rainstorms	■ Increased pressure to use City reservoirs for flood control could reduce water supply for NYC ■ Change in Maximum Probable Flood raises dam safety concerns
More frequent and severe droughts	■ More frequent "drought emergencies"
Combination of temperature increases and precipitation changes	■ Changed ecology of watersheds raises concerns about ability to maintain filtration avoidance in Catskill and Delaware systems
Movement of salt front in Hudson River due to sea level rise	■ Threat to ability to use Chelsea Pump Station as an emergency water supply
Movement of salt front in Delaware River due to sea level rise	■ More pressure for increased Delaware releases could reduce water supply for NYC

DRAINAGE AND WASTEWATER MANAGEMENT

POTENTIAL CLIMATE CHANGE EFFECT	POTENTIAL IMPACT TO DEP
Increased temperature of harbor waters	■ Water quality impairment due to thermal stratification, reduced dissolved oxygen concentrations, and increased ammonia toxicity
More frequent intense rainfalls	■ More street and basement flooding ■ Sewer flood ■ Capacity exceedances for sewers and treatment facilities ■ Need to manage more CSOs to prevent water quality standards non-compliance
Sea level rise	■ More coastal flooding ■ More street and basement flooding ■ Increased inflow of seawater to sewers and WPCPs ■ Reduced ability to discharge CSOs and WPCP effluent by gravity ■ Rise in groundwater levels could cause basement flooding and sewer infiltration
More frequent coastal storms	■ More damage to coastal infrastructure

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POTENTIAL ADAPTATIONS

WATER SUPPLY

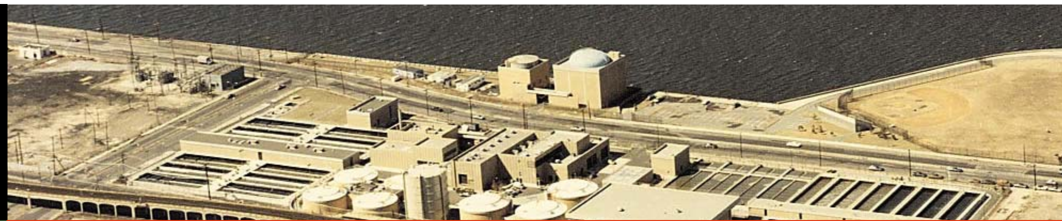
POTENTIAL IMPACT TO DEP	POTENTIAL ADAPTATION

Decrease quantity of supplies	■ Further diversify the water supply system:
	    ▪ Bank surface water in aquifers
	    ▪ Desalinate Hudson or Harbor waters
	    ▪ Expand groundwater system
	    ▪ Interconnect systems with other municipalities
	■ Implement conservation and water use restrictions
	■ Increase system redundancy (e.g., additional tunnels and new pumps for transferring water between systems)
	■ In addition to enhancing flood works at select DEP reservoirs and other non-mandated DEP measures for assisting with flood mitigation in and downstream of the watershed, require operators of other (non-NYC) impoundments to mitigate reservoir spills
	■ Require jurisdictions potentially impacted by flooding to restrict development in flood plains

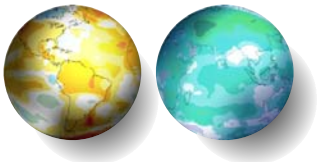
Decreased quality of supplies	■ Increase and improve water supply quality protection measures such as the Stream Management Program in the Catskill Watershed and the Waterfowl Management Program ■ Acquire additional land and enhance land-use management ■ Increase operational flexibility (e.g., rely more heavily on the filtered Croton system during turbidity events and drought) ■ Apply alum and sodium hydroxide when necessary to reduce peak levels of turbidity ■ Apply structural and non-structural controls to reduce turbidity as necessary ■ Balance water supply needs with maintenance

Increased water demand	■ Reduce demand through conservation programs:
	    ▪ Address illegal opening of fire hydrants
	    ▪ Develop programs for City and non-City seasonal use reductions
	    ▪ Increase in-City conservation programs

DRAINAGE AND WASTEWATER MANAGEMENT



POTENTIAL IMPACT TO DEP	POTENTIAL ADAPTATION
Street, basement flooding, and sewer flood	■ Augment collection system ▪ Increase sewer cleaning ▪ Build "high level" storm sewers ▪ Implement stormwater controls at the source ▪ Retain stormwater using rooftop or off-line storage and reuse it for ecologically productive purposes ▪ Pump stormwater ▪ Increase WPCP wet weather capacity ▪ Build larger sewers ■ Revise drainage design criteria ■ Enhance natural landscape and drainage features for runoff control ■ Manage flooding unconventionally (e.g., plan for controlled flooding in designated areas during storms)
Coastal flooding	■ Raise elevations of key infrastructure components ■ Construct watertight containment for critical equipment and control rooms ■ Use submersible pumps ■ Have additional backup emergency management equipment in reserve ■ Install local protective barriers ■ Construct large harbor-wide storm surge barriers ■ Develop plans allowing for coastal inundation in defined areas ■ Gradually retreat from the most at-risk areas or use these areas differently, such as for parkland that could flood with minimal damage
Wastewater treatment process disruptions	■ Discuss with regulators the possibility of water quality variances for severe weather conditions ■ Increase blower capacities or use redundant equipment for high temperature events ■ Increase backup power capacity ■ Clean interceptors and catch basins to reduce grit and sediment loads during wet weather ■ Improve main sewage pumps and screening for wet weather ■ Relocate vulnerable equipment and construct watertight containment for critical equipment ■ Raise freeboard for flooding ■ Revise design criteria for flood protection ■ Pump effluent
Receiving water quality impairment	■ Aerate critical water bodies ■ Upgrade WPCP processes to improve effluent quality ■ Enlarge or supplement CSO control facilities ■ Reduce runoff into the stormwater and combined sewer systems



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CLIMATE CHANGE PROGRAM

6

Climate Change Action Plan

The Action Plan summarizes the actions, potential impact areas that the action will address, identifies the responsible DEP Bureau(s) for leading and implementing the task, the Bureau(s) that would be involved in the task, funding issues, if any, and the current status of implementation.

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM

ACTION PLAN

BCIA Bureau of Intergovernmental Affairs
BCS Bureau of Customer Services
BEC Bureau of Environmental Compliance
BEDC Bureau of Engineering Design and Construction
BEPA Bureau of Environmental Planning and Analysis
BLA Bureau of Legal Affairs
BWS Bureau of Water Supply
BWSO Bureau of Water and Sewer Operations
BWT Bureau of Wastewater Treatment

TASKS AND ACTIONS	POTENTIAL IMPACTS ACTION WILL ADDRESS				BUREAUS IMPACTED	
TASK 1 Work with Climate Scientists to Improve Regional Climate Change Projections	Water Supply Quantity, Quality, and/or Demand	Street, Basement, and/or Coastal Flooding	Wastewater Treatment Process Disruptions	Harbor Water Quality Impairment	Responsible Bureaus	Involved Bureaus
Work with the scientific community and others to develop more refined regional climate change projections. As part of this action DEP will:	✔	✔	✔	✔	BEPA	BWS BWT BEDC BWSO
■ Assemble a comprehensive suite of regional climate projections						
■ Apply a Regional Climate Model to the New York City Watershed Region						
Work with other agencies on the PlaNYC initiative to ensure the City's 100 year flood plain maps are updated		✔	✔	✔	BEPA	BWS BWT BEDC BWSO BLA
Identify additional data and monitoring stations needed to track climate changes	✔	✔	✔	✔	BWS BWT BEDC BWSO	BEPA
Support development of climate model data needed for use as input to run DEP management and operation models	✔	✔	✔	✔	BEPA	BWS BEDC
Track improvements in climate change science, climate models, and estimates of changes in the severity, duration and frequency of weather events	✔	✔	✔	✔	BEPA	
TASK 2 Quantify Potential Climate Change Impacts on NYC Water Systems						
Conduct a phased integrated modeling project to quantify the potential impacts of climate change on drinking water quality, supply, and demand.	✔				BWS BEPA	
■ Phase I: Initial sensitivity tests and model integration using initial regional climate projection data to identify quantity and quality changes with existing modeling tools	✔					
■ Phase II: Model enhancements based on needs identified in Phase I and use of more refined climate projection data for more accurate results and analyses of operational issues	✔					
Undertake a project to quantify the potential impacts of climate change induced sea level rise, coastal flooding and precipitation changes in City infrastructure and harbor water quality		✔	✔	✔	BWT BEDC BWSO BEPA	
■ Identify the flooding impacts of changes in sea level and storms by 1) identifying the elevations of all outfalls and the critical flood elevations at all major DEP facilities, 2) identifying and mapping the current and potential range of future sea levels and 100-year flood plain areas at DEP facilities, and 3) comparing the outfall and critical flood elevations with the updated sea levels and inundations areas		✔			BWT BEDC BWSO	BEPA
■ Develop estimates of changes in rainfall intensities under climate change scenarios based on state of current science					BEDC BWSO	BEPA
■ Evaluate to what extent street and basement flooding and CSOs may be exacerbated by climate change		✔	✔	✔	BEPA BEDC BWSO	BWT
■ Estimate the costs that may be incurred due to potential damage to DEP's in-City infrastructure		✔	✔	✔	BWT BEDC BWSO	BEPA
■ Estimate changes in groundwater levels due to sea level rise and changing precipitation patterns and the potential for greater infiltration or inflow of groundwater into the wastewater conveyance system	✔	✔	✔	✔	BWSO BEDC	BWT BEPA
■ Estimate the potential rise in harbor water temperature and assess the associated impacts on dissolved oxygen levels and other harbor water quality indicators				✔	BEPA BEDC	BWT BWSO
Establish a uniform Department-wide system for documenting the occurrence, levels, and impacts of flooding and other extreme weather incidents on DEP's systems	✔	✔	✔		BEDC BWSO BWT BWS	BEPA
Conduct more detailed interviews with system operators; catalog all known system vulnerabilities	✔	✔	✔	✔	BEPA	ALL
Update impact studies to quantify impacts as needed based on long-term developments in climate change science	✔	✔	✔	✔	BEPA	ALL

* Denotes PlaNYC affiliated actions

TASKS AND ACTIONS »	POTENTIAL IMPACTS ACTION WILL ADDRESS				BUREAUS IMPACTED	
TASK 3 Determine and Implement Appropriate Adjustments to NYC's Water Systems	Water Supply Quantity, Quality, and/or Demand	Street, Basement, and/or Coastal Flooding	Wastewater Treatment Process Disruptions	Harbor Water Quality Impairment	Responsible Bureaus	Involved Bureaus
NOTE: TASK 3 IS ORGANIZED BY RESPONSIBLE BUREAU/ AGENCY						
BCS's Ongoing Actions that increase water systems resiliency Launch an effort to reduce City-wide water consumption by 60 mgd by 2012 through rebate programs*	✔				BCS	BEPA BWS BLA
BWT's Ongoing Actions that increase water systems resiliency Continue maintenance and upgrade programs for WPCPs, tide gates, and other infrastructure		✔	✔	✔	BWT	
BEPA's Ongoing Actions that increase water systems resiliency ■ Expand, track, and analyze new BMPs for runoff and CSO control*		✔		✔	BEPA	BWSO BEDC
■ Investigate low-impact development strategies on individual tax lots*		✔		✔	BEPA	BWSO
■ Implement the Jamaica Bay Watershed Protection Plan		✔		✔	BEPA	BWSO BEDC BLA
BEPA's Planned Actions to address climate change ■ Create a methodology for the City Environmental Quality Review process so that potential climate change impacts are assessed before decisions are made	✔	✔	✔	✔	BEPA	ALL
BWS's Ongoing Actions that increase water systems resiliency ■ Enhance the Watershed Protection Program, including investing $300 million in land acquisition in the watershed*	✔				BWS	BLA
■ Maximize water supply from existing facilities such as the groundwater system and the New Croton Aqueduct*	✔				BWS	BWSO BEDC
■ Continue to coordinate with the National Weather Service and River Forecast Centers	✔				BWS	
■ Continue working with the Delaware River Basin Commission to implement a broad, basin-wide flood mitigation strategy	✔	✔			BWS	BLA
■ Continue the ongoing development of the watershed modeling system	✔				BWS	BEDC
BWS's Ongoing Actions that increase water systems resiliency Evaluate, assess cost and implement potential adaptation strategies based on the findings of climate change integrated modeling project. These could include operational, structural and tracking measures and/or new projects and modifications to the water supply system.	✔				BWS	BEPA BEDC
BWSO's Ongoing Actions that increase water systems resiliency ■ Expand the Staten Island Bluebelt program*		✔		✔	BWSO	
■ Convert certain combined sewers into High Level Storm Sewers (HLSS) and integrate HLSS into major new developments, especially on the waterfront		✔		✔	BWSO	BEPA
■ Expand use of the groundwater system*	✔	✔			BWSO	
■ Identify locations for stormwater management in the Bronx River Watershed*		✔		✔	BWSO	BEPA

* Denotes PlaNYC affiliated actions

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM

ACTION PLAN

TASKS AND ACTIONS	POTENTIAL IMPACTS ACTION WILL ADDRESS				BUREAUS IMPACTED	
TASK 3 (Continued)	Water Supply Quantity, Quality, and/or Demand	Street, Basement, and/or Coastal Flooding	Wastewater Treatment Process Disruptions	Harbor Water Quality Impairment	Responsible Bureaus	Involved Bureaus
BWSO's Ongoing Actions that increase water systems resiliency ■ Continue ongoing spray cap, hydrant lock, and enforcement programs	✔				BWSO	
■ Accelerate sewer and outfall cleaning and repair		✔			BWSO	
■ Build out sewer systems		✔		✔	BWSO	
■ Improve drainage systems in accordance with updated zoning		✔		✔	BWSO	BEPA
■ Maximize the installation of separately sewered systems		✔		✔	BWSO	
BWSO's Planned Actions to address climate change ■ Consider estimates of the range of future sea and tide levels in sewer design and siting of outlets		✔	✔		BWSO	BEPA
■ Implement changes to sewer design criteria to respond to potential climate change impacts if warranted based on the results of Task 2 studies		✔	✔	✔	BWSO	BEPA
BEDC's Ongoing Actions that increase water systems resiliency ■ Construct the Catskill/Delaware Ultraviolet Light Disinfection Facility*	✔				BEDC	BWS
■ Construct the Croton Filtration Plant*	✔				BEDC	BWSO
■ Establish a connection between the New Croton and Delaware Aqueducts for emergency needs*	✔				BEDC	BWS
■ Continue the Catskill Turbidity Control Study	✔				BEDC	BEDC
■ Construct the Brooklyn Queens Aquifer Station 6 Water Treatment Plant	✔	✔			BEDC	BWS BWSO
■ Develop and implement CSO Long-Term Control Plans for all drainage areas*		✔		✔	BEDC	BEPA
■ Expand wet weather capacity at the Newtown Creek and 26th Ward WPCPs*			✔	✔	BEDC	BWT
■ Construct the Shellbank Basin Destratification Facility				✔	BEDC	BWT
BEDC's Planned Actions to address climate change ■ Add climate change as a factor in DEP's Risk Prioritization project	✔	✔	✔	✔	BEDC	ALL
■ Update flood protection design criteria for DEP facilities		✔	✔	✔	BEDC	

* Denotes PlaNYC affiliated actions

TASKS AND ACTIONS » TASK 3 (Continued)	POTENTIAL IMPACTS ACTION WILL ADDRESS: Water Supply Quantity, Quality, and/or Demand	Street, Basement, and/or Coastal Flooding	Wastewater Treatment Process Disruptions	Harbor Water Quality Impairment	BUREAUS IMPACTED: Responsible Bureaus	Involved Bureaus
BEDC's Planned Actions to address climate change ■ Identify equipment that is vulnerable to flood damage and integrate flood prevention measures into the capital upgrade cycle (most immediately at Rockaway, Hunts Point, and Tallman Island WPCPs)		✔	✔	✔	BEDC	BWT BEPA
■ Examine changes in the maximum probable flood and other dam safety criteria	✔				BEDC	BEPA BWS
Multi-Bureau Ongoing Actions that increase water systems resiliency ■ Evaluate new water sources and projects for helping to meet a shortfall during shutdown of the Delaware Aqueduct for repair*	✔				BEDC BEPA	BWS BWSO
■ Capture some benefits of the City's open space plan, which will expand the amount of green, permeable surfaces across the City*		✔		✔	BWSO BEPA	
■ Incorporate BMP designs into the reconstruction of the Belt Parkway bridges*		✔		✔	BWSO BEPA	
■ Identify City property for opportunities to convert impervious pavement to porous pavement*		✔		✔	BWSO BEPA	
■ Continue to modernize in-City distribution by completing Water Tunnel No. 3 and a backup tunnel to Staten Island, and by accelerating the replacement of old water mains*	✔				BEDC BWSO	BWS
Multi-Bureau Planned Actions to address climate change ■ Weigh the costs and benefits and develop a long-term plan to implement recommended additional structural and non-structural measures for mitigating damage to DEP infrastructure components, flooding throughout the drainage system, and harbor water quality impacts from climate change		✔	✔	✔	BEDC STRUC-TURAL BEPA NON-STRUC-TURAL	BWSO BWT
■ Identify "indicators" that may trigger the planning or implementation of specific adaptations		✔	✔	✔	BEDC BWT BWSO	BEPA
■ Develop design, implementation schedule and a process for monitoring the effectiveness of adaptations		✔	✔	✔	BEDC BWT BWSO	BEPA
■ Develop a procedure for providing the resources needed to operate infrastructure systems when damaged during a storm and for rapidly restoring full services after the storm recedes	✔	✔	✔	✔	BEDC BWT BWSO	ALL
■ Propose modifications to current DEP and City-wide stormwater management programs based on analyses of Task 2		✔		✔	ALL	
Other Ongoing City Agency Actions that increase water systems resiliency ■ Develop a comprehensive policy for protecting and managing the remaining wetlands in the City*				✔	DEPART-MENT OF PARKS & RECRE-ATION	BWSO BEPA
■ Develop an interagency approach to stormwater control to maximize stormwater capture at its source*		✔		✔	PLANYC	BEPA BWSO
■ Pilot promising BMPs: create a mollusk habitat pilot program, plant trees with pits that have below-grade water catchments, create vegetated ditches along highways, pilot vegetation and infiltration techniques for treating and capturing stormwater from parking lots, and create tax incentives to offset the installation cost of green roofs*		✔		✔	PLANYC	BEPA BWSO

* Denotes PlaNYC affiliated actions

The New York City Department of Environmental Protection
CLIMATE CHANGE PROGRAM

ACTION PLAN

TASKS AND ACTIONS	POTENTIAL IMPACTS ACTION WILL ADDRESS				BUREAUS IMPACTED	
	Water Supply Quantity, Quality, and/or Demand	Street, Basement, and/or Coastal Flooding	Wastewater Treatment Process Disruptions	Harbor Water Quality Impairment	Responsible Bureaus	Involved Bureaus
TASK 4 Inventory and Reduce Greenhouse Gas Emissions						
Conduct a feasibility study for GHG inventory					BEPA	BWT
Identify opportunities for digester gas capture and use at the WPCPs					BWT	
Investigate producing and use of biofuels at the WPCPs					BWT BEPA	
Complete a comprehensive baseline emissions inventory and develop a process for yearly updates	✔	✔	✔	✔	BEPA	ALL
Develop a Department-wide GHG management plan with facility-specific management plans that are integrated with the capital improvement programs	✔	✔	✔	✔	BEDC	BWT BWSO BWS BEPA
Review current and proposed construction and equipment replacement contracts to identify opportunities for energy efficiency improvements and switching to cleaner burning fuels	✔	✔	✔	✔	BEDC	BWT BEPA
Accelerate the replacement of aging infrastructure with equipment that will minimize GHG emissions, when the benefits outweigh the costs	✔	✔	✔	✔	BEDC BWT	ALL
Reduce methane leaks from sewage processing equipment and expand the use of digester gas for on-site energy production at the WPCPs	✔	✔	✔	✔	BWT	BEDC BEPA
Continue to support City efforts to seek judicial and administrative relief from injuries to the City caused by the uncontrolled emissions of GHGs nationally	✔	✔	✔	✔	BLA	ALL
TASK 5 Improve Communication and Tracking Mechanisms						
Develop a plan for staff and consultant resources necessary for the continued success of DEP's Climate Change Program. The first two steps will be to:		✔	✔	✔	BEPA	ALL
■ Establish a senior-level climate change steering committee within DEP	✔	✔	✔	✔	EXECU-TIVE OFFICE	ALL
■ Establish a Climate Change Office within BEPA	✔	✔	✔	✔	BEPA	
Develop a Climate Change intranet site at DEP	✔	✔	✔	✔	BCIA	ALL
Develop a reporting mechanism that sets performance benchmarks and establishes key indicators for tracking and quantifying progress	✔	✔	✔	✔	BEDC BWS BWSO BWT	BEPA
Participate in the NYC Climate Change Task Force and the NYC Best Management Practices Task Force	✔	✔	✔	✔	BEPA BWSO	ALL
Foster relationships with other water supply and wastewater organizations in order to exchange ideas, pool resources, and formulate research agendas	✔	✔	✔	✔	BEPA	ALL

* Denotes PlaNYC affiliated actions

Appendices

Appendix 1 | Contributors

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Appendix 2 | Acronyms and Abbreviations

ACIA	Arctic Climate Impact Assessment
ADG	Anaerobic Digester Gas
Alum	Aluminum sulfate
BEPA	Bureau of Environmental Planning and Analysis
BMPs	Best Management Practices
BNR	Biological Nutrient Removal
CCSR	Columbia University Center for Climate Systems Research
CLIME	Climate and Lakes Impacts in Europe
CO_2e	Carbon Dioxide Equivalent
CSO	Combined Sewer Overflow
DEP	Department of Environmental Protection
FAD	Filtration Avoidance Determination
ºF	Degrees Fahrenheit
GCM	Global Climate Model
GHG	Greenhouse Gas(es)
GISS ModelE	NASA/Goddard Institute for Space Studies Global Climate Model (New York, NY)
GWLF	Generalized Watershed Loading Function
GWP	Global Warming Potential
IDF	Intensity-Duration-Frequency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt Hour
mgd	Million Gallons Per Day
MPF	Maximum Probable Floods
MPI ECHAM5	Max Planck Institute Global Climate Model (Hamburg, Germany)
NASA	National Aeronautics and Space Administration
NCAR CCSM3.0	National Center for Atmospheric Research Global Climate Model (Boulder, CO)
NCDC	National Climatic Data Center
NGO	Non-Governmental Organization
NHTSA	National Highway Traffic Safety Administration
NTU	Nephelometric Turbidity Units
NYC	New York City
NYSERDA	New York State Energy Research and Development Authority
PATH	New York Harbor Pathogens Model
RCM	Regional Climate Model
SRES	Special Report on Emissions Scenarios
SWEM	System-Wide Eutrophication Model
UKMO HadCM3	United Kingdom Meteorological Office Global Climate Model (Devon, UK)
UV	Ultraviolet
WPCP	Water Pollution Control Plant

Appendix 3 | Glossary of Terms

Anthropogenic
Resulting from or produced by human beings.

Best Management Practices
A device, practice, or method used to manage stormwater runoff.

Carbon Dioxide (CO_2)
A naturally occurring gas that is also a by-product of burning fossil fuels and biomass and can also be emitted by other industrial processes and land-use changes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a *Global Warming Potential* of 1.

Carbon Foot Print
A representation of the effect human activities have on the climate in terms of the total amount of greenhouse gases produced (measured in units of carbon dioxide).

Climate
Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is 3 decades, as defined by the World Meteorological Organization. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate Adaptation
Adjustments in natural or human systems, in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities.

Climate Adaptation Process
The practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility.

Climate Change
Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the *United Nations Framework Convention on Climate Change*, which defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." See also *climate variability*.

Climate Impact Assessment
The practice of identifying and evaluating the detrimental and beneficial consequences of climate change on natural and human systems.

Climate Impacts
Consequences of *climate change* on natural and human systems.

Climate Model
A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components and the components' interactions and feedback processes. The *climate system* can be represented by models of varying complexity (i.e., for any one component or combination of components a hierarchy of models can be identified) differing in such aspects as the number of spatial dimensions the extent to which physical, chemical, or biological processes are explicitly represented or by the level at which empirical parameterizations are involved. Coupled atmosphere/ocean/sea-ice *General Circulation Models* provide a comprehensive representation of the *climate system*. There is an evolution towards more complex models with active chemistry and biology. Climate models are applied as a research tool to study and simulate the climate and also for operational purposes.

Climate Prediction
A climate prediction or climate forecast is the result of an attempt to produce a most likely description or estimate of the actual evolution of the climate in the future (e.g., at seasonal, annual, or long-term timescales. See also *climate projection* and *climate scenario*.

Climate Projection
A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate Scenario
A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as observations of the current climate. A "climate change scenario" is the difference between a climate scenario and the current climate.

Climate System
The climate system is the highly complex system consisting of five major components (the atmosphere, the hydrosphere, the cryosphere, the land surface, and the biosphere) and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and human-induced forcings such as the changing composition of the atmosphere and land use.

Climate Variability
Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the *climate* on all temporal and spatial scales beyond that of a single weather event. Variability may be due to variations in natural internal processes within the *climate system* or in natural or *anthropogenic* external forcings.

Cryptosporidium
A genus of water-polluting protozoa which causes gastroenteritis (stomach upsets) in humans.

Downscaling
Reducing the spatial scale of a model from a global to a regional level.

Drought
Drought is a normal recurrent feature of climate characterized by a deficiency of precipitation for an extended period of time, resulting in a water shortage for some activity, group, or environmental sector. Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration (i.e., evaporation + transpiration) in a particular area.

Ecosystem
A distinct system of interacting living organisms and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

Emissions Scenario
A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., *greenhouse gases* and aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development and technological change) and their key relationships. In 2000, the *IPCC* published the *Special Report on Emission Scenarios* (Nakicenovic et al., 2000) - the SRES scenarios - which are the emissions scenarios currently used to drive *climate models*.

Eutrophication
The process by which a body of water becomes (either naturally or by pollution) rich in dissolved nutrients causing an increased growth of algae with a seasonal deficiency in dissolved oxygen.

Extreme Weather Event
An event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called "extreme weather" may vary from place to place. An "extreme climate event" is an average of a number of weather events over a certain period of time, an average which is itself extreme (e.g., rainfall over a season).

Forcing
A boundary condition or other input to a mathematical model which must be specified by the user prior to model execution, e.g., temporal variations in solar irradiance; future GHG emissions, etc.

General Circulation Model (GCM)
Also known as Global Climate Model. See *climate model*.

Giardia
A protozoan that causes stomach and intestinal illness.

Glacial Isostatic Adjustment
Glacial isostatic adjustment (also called continental rebound, post-glacial rebound, or isostatic rebound) is the movement of land masses in a process of achieving equilibrium in the Earth's crust. On a local level, the land mass in the New York City region is becoming lower as land masses to the north that were depressed by the weight of ice sheets during the last ice age are rebounding.

Global Warming Potential (GWP)
The ratio of the warming caused by a substance to the warming caused by a similar mass of *carbon dioxide.*

Greenhouse Effect
Greenhouse gases absorb infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect." Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of on average -2°F, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of on average 57°F. An increase in the concentration of *greenhouse gases* leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase of the temperature of the surface-troposphere system. This is called the "enhanced greenhouse effect."

Greenhouse Gases
Greenhouse gases are those gaseous constituents of the atmosphere, both natural and *anthropogenic*, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the *greenhouse effect*. Water vapor (H_2O), *carbon dioxide* (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine-and bromine-containing substances. Beside CO_2, N_2O, and CH_4, the Kyoto Protocol deals with the greenhouse

Greenhouse Gases (Continued)
gases sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Intergovernmental Panel on Climate Change (IPCC)
A body established in 1988 by the World Meteorological Organization and the United Nations Environment Programme, the IPCC is the authoritative international body charged with studying *climate change*. The IPCC surveys the worldwide technical and scientific literature on *climate change* and publishes assessment reports.

Kyoto Protocol
The result of negotiations at the third Conference of the Parties (COP-3) in Kyoto, Japan, in December of 1997. The Kyoto Protocol sets binding greenhouse gas emissions targets for countries that sign and ratify the agreement. The gases covered under the Protocol include *carbon dioxide*, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride.

Mitigation
An *anthropogenic* intervention to reduce the sources or enhance the *sinks* of *greenhouse gases*.

Radiative Forcing
Radiative forcing is the change in the net vertical irradiance [expressed in Watts per square meter (Wm^{-2})] at the tropopause (a boundary region in the atmosphere between the troposphere and the stratosphere) due to an internal change or a change in the external forcing of the *climate system*, such as a change in the concentration of CO_2 or the output of the Sun. Radiative forcing is usually computed after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with all tropospheric properties held fixed at their unperturbed values.

Saltwater Intrusion/Encroachment
Displacement of fresh surface water or groundwater by the advance of saltwater due to its greater density, usually in coastal and estuarine areas.

Sea Level Rise
An increase in the mean level of the ocean. Eustatic sea-level rise is a change in global average sea level brought about by an alteration to the volume of the world's oceans. Relative sea level rise occurs where there is a net increase in the level of the ocean relative to local land movements. Climate modelers largely concentrate on estimating eustatic sea level change. Impact researchers focus on relative sea level change.

Seawall
A human-made wall or embankment along a shore to prevent wave erosion.

Sequestration
The process of increasing the carbon content of carbon pools other than the atmosphere (such as oceans, soils, and forests).

Sink
Any process, activity, or mechanism that removes a *greenhouse gas,* an aerosol, or a precursor of a *greenhouse gas* or aerosol from the atmosphere.

Source
Any process, activity, or mechanism that releases a *greenhouse gas*, an aerosol, or a precursor of a *greenhouse gas* or aerosol into the atmosphere.

Thermal Expansion
In connection with *sea level rise*, this refers to the increase in volume and decrease in density that result from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence an increase in sea level.

Uncertainty
An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Urban Heat Island
An area within an urban area characterized by ambient temperatures higher than those of the surrounding area and created when naturally vegetated surfaces are replaced with non-reflective, impervious surfaces that absorb a high percentage of incoming solar radiation (Taha, 1997).

Vulnerability
The degree to which a system is susceptible to, or unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

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