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New York City Panel on Climate Change 2015 Report Chapter 6: Indicators and Monitoring

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Introduction

Among the crucial challenges for climate change facing New York City are measurement, monitoring, and evaluation of critical indicators of climate change. This involves developing indicators not only of the climate itself and its impacts, but also of resiliency measures. These need to be tracked over time in order to provide relevant information on the effectiveness of current and future response strategies. Required are a manageable set of climate change indicators and a monitoring system that enables evaluation of the dynamic processes associated with climate change, its associated impacts, and flexible adaptation and resiliency practices (see Box 6.1 for definition of climate change indicators).

The first report by the New York City Panel on Climate Change (NPCC, 2010) set out an approach to indicators and monitoring for tracking climate risks and presented potential sources of data from existing monitoring systems in the city (NPCC, 2010; Jacob *et al.*, 2010). Building on this approach, the objective of this chapter is to identify how New York City can establish a Climate Resiliency Indictors and Monitoring System that is more responsive to current and future climate change.

A logic similar to the climate protection level (CPL) discussion of the first NPCC is employed (Solecki *et al.*, 2010). The CPL analysis focused on a basic question: Given that there were already an extensive number of codes and standards designed to protect critical infrastructure and human well-being from climate risks, how can the existing legal, managerial, and operational climate protection strategies be adjusted and enhanced to be responsive to future climate change? Because the City (along with its state and federal partners) already maintains an extensive set of environmental indicator and monitoring programs to track a variety of environmental quality and human and ecological health indicators, this chapter explores how, and under what conditions, the City of New York can expand these programs to be fully capable of assessing climate risks and resiliency opportunities as they evolve. Specifically, this chapter addresses three questions:

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Box 6.1. Definition of climate change indicators

Climate change indicators are defined as empirically-based quantities that can be tracked over time to provide relevant information for stakeholder decisions on climate resiliency and on the efficacy of resiliency measures to reduce vulnerability and risk.

1. What indicator and monitoring systems are currently in place within the City of New York?
2. What are the opportunities and challenges to establishing the New York City Climate Resiliency Indicators and Monitoring System?
3. What can be learned from a case study on the existing urban heat island indicator and monitoring system within the City?

The chapter identifies opportunities and gaps in the existing systems with respect to monitoring and adapting to climate change and illustrates some conditions under which these gaps could be filled. The use of innovative monitoring methods including remote sensing, flexible systems (e.g., mobile), and microsensors is highlighted. The chapter uses the urban heat island as a test bed to evaluate the specific requirements for an indicator and monitoring system associated with a particular resiliency strategy. The existing NYC Cool Roofs Program reveals several real-world issues and demands on indicators and monitoring systems that include evaluation challenges and the need to maintain efficiency and effectiveness over time.

6.1 Background and framework

Augmenting the approach developed in NPCC 2010, this section presents an overview of the NPCC2 indicators and monitoring framework and indicator system design and process.

NPCC 2010 approach

The first report by the NPCC established three selection criteria for indicators: policy relevance, analytical soundness, and measurability (NPCC, 2010; Jacob *et al.*, 2010). The climate change indicators were seen as creating a mechanism for alerting stakeholders to emerging climate change and related risk information; warning decision-makers of potential system-level thresholds (which may lead to tipping points that could alter elements in the risk-assessment process); and providing decision triggers for altering adaptation pathways. Three categories of indicator variables were highlighted: (1) physical climate change variables; (2) risk exposure, vulnerability, and impact metrics; and (3) adaptation measures and their effectiveness. For each category, a variety of potential indicators were presented and discussed.

NPCC2 framework 2015

Monitoring frameworks have been developed for urban climate resiliency (Tyler *et al.*, 2014; Moench *et al.*, 2011), urban vulnerability (Swart *et al.*, 2012; Romero Lankao and Qin, 2011), urban sustainability (Shen *et al.*, 2011), and urban environmental performance (EIU, 2012). Building on earlier work, the NPCC2 has developed an indicator and monitoring framework that relates to climate hazards, impacts, and resiliency and that strengthens the potential for identification of system-level tipping points or thresholds. The NPCC2 monitoring framework is tailored to the purpose of the indicator set, and encapsulates the conceptual linkages between climate change and different urban systems.

Indicator development process

Cities need a robust yet flexible process for climate change indicator development that includes multiple stakeholders. Cities already track a large number of indicators, and the challenge is to evolve current systems of indicators and monitoring to include climate change. The NPCC2 process for development of climate resilience indicators consists of seven steps (Fig. 6.1):

1. Meet with stakeholders to decide relevant climate adaptation and resilience decision areas, information needs, and key questions
2. Determine what data are available and how they can be accessed
3. Conduct indicator research to develop a small set of preliminary indicators
4. Present set of preliminary indicators to stakeholders for feedback and to scope implementation

5. Revise indicators based on stakeholder feedback
6. Set up indicator system reflecting the defined framework
7. Conduct evaluation, iterative research, and stakeholder interaction through time

The process of establishing indicators and an indicator and monitoring system involves engaging with stakeholders (producers and users) who can contribute to the design of the indicators, engaging them in a process from development to implementation to evaluation. It defines the key questions (Box 6.2) the indicators are meant to address. Prototype indicators can be tested with users during this phase. Finally, a system should be set up to sustain the production and archiving of the indicators, and periodic evaluations should be carried out to ensure that the indicators continue to meet user needs and policy and management objectives.

Climate resiliency indicators

Effective indicators are resonant (i.e., strike a chord with the intended audience and are scientifically credible), salient (i.e., timely and relevant to decision-makers' needs), and targeted (i.e., tailored to the appropriate context) (de Sherbinin *et al.*, 2013). Indicators generated by government agencies can contribute to management and policymaking processes and have the potential to be sustained over time. Indicators also can be used for public engagement and outreach purposes to identify significant risks, impacts, and adaptation opportunities.

Figure 6.2 provides a flow diagram of the major climate extremes and the urban systems they impact. Although climate trends are important for medium- to long-term planning purposes, extremes are temporally limited events such as heat waves and coastal storms that generally have the greatest impact on urban systems. Major systems that are affected by extremes include energy supply, health, ecosystems, transportation infrastructure, water supply, and building stock.

Candidate indicators that could be included in the New York City Climate Resiliency Indicators and Monitoring System are shown in Tables 6.1, 6.2, 6.3, and 6.4. This list is not intended to be comprehensive because a final list would need to be vetted with stakeholders. Most are current trend indicators for New York City as a whole, but some are comparative and spatially discrete. Those with city-wide coverage allow

Figure 6.1. NPCC2 indicator development process.

Box 6.2. Key questions for development of urban climate indicators

Several questions need to be addressed regarding the role and purpose of urban climate impact, vulnerability, and adaptation indicators as well as their design.

Climate change impacts, vulnerability, and resiliency

- What important climate impacts are occurring or are predicted to occur in the future?
- What are fundamental vulnerabilities and resiliencies to climate variability and change?
- What systems are most at risk of climate impacts?
- What are the targeted policy questions for which indicators should be designed?
- What information is needed to improve resiliency to rapid change or extreme events related to climate?
- What adaptation measures are in place, and how may they change over longer time frames?

Climate change indicators and monitoring

- Is climate in the metropolitan region changing now?
- How is the climate projected to change in the future?
- What are the critical climate variables, indices, and extreme events to monitor?
- What is the baseline reference for the data (i.e., start date and end date)?
- For a given indicator, should it be calculated annually, seasonally, monthly, or weekly?
- What is the appropriate averaging period (e.g., 1-day or 4-day precipitation)?
- What is the appropriate spatial averaging (e.g., neighborhood, city, metropolitan region)?
- How should thresholds be chosen: statistically (e.g., 95th percentile) or relative to a critical value based on infrastructure vulnerability?
- What evidence is needed to determine if/when certain thresholds are being reached?

policy-makers to evaluate differences in indicator values and trends across administrative units within the city.

The social vulnerability indicators reflect an understanding that exposure to climate hazards alone does not explain outcomes but that differential levels of sensitivity (susceptibility) and adaptive capacity also play a role. In other words, the climate impacts in terms of people's experience will not be the same across all neighborhoods for an event of the same magnitude. Their measurement can help, when combined with climate risk information, to identify neighborhoods in need of intervention. These are particularly important for indicator development for public health (see Chapter 5, NPCC, 2015).

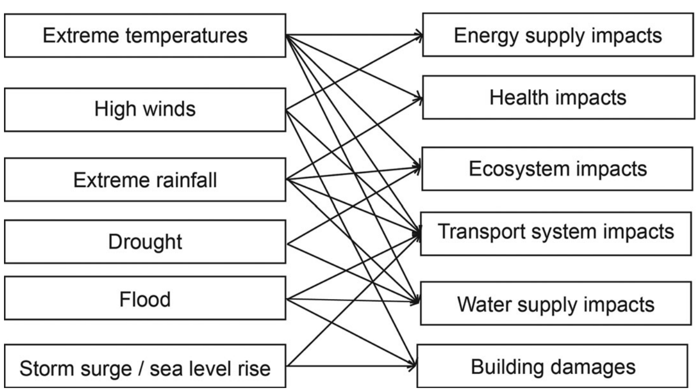

Figure 6.2. Climate extremes and potential impacts on urban systems.

Table 6.1. Potential climate indicators

- Number of heat advisories per year
- Change in surface and air temperature during peak periods (July–August)
- Number of extreme precipitation events (95th percentile values) per year
- Number of coastal flooding advisories for major or moderate flooding
- Trend in mean sea level
- Trend in peak storm surge for 100-year and 500-year storms
- Number of days per year with sustained winds or gusts exceeding certain thresholds

Regional and multi-institutional integration

The creation of a New York City Climate Resiliency Indicators and Monitoring System needs to encompass multiple institutions and to extend beyond city and even state borders, and thus should be metropolitan region in scope. Data need to be integrated across different spatial and temporal resolutions and across different formats. Planning must be undertaken to ensure that the incorporated data are of the appropriate quality, and funding must be provided to ensure that monitoring efforts remain consistent and continuous throughout the coming decades.

Regional integration. A clear need exists for a regional approach in the development of the New York City Climate Resiliency Indicators and Monitoring System. New York City's drinking water supply sources, for example, lie outside city boundaries, and much of New York City's labor force lives outside of the boundaries of the five boroughs. Disruptions to regional commuter transit can have serious economic consequences for the city. Furthermore, New York City is connected to a regional energy grid that provides more than 80% of its electricity and is thus affected by regional storms and heat waves that may disrupt regional generation. A selected inventory of measurement systems for potential inclusion in an integrated New York City Climate Resiliency Indicators and Monitoring System is presented in Appendix IIF.

Multi-institutional integration. Some existing monitoring networks in New York City, including the Hudson River Environmental Conditions Observing System (HRECOS), the New York Harbor Observing and Prediction System (NYHOPS), and the New York City Meteorological Network (NYCMetNet) have already begun multi-institution data integration efforts. The New York City Environmental Public Health Tracking Portal provides an example of long-term public health data management; it is integrated across various agencies and made publicly available through a Web site: http://a816-dohbesp.nyc.gov/IndicatorPublic/.

The National Science Foundation's Long-Term Ecological Research Network (LTER-NET; Redman *et al.,* 2004; see also http://www.lternet.edu) also may serve as a model for the integration of long-term interdisciplinary ecological data. The mission of LTER-NET is to provide scientists, policy-makers,

Table 6.2. Potential impact indicators

- Heat-related morbidity and excess mortality from extreme heat events per year
- Other health-related heat impacts (e.g., heat-induced strokes)
- Other climate hazard–related morbidity and mortality per year (e.g., drowning due to storms)
- Number of days per year with observed air quality index > 100
- Cooling (and heating) degree days per year
- Duration of blackouts/brownouts per year associated with weather-related events
- Number of weather-related transit and subway outages per year
- Number of weather-related telecommunications outages and customer hours without telecommunications per year
- Area of land inundated by coastal flooding per year
- Costs of additional water treatment owing to extreme rainfall events per year
- Total economic losses from climate-related events per year

Table 6.3. Potential social vulnerability indicators

- Disparity in heat-related morbidity and mortality across neighborhoods with respect to a variety of equity conditions (e.g., income, race/ethnicity, non-English speaking population, housing stock)
- Disparity in other climate-related morbidity and mortality across neighborhoods with respect to a variety of equity conditions.
- Disparity in households without air conditioning across neighborhoods with respect to a variety of equity conditions.
- Percentage population with a disability (one or more of six types: hearing, vision, cognitive, ambulatory, self-care, independent living)
- Social vulnerability indices, tailored as needed to specific climate hazards, for example:
  - Heat Vulnerability Index in census block groups experiencing relatively higher heat stress
  - Social Vulnerability Index scores related to access to green space
  - Social Isolation Index in census block groups in flood evacuation zones[1]

[1]The Heat Vulnerability Index (HVI) and Social Vulnerability Index (SVI) are composite measures based on multiple indicators that summarize population vulnerability by geography to extreme heat based on published epidemiological studies and, in the case of the HVI, prediction of increased mortality during extreme heat events (the SVI is described in Reid *et al.* 2009; the HVI in Madrigano pers. com., 2014). Social isolation has been a risk factor for heat-related mortality and can increase vulnerability to a variety of climate hazards. A commonly used index for assessing social connections and isolation among seniors is described in Lubben (1998).

and the general public with the scientific information needed to manage the nation's ecosystems. Its disciplinary scope includes population and community ecology, ecosystem science, social and economic sciences, urban studies, oceanography, and science education. There are clear parallels between this program and the multisectoral Climate Resiliency Indicators and Monitoring System needed in New York City.

Although these data integration programs vary considerably in their objectives, scope, and scale, they share four common features:

Table 6.4. Potential resiliency indicators

- Change in vegetation cover
- Number of trees planted per year
- Square footage of white/green roofs
- Surface temperature change in areas that have adopted white/green roofs relative to non-white/green roof locations
- Estimated percent of households with residential air conditioning
- Number of citizen groups engaged in climate resiliency programs per year
- Square footage of residential, commercial, industrial space not flood-proofed or elevated in areas within the 100-year floodplain
- Number of residential units in 100-year floodplain implementing Core Flood Resiliency measures[1]
- Percentage of flood-affected areas with improved storm drainage
- Acres of restored coastal wetlands
- Miles of coastal defenses erected (dune replenishment/hard defenses)
- Population growth/decline in the 100-year floodplain
- Percentage of NYC transportation assets adapted for climate change resiliency
- Financial expenditure on resiliency activities per year; as a percent of total expenditure

[1]Core Flood Resiliency Measures, proposed in the *Special Initiative for Rebuilding and Resiliency* (City of New York, 2013), include elevation or other flood protection of critical building equipment and utilities: fire protection, electricity, heating, ventilation, air conditioning, plumbing, telecommunications, elevators, and emergency generators and associated fuel tanks and pumps.

- Early, documented planning to ensure data consistency and quality
- Dedicated resources and infrastructure to provide post-processing, harmonization, and long-term data management from different sources
- A coordinating institution or office responsible for data management
- A dedicated group of scientists to conduct on going evaluations

6.2 New York City environmental indicators

The section presents the current status of indicators now monitored by New York City, identifies gaps, and suggests potential ways that climate change can be incorporated.

An extensive web of environmental monitoring systems currently collects data that can support climate resiliency indicators monitoring for the New York metropolitan region. Many of these systems originally were developed to meet the requirements of environmental legislation and to address public health concerns, but they can also provide important information for climate change resiliency planning.

The ongoing monitoring of physical climate change variables is conducted through two approaches: site-based instrumentation and remote sensing. Site-based instruments monitor and provide long-term conditions at a particular location, complementing remotely sensed data. Site-based monitoring procedures must be harmonized in order to allow for rigorous comparison throughout the region.

Remote sensing can provide standardized, quantitative data on conditions throughout the entire metropolitan region at regular time intervals. For many physical climate change parameters, federal agencies such as the National Oceanic and Atmospheric Administration (NOAA) or the U.S. Geological Survey (USGS) provide standardized remote sensing data throughout the region. Making distributed observations with remote sensing techniques provides broad, continuous coverage. However, these must be integrated with ground-based data to enhance their utility.

The process of producing climate indicators is dependent on choosing appropriate sampling strategies and effective combinations of these complementary monitoring systems. A selected inventory of the government agencies, nongovernmental organizations, and academic institutions conducting monitoring is presented in Appendix IIF (NPCC, 2015). This includes systems that measure relevant parameters in the atmosphere, on land, and throughout regional water bodies and coastal zones.

Weather and climate

Ongoing weather and climate monitoring is conducted by multiple federal agencies, academic institutions, and private companies. Long-term observation sites include the National Oceanic and Atmospheric Administration's Historic Climatology Network (HCN), with 712 sites in the 31-county region (Fig. 6.3). At these sites, instruments collect continuous data on basic meteorological variables such as surface temperature, precipitation, wind speed, and solar radiation, among many others. Data from these sites are subject to a common suite of quality-assurance reviews and integrated into a database of daily data. In addition to the HCN, NOAA also maintains one United States Climate Reference Network (USCRN) site (Milbrook, NY) in the 31-county region. USCRN sites are managed with the express purpose of detecting climate change signals, and they are located in pristine settings to exclude the impacts of development on local climate (Diamond *et al.*, 2013).

In addition to the NOAA surface observation sites, the Optical Remote Sensing Laboratory at the City University of New York maintains several upper-air measurement sites, which provide data on wind-speed profiles, aerosol concentrations, air quality, and atmospheric water content (Fig. 6.4). These have been highlighted in a recent publication by the National Academies of Science on Urban Meteorology (National Academy of Sciences, 2012). The observations from these ground-based remote-sensing instruments allow for the urban boundary layer (the layer in the atmosphere above a city where spatially integrated heat and moisture are exchanged with the overlying air) to be monitored and studied. Real-time displays from these observations are presented on the NYCMetNet web portal (http://nycmetnet.ccny.cuny.edu/) along with a large set of regional surface observations

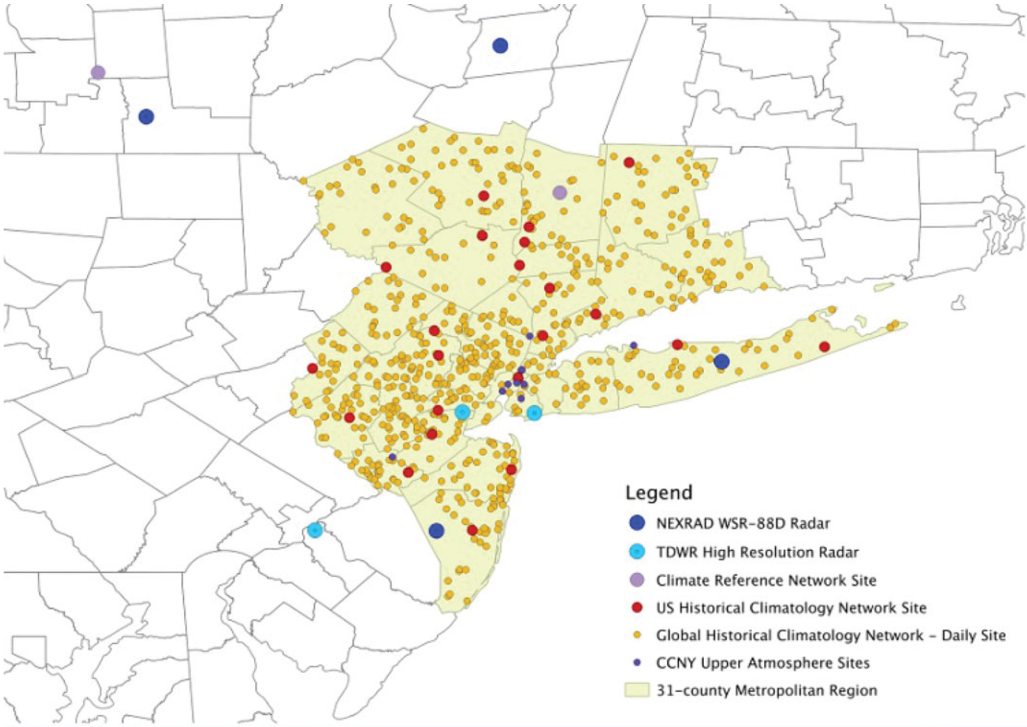

Figure 6.3. Sites important in supporting climate change monitoring in the New York metropolitan region. These include NOAA's Historic Climatology Network (HCN) and Climate Change Reference Network (USRCN), the City College of New York Upper Atmosphere Monitoring Sites, and Weather Radar Sites operated by the National Weather Service and the Federal Aviation Administration.

from public and private agencies in the metropolitan region.

Next steps. Further integration is necessary to harmonize and adapt the weather and climate data from the various sources to support climate change–related monitoring. Weather and climate data collected at observing stations can be used to develop tailored climate projections requested by stakeholders. Examples of this are relative humidity projections and their potential application for electric utility providers. A Climate Resiliency Indicator and Monitoring Working Group with representatives from all the groups currently collecting weather and climate data should be formed to further the integration of these sources for climate change–related information.

Coastal zones and sea level rise

Sea level rise will produce some of the most significant climate change impacts on New York City. NOAA maintains tide gauge stations at the Battery and Kings Point/Willets Point. These are indispensable for monitoring long-term changes in local mean sea level, water heights, and surge levels.

New York Harbor Observing and Prediction System (NYHOPS) maintains a network of buoy-mounted sensors, underwater probes, boat-mounted instruments, and unmanned underwater vehicles. These devices monitor water levels, currents, and water quality in the New York Harbor, the New Jersey Coast, and western Long Island Sound, all of which are critical for assessing the rate of sea level rise and the magnitude of storm surges. NYHOPS adheres to NOAA's standards and guidelines for operational oceanographic products and services. The NYHOPS data as well as synthesized analyses are made accessible at http://hudson.dl.stevens-tech.edu/maritimeforecast.

Next steps. In order to support climate change–related monitoring of site-based and remote sensing data, it is important to integrate and modify the coastal zone data from the various sources. Efforts to coordinate the many sources of coastal zone data

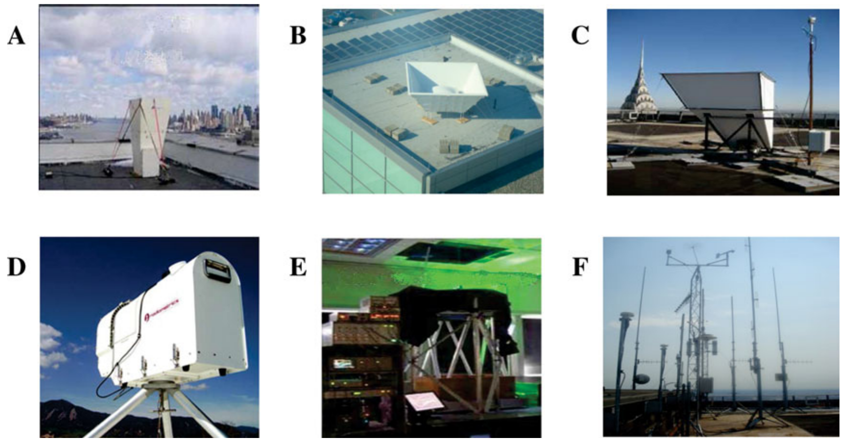

Figure 6.4. Instruments of the NYCMetNet: (A) and (C) Sodar wind vertical profiler (to ∼1500 ft); (B) Radar wind vertical profiler (to 2 miles); (D) Temperature, humidity and liquid water vertical profiler (to ∼1.3 miles); d) ; (E) CCNY Aerosol Raman lidar vertical profiler (to ∼6 miles); (F) Skyscraper-mounted weather stations (Source: Mark Arend, CCNY Optical Remote Sensing Lab and NOAA CREST).

will require a Climate Resiliency Indicator and Monitoring Working Group with representatives from all the groups currently collecting the information.

Water resources

Currently, overall precipitation and heavy downpours are increasing in the New York metropolitan region (see Chapter 1 and Appendix I in NPCC, 2015). These climate change trends are expected to continue. Today, water levels in the upstate reservoirs that supply New York City's drinking water are closely monitored by the New York City Department of Environmental Protection (NYCDEP, 2011). In addition, the U.S. Geological Survey (USGS) collects continuous data on streamflow, tidal flow, and groundwater at numerous sites distributed throughout the 31-county region. This enables the assessment of how precipitation changes impact the region's other water resources as well as the frequency and magnitude of flooding events (Fig. 6.5).

Next steps. Hydrological data from the various sources need to be synchronized to support climate change–related monitoring. Representatives from the groups that currently gather hydrological data should join together to form a Climate Resiliency Indicators and Monitoring Working Group that will be able to link the many sources of climate change–related information.

Water quality

Climate change is expected to have significant impacts on water quality (Murdoch *et al.*, 2000). Numerous government agencies and NGOs conduct regular water-quality monitoring in the New York metropolitan region (see Appendix IIF, NPCC, 2015). However, the datasets they collect are not standardized across institutions, which makes comparison difficult and creates a challenge to their use in developing climate change indicators.

The recently established Hudson River Environmental Conditions Observing System (HRECOS), a network of water-quality monitoring stations in the Hudson River Estuary, may serve as a model for integrating water-quality monitoring data to support climate change indicators. HRECOS sites are operated by a consortium of government agencies, research institutes, and NGOs. Data from the network of stations along the length of the tidal Hudson River are collected using clear guidelines defined in the project's Quality Assurance Plan, and data are thus readily intercomparable. Further data collected through the project are integrated, archived, and made accessible through the project website http://hrecos.org.

Next steps. Water quality data from HRECOS, NYC DEP, USGS, and NYC DEC need to be combined to support climate change–related monitoring. A Climate Resiliency Indicator and Monitoring

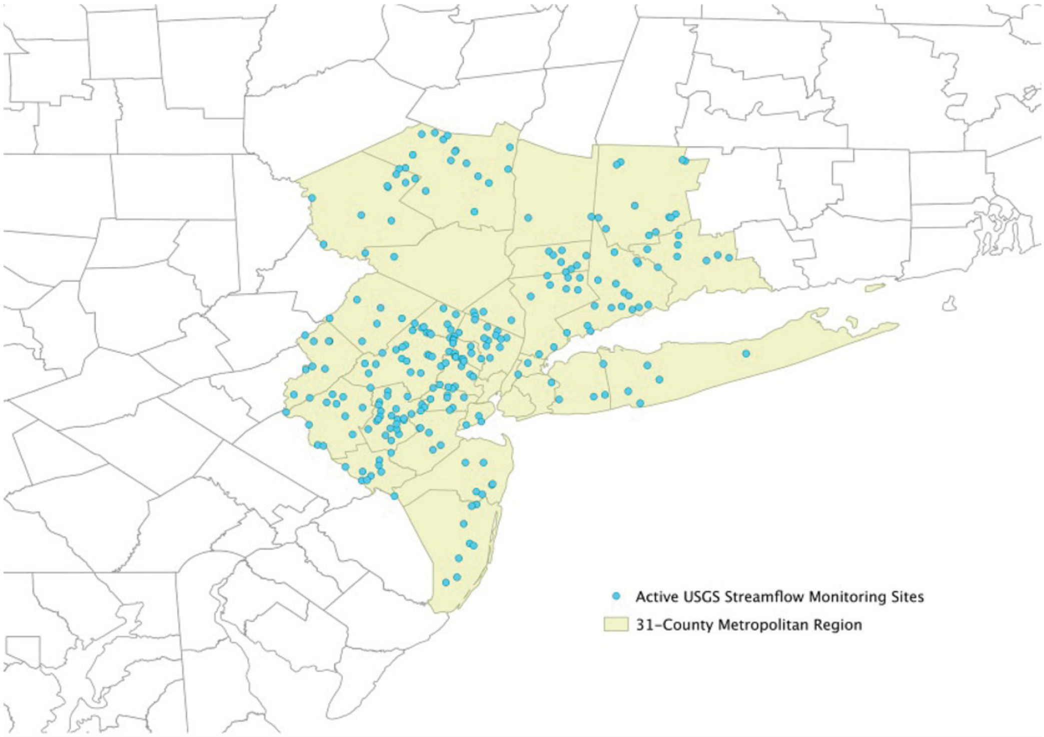

Figure 6.5. Active USGS streamflow sites in the New York metropolitan region.

Working Group with members from all the groups currently collecting water quality data should be formed to advance integration of these sources for climate change-related information.

Biodiversity and ecosystems

Climate change will have important but poorly understood impacts on the wildlife and ecosystems of the New York metropolitan region. Studies conducted in other parts of the Northeast have shown that the timing of spring migration of songbirds has changed over the last 40 years (Van Buskirk, 2012). Climate change has also been implicated in the northward expansion of kudzu (*Pueraria lobata*), an aggressive invasive plant that threatens New York City's native flora (Bradley *et al.*, 2010). However, there are currently limited observational data available to assess how climate change has impacted natural ecosystems in the New York metropolitan region. Field surveys are conducted in different parts of the region by the U.S. Fish and Wildlife Service, the National Parks Service, the New York City Department of Parks and Recreation, as well as many local organizations and academic researchers. To date, few efforts have been made to synthesize the results and analyze them to better understand how climate change may be influencing regional ecosystems. Efforts to do so should be a priority in the development of the New York City Climate Resiliency Indicators and Monitoring System. The biodiversity indicators developed to support the global Convention on Biological Diversity (Butchart *et al.*, 2010) may provide a good model for a New York City framework. Examples of these indicators include metrics for wild bird population trends, trends in the areal extent of wetlands and marine grasses, and trends in numbers of invasive species.

Remote sensing data, such as aerial photography, provide an important source of fine-scale information on the ecosystems of the New York metropolitan region and how they are being affected by climate change (Morgan *et al.*, 2010). Aerial photos for New York City are managed by the Department of Information Technology and Telecommunications (NYC DoITT). Aerial imagery for the remainder of the 31-county area can be obtained from the New York Statewide Digital Orthophotography Program (NYSDOP), the New

Jersey Department of Environmental Protection, and the Connecticut Department of Environment. However, in order to utilize this imagery for the development of ecosystems indicators, algorithms will need to be developed to standardize these different datasets for the New York metropolitan region.

Regional land cover plays an important role in the interpretation of climate change–monitoring data and the development of indicator metrics. Land cover data sets that cover the entire 31-county region at 30-m resolution can be obtained from the National Land Cover Database (Homer *et al.*, 2012), developed in partnership by several federal agencies. Updates to this database are released approximately every 9 years.

However, although this data set provides important information on the vegetative or impervious land cover (i.e., deciduous forest, wetlands, urban, etc.), it would be greatly enhanced by analyzing supporting data on land use activities (i.e., commercial, residential, etc.). This type of information is provided for counties in New Jersey by the New Jersey Department of Environmental Protection (NJDEP, 2010), but similar data sets are not available for other parts of the New York metropolitan region.

Next steps. Ecosystem measurements at the regional scale should be synthesized as part of the development of the New York City Climate Resiliency Indicators and Monitoring System.

6.3 Climate resiliency indicators and monitoring test bed—Reducing the urban heat island

In this section, climate resiliency indicators and monitoring are explored in relation to a specific urban climate challenge and a program to address it. The urban heat island effect (UHI) is the phenomenon of cities being warmer (up to approximately 8°F) than surrounding suburban and rural areas due to the abundance of dry impermeable surfaces such as roads and buildings (see Box 6.3). The UHI effect increases ambient temperatures, heat stress, exposure during heat waves, and energy use for cooling.

Methods to reduce the UHI include cooling buildings through increasing the albedo of their roofs and increasing evapotranspiration. These methods are part of a set of green infrastructure technologies, which include green vegetated roofs and bioswales (landscape features that improves drainage). Green roofs and bioswales can offer both UHI reduction and stormwater management.

This section addresses the following topics related to the challenges posed by the UHI effect in New York City and the NYC Cool Roofs Program designed to alleviate it:

- Science challenges
- NYC Cool Roofs Program
- Indicators and monitoring
- Next steps

Science challenges

A key challenge for UHI research and monitoring is quantifying the urban energy balance, especially the relationships between surface temperature and air temperature. This includes understanding by how much air temperatures can be reduced by lowering surface temperatures through increasing albedo and evapotranspiration.

Rooftops collectively comprise a substantial fraction of land area in urban settings. The percentage varies from city to city but may range from 10% to 20% (Rosenzweig *et al.*, 2009). For New York City, rooftops cover about 19% of its total land area. These rooftop surfaces and their micrometeorological fluxes interact with the atmosphere and thereby are part of the city's UHI phenomenon. They are thus key targets for UHI interventions.

The fundamental scientific principle that governs rooftop temperatures is that of the surface energy flow budget. This is the budget of energy into and energy out of a rooftop and any other surface exposed to the atmosphere. In sunlight, the energy flow fluxes are often more important than air temperature in determining surface temperatures; in other words, the energy flows involved in sunlight and thermal radiation often greatly outweigh the other surface energy flows such as windspeed and evaporative cooling. Evaporative and windspeed cooling, however, can strongly modulate the energy balance under some weather conditions and times of day (Gaffin *et al.*, 2010).

During peak sunlight times, black roofs can reach surface temperatures of 170°F (77°C) (Gaffin *et al.*, 2012b). Such peak temperatures are generally much more strongly dependent on incident sunlight conditions rather than high summertime air

Box 6.3. Urban heat island definitions

Air temperature (°F)
Temperature of the ambient air.

Albedo (%)
Ratio of solar radiation reflected by a surface to the radiation incident on it.

Cooling degree days
The number of degrees by which the daily mean temperature exceeds 65°F. Cooling degree days are calculated on a daily basis and are primarily used to track energy use.

Evapotranspiration (in. day^{-1})
Sum of the physical processes of evaporation and plant transpiration that combine to return water to the atmosphere.

Surface temperature (°F)
The temperature at the surface of a body.

Urban energy balance
Energy balance between the fluxes of heat, moisture, and momentum in urban areas.

Urban heat island
Thermal characteristics of cities that cause them to be warmer than surrounding suburban areas.

temperatures. This presents an opportunity for albedo modification, i.e., changing from black to white roofs, to alleviate the high surface temperatures of New York City roofs. Surface temperatures are sometimes even higher during spring than summer when less hazy urban air prevails.

Extreme hot and cold temperature cycles have practical implications for rooftop service life and building energy gains or losses. The temperature cycles are a major factor in roof-membrane wear and tear as they lead to material expansion and contraction cycles.

During a typical summer day, flat, black asphalt rooftops can reach temperatures up to 170°F, which is 90°F hotter than the surrounding air temperature. Cool roof coatings have been shown to reduce external roof temperatures, thus helping to mitigate the UHI effect. They also reduce internal building temperatures by up to 30%, making the building cooler and more comfortable during the hot summer months. Further, cool roofs lower carbon emissions by reducing demand for power. Every 2500 square feet of roof that is coated can reduce the city's carbon footprint by 1 ton of CO_2. Furthermore, cool roofs improve air quality by lowering air pollution and extend the lifespan of rooftops and HVAC equipment. A cool roof coating better regulates a roof's temperature as compared to typical rooftop surfaces. Decreasing the roof temperature and cooling loads can extend the life of the rooftop and cooling equipment.

NYC Cool Roofs Program

New York City has instituted the Cool Roofs Program to apply white paint to roofs in areas experiencing urban heat island effects. The goal of the program is to promote alleviation of the UHI and reduction in health risks associated with heat stress and heat exposure. By helping to cool buildings on hot days, NYC Cool Roofs contributes to reducing energy use and peak demand for electricity during extended heat waves (see www.nyc.gov/coolroofs).

In 2009, the City launched a Cool Roofs Pilot Program in Long Island City, Queens, a designated "hot spot" to test the effectiveness of cool roof coating in reducing energy consumption and cooling costs

Figure 6.6. Pilot paint program to brighten NYC dark roofs and monitoring sensors. The whitened test surface freshly coated is shown alongside an untreated square of the original asphaltic membrane. The surrounding gray area is the state of the paint two years after an initial coating. (Gaffin *et al.*, 2012b).

and to support the City's goal to reduce greenhouse gas emissions by 80% by 2050 (City of New York, 2014). A group of 244 volunteers were trained to coat 100,000 square feet of rooftop with elastomeric acrylic paint. To measure the effects of the white roofs, the city partnered with Columbia University (Fig. 6.6). The study showed that daytime peak black temperatures were, on average, 75°F warmer than the test white surface on rooftops; thus white roofs significantly reduced the need for air conditioning and energy consumption, which can result in real cost savings for building owners and tenants.

Based on the pilot program's initial success, a full program was launched citywide in 2010, in collaboration with NYC Service, the New York City Department of Buildings (DOB), and the New York City Mayor's Office of Long-Term Planning and Sustainability (OLTPS) with the goal of coating 1 million square feet of rooftop per year. The technology can be applied either by the building owner or by a labor service program created by the City. The Program focused on coating a range of nonprofit, low-income housing, and government buildings, among others.

To date, 5.8 million square feet of rooftops have been coated on 620 buildings, and 5600 volunteers have been engaged. In addition to the volunteer component, New York City also launched a "Cool-it-Yourself" campaign to encourage building owners to coat their own rooftops. This was promoted through bus shelters, several city websites, and word-of-mouth. New Yorkers who participate in the Cool-it-Yourself campaign log their data and address into the NYC Cool Roofs website.

Indicators and monitoring

New York City currently tracks the following metrics for the Cool Roofs Program:

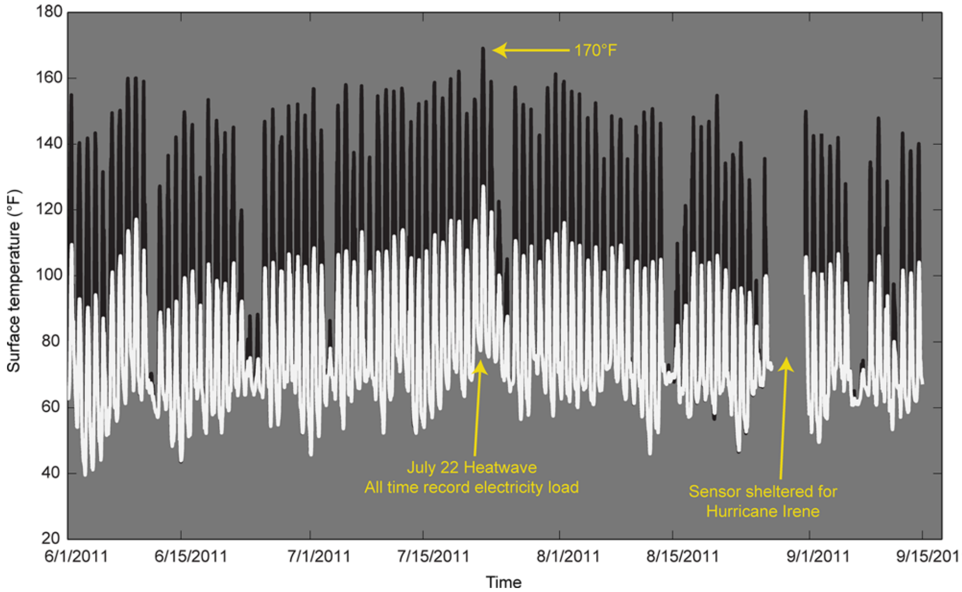

Figure 6.7. Surface temperatures for a freshly painted white roof compared to those of a control black roof at the Museum of Modern Art, Queens, NY. Source: Gaffin *et al.*, 2012.

1. Electricity usage in wattage and money spent in select buildings that have received an NYC Cool Roof coating
2. Number of square feet of rooftop coated
3. The amount of carbon reduced, calculated from the square footage of roofs coated
4. Number of volunteers engaged
5. Number of buildings coated
6. Number of green workforce[b] participants
7. Number of green workforce participants who secure jobs and/or further their education.

A pilot monitoring system for the Cool Roofs program has been installed by the New York City Mayor's Office and Department of Buildings (DOB) (Gaffin *et al.*, 2012a). Data have been collected on surface temperatures, albedo, and thermal emissivity for a test-coated and an uncoated asphaltic control surface. The experimental set-up including sensors is shown in Figure 6.6.

[b]Green workforce members are men and women from underserved communities in New York City who have applied for and successfully completed a 17-week training program. Eligibility requirements include 18 years of age (or greater), a GED or high school diploma, and a strong interest in pursuing a career in clean energy.

The figure shows the sensor deployment including infrared radiometers used to measure surface temperature, as well as a contact temperature probe used to verify the emissivity that is assumed when programming the infrared sensors. Also shown is an albedometer on a boom-arm consisting of two back-to-back pyranometers.

Analyses of temperature data from white and black roofs show that a significant reduction in peak temperatures is achieved with the paint (Fig. 6.7). Of note in Figure 6.7 is the peak black surface temperature (170 °F) during a heat wave that also set a record at that time (but since has been broken) for citywide electricity load for air conditioning. It is likely that this surface temperature is representative of similar dark asphalt surfaces through the metropolitan region including pavements. This is a surface temperature load that urban climate resiliency measures can target to mitigate the urban heat island effect.

Nighttime temperatures on the white and black roofs are comparable. This is expected because rooftops of both types have low internal energy storage and comparable emissivities. Thus, at sunset, both roof surfaces cool off rapidly and similarly.

Using data gathered on the NYC Cool Roofs Program (www.nyc.gov/html/coolroofs), a team of scientists at the Princeton Plasma Physics Laboratory conducted an energy-benchmarking study to analyze the building data collected by the program prior to and after the white roof coating. The study focused on months with the most cooling degree days: June, July, and August. With kilowatt hours provided from the utility companies, the researchers compared energy use from the months prior to the coating to energy use from the months following the coating. Using an average fractional analysis, they were able to determine the change in electric consumption from before the coating to after the coating.

Results of the energy-benchmarking analyses show that three of the five buildings analyzed had a 10–20% reduction in kilowatt hours used. The researchers concluded that if certain building characteristics (including high roof-area/wall-area ratio, low-rise and mid-rise structures, and overall air tightness, such that the contribution of roofs to total building energy gain is not negligible) are met, coating a rooftop with a light albedo paint or surface can help achieve significant reductions to building energy use.

Next steps

New York City will continue to monitor and analyze the benefits and science of cool roof coatings and is currently engaged on the following activities:

1. Indicators and monitoring
   - Deploy high-precision, high-resolution thermal infrared imaging cameras to further the studies of urban climate and of heat island causation and reduction technologies.
2. Site-specific analyses
   - Assess the performance of the sites coated so far, specifically the reflectivity and emissivity of buildings coated 1, 2, 3, and 4 years ago in designated neighborhoods.
   - Characterize positive impacts of increasing cool roofs as they affect carbon emissions reduction, health, and urban cooling.
   - Study the causes of albedo loss on treated roofs.
3. Regional scale research
   - Urban climate monitoring should increasingly pursue improved characterization of urban temperatures. Among the complicating factors are that air temperatures in a given locale are mixing with surrounding air masses, and this tends to dominate the resulting air temperature locally.
   - Additionally, a small area of cool surface temperatures, for example, is unlikely to have even a measurable effect on the overlying air parcels. To study this requires a large-enough footprint of specific types of surface temperatures (e.g., green areas, pavements, sidewalks, higher-albedo test surfaces) to assess any relationship.
   - Research should also be completed to determine how areas large enough to affect urban climate scale.
   - Monitoring should routinely include surface as well as air temperature. Currently, most monitoring of temperatures at official weather stations involves only air temperature.

The next phase of research will be to acquire temperature data on cool rooftops of different ages. A parallel effort to diagnose the causes for the losses in albedo and temperature control over time will be made. A third area of study will include an effort to better understand the temperature benefits of the Cool Roofs Program to air parcels overlying the treated roof surfaces.

Many green infrastructure options (e.g., urban forestry, green streets and roofs, and perhaps eventually green walls) are also increasingly being installed, and their effectiveness at providing desirable environmental services such as temperature and stormwater control needs to be further quantified.

It is also important to develop improved public awareness and education campaigns about heat wave risks and sensible strategies New Yorkers can use to protect themselves as well as to lower energy demand during such extreme events (see Chapter 5). Public awareness of the importance of green infrastructure will also aid in the maintenance of the projects, which is currently a challenge.

6.4 Conclusions and recommendations

New York City level efforts may benefit from linkages to broader national indicator efforts such as the U.S. National Climate Assessment's (NCA) Indicator System (http://www.globalchange.gov/what-we-do/assessment/indicators-system). Because this system is still under development and covers a wide range of systems, New York City and the broader region have the opportunity to lead in the development and use of urban indicators. This is particularly important because many proposed indicators under the NCA are designed to prove that climate change is having an impact on environmental and human systems rather than to support decision-making in light of climate change. Although proving cause and effect may be important for spurring national mitigation policies, it will be of less utility for identifying local adaptation options.

Conclusions

Based on a review of the existing indicators and monitoring activities in general, and the Cool Roofs Program in particular, the NPCC2 concludes the following:

- Existing indicators and monitoring systems in New York City can be adapted to provide targeted information for climate resiliency decisions.
- A comprehensive, integrated, and adequately funded interagency/multijurisdictional system for indicator and monitoring assessment is needed to enhance the scope and the robustness of New York City's climate resiliency efforts.

Recommendations

The NPCC2 recommends New York City take the following steps to develop its Climate Resiliency Indicators and Monitoring System:

- Build on existing efforts by the NPCC, City Agencies, and Federal partners by engaging a wide range of stakeholders—including infrastructure specialists, city planners, and community representatives—in order to develop a program to integrate climate indicators, monitor data, and explore possibilities to secure funding to support these efforts.
- Identify the gaps between the existing systems and the demands of urban climate change and the best opportunities for effectively bridging these gaps. Target those existing monitoring systems that can be easily enhanced while identifying those systems where more extensive adjustments will have to take place.
- Engage stakeholders and scientists in regard to environmental monitoring and adaptation planning for climate change:
  - Organize and implement a comprehensive regional New York City Climate Resiliency Indicators and Monitoring System with proper protocols for resiliency and adaptation adjustments.
  - Form weather and climate, coastal zones and sea level rise, water resources and water quality, health (see Chapter 5), and biodiversity and ecosystems working groups to set up the Climate Resiliency Indicators and Monitoring System.
  - Ensure that the indicator and monitoring results are the main drivers used to assess implementation outcomes.
- Develop and foster a community-driven approach whereby local organizations and individuals are empowered and encouraged to participate in New York City's climate resiliency process, practice, and decisions.

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