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Chapter 7: Indicators and monitoring

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A popular paradigm states: *What cannot be measured cannot be managed*. The programmatic and practical objectives of the city and members of the New York City Climate Change Adaptation Task Force are to develop Flexible Adaptation Pathways for the region's critical infrastructure. These objectives will require ongoing and consistent monitoring of a set of climate change indicators. Monitoring of key indicators can help to initiate course corrections in adaptation policies and/or changes in timing of their implementation. The relevant indicators are related to changes in the climate, climate science, climate impacts, and adaptation activities. Thus, these indicators need to be devised and tracked over time to provide targeted quantitative measures of climate change impacts, and adaptation in order to provide useful information to decision makers in regard to timing and extent of adaptation actions.

7.1 Choosing what to watch

Indicator categories extend beyond physical climate data collection to include new climate change research findings and projections. Furthermore, because effective infrastructure adaptation is a long-term process that encompasses much more than climate considerations, indicators ranging from greenhouse gas emissions, to demographic projections and advances in materials science are important as well.

There is a growing awareness of the importance of long-term data sets that span a range of disciplines for solving environmental challenges (NOAA, 2009a, 2009b). This is an emerging area in climate change research, and therefore the opportunity and need for collaboration and long-term partnerships across disciplines so that integrated solutions can be fostered are great. For example, climate scientists alone will not be able to determine what climate variables and temporal resolutions should be monitored; drainage engineers, for example, could require precipitation data in more frequent intervals than climate scientists would otherwise select. Conversely, agency experts should lead the selection of impact indicators, but there is a role for scientists as well to ensure that the integration of impacts and climate processes is sound. While the need for strong collaboration is challenging, it offers an opportunity to forge strong partnerships that will contribute to effective monitoring to inform future decision making.

Monitoring climate change, impacts, and adaptations, and developing the related indices for conveniently capturing their trends will be a complex array of tasks. This array may range from assuring the continuation of monitoring and tracking of existing indicators, to starting entirely new ones, and to finding the institutions to which these new tasks can be assigned with the expectation of continuity, reliability, quality control, and public accessibility.

During the last few decades, various methodologies for designing appropriate indicators have been developed (Huntington *et al.*, 2004; Hodgkins *et al.*, 2003), often in the context of environmental sustainability or for directly tracking climate change and its impacts. To be useful and practical, indicators must be tailored to the New York City regional circumstances and needs, while simultaneously based on easily accessible and verifiable data.

Criteria for selection

One approach favored by some indicator developers working in the field of environmental sustainability is known as the "*Pressure/State/Response*" (PSR) method.[1] In the context of climate change, *pressure* can be taken to mean the various types and levels of hazards associated with climate change (such as heat waves, extreme precipitation events, sea level rise, and coastal flooding). *State* relates to the impacts of the hazards, and *response* to the adaptation measures. Based on the PSR approach described by the Organisation for Economic Co-operation and Development (OECD) in 2004, we developed a set of criteria for selecting climate change indicators to address the needs of decision makers in the New York City region. To the extent possible, a given climate change indicator should fulfill the following multiple criteria, and the data required to support the indicator should be both available and measurable.

Policy relevance

- Provide a representative picture of climate conditions;
- Measure stakeholder-relevant climate change hazards and society's responses;
- Be simple, easy to interpret, and able to show trends over time;
- Be responsive to changes in climate and related human activities;
- Provide a basis for intra- and intercity comparisons;
- Have a scope applicable to critical regional climate change issues; and
- Have a baseline, threshold, or reference value or range of values against which to compare, so that users can assess the significance of the values associated with it through time.

Analytical soundness

- Be theoretically well founded in technical and scientific terms;
- Based on local, national, or international standards with consensus about its validity; and
- Readily linked to economic models, scenario projections, and information systems.

Measurability

- Based on readily available data or data available at a reasonable cost–benefit ratio;
- Be adequately documented and of known quality;
- Updated at regular intervals, in accordance with reliable procedures; and
- Of sufficient length in time and numbers to allow a quantitative statistical evaluation of the uncertainties associated with the data.

Not all of these criteria can be met for each indicator, especially because monitoring of climate change, its impacts, and adaptation actions is relatively new. Therefore, new indicators will need to be developed for some categories, and a consensus for what are appropriate, suitable, and effective indicators will emerge over time, on the basis of gradually gained learning and experience.[2]

Some sociologists differentiate between "bottom-up" and "top-down" indicators, with the latter defined as tools for administrative management, often applying to highly aggregated units (e.g., for an entire city), and the former as those incorporating community-based engagement and stakeholder involvement. Bottom-up indicators may be tailored to the needs and objectives of individual neighborhoods and community groups.[3] In actuality, there is a wide range of stakeholders, including the managers of critical infrastructure, who need readily available and accessible climate risk information at both city-wide and neighborhood scales. Furthermore, climate change information needs to be easily understood by the public in order to contribute to effective urban decision making.

7.2. Categories of indicators

Urban climate change analysis, indicators, and related monitoring activities, in particular:

- Create a mechanism for alerting stakeholders to emerging climate change data and related risk information;

- Warn of certain thresholds, some of which may lead to "tipping points" that may alter elements in a risk assessment process;
- Provide decision triggers for altering a certain adaptation path; and
- Initiate course corrections in adaptation policies and/or changes in timing of their implementation if and when necessary.

Climate change is only one possible motivation for a course correction in adaptation pathways. Shifts in projected impacts due to population growth rates and socio-economic changes (e.g., income, energy use, land use/urbanization, demographic changes) and shifts in the perceived relative merit of different adaptation strategies (e.g., due to technological innovations or emerging evidence of strategy co-benefits unrelated to climate change or risk tolerance) might also lead to such Flexible Adaptation Pathways.

Therefore, indicators should be identified for:

- Physical climate change variables;
- Risk exposure vulnerability and impacts;
- Adaptation measures; and
- New research within each of these categories.

We provide a narrative description of potential indicators for each category. Where appropriate, we also provide a summary table with a brief overview on examples of indicators, an indication of whether a database for the indicator exists or needs to be created, and the rationale for and significance of the indicator.

Physical climate change variables

The physical climate change trends need to be monitored, and indicators need to be devised so deviations of climate change trends relative to the forecast values, for instance those used in the New York City Panel in Climate Change (NPCC) Climate Risk Information (CRI) (Appendix A) Report, can be captured. For adaptation strategies to remain effective, it is important that the public knows whether actual climate change variables and their time derivatives (gradients) differ distinctly from those described in the CRI document.

For many decades, climate has been monitored and archived by federal and regional institutions, such as the National Oceanic and Atmospheric Administration (NOAA)'s National Climate Data Center (NCDC), the Northeast Regional Climate Center (NRCC[4]), and the New York State Climate Office. Standard climate and related variables (e.g., sea level rise) are readily available from these standard sources. Some of the climate data are further processed into what is known as "climate normals." The most commonly used normals for many engineering designs (e.g., dimensioning of drainage culverts and retention basins) are 30-year monthly and annual averages of precipitation and of maximum, minimum, and mean temperature. Monthly and annual average heating and cooling degree days are also important. The CLIM81 (Climatography of the United States No. 81[5]) publication contains these monthly normals, plus monthly median precipitation and median mean temperature, for several thousand locations across the United States.

Table 7.1 provides an overview of the three most basic types of climate change variables (temperature, precipitation, and sea level rise and associated coastal storms) that are considered critical for monitoring and/or deriving climate change indicators. The table also highlights which raw data are currently available, the timescale for which they are available, and their source.

From Table 7.1, it is apparent that some climate variables are readily available on a local or regional level and over different time horizons (say, for instance, temperature and precipitation). Others (for instance, the number and strength of nor'easter storms) can be extracted from various historic records and sources but would need to be processed. Moreover, the data will need to be systematically collected in the future. From the various weather and climate data sets available, a subset will need to be selected as indicators of climate change in New York City. Some of the climate variables presented in Table 7.1 that are already available and have been tracked over the past century are shown in Figure 7.1.

Some of the climate hazards shown in the table are more or less useful indicators, depending on the period they represent. While raw data are available at short timescale, they can be processed to represent averages over longer time intervals that may be more appropriate for certain climate change impacts. For example, precipitation data are tracked on a daily timescale, and converting these data into seasonal or annual values can be more helpful for monitoring climate change impacts (e.g., for tracking impacts on water supply). In addition, depending on the

Table 7.1. **Basic climate change variables for monitoring and development of indicators**

	Climate hazard	Location	Time series	Timescale	Source[a]
Temperature	Mean temperature	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1948–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Days with temp > X°F	Central Park	1944–present	Monthly	NCDC
	Days with temp < X°F	La Guardia Airport	1948–present	Monthly	NCDC
	Number of consecutive days[b]	Central Park	1876–2001	Monthly, annual	NCDC
		Kennedy Airport	1949–present	Monthly	NCDC
		LaGuardia Airport	1949–2001	Monthly, annual	NCDC
			1948–2001	Monthly, annual	NCDC
	Global surface temperatures	Global value	1880–present	Annual	NCDC
	U.S. heat stress index	New York City	1948–present	Annual	NCDC
Precipitation	Total precipitation	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1949–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Drought	New York City region	1900–present	Monthly	NCDC
	Thunderstorms/lightning	New York County	1950–present	Daily	NCDC
	Snow	Central Park	1876–present	Daily, monthly	NCDC
		Kennedy Airport	1948–present	Daily, monthly	NCDC
		LaGuardia Airport	1947–present	Daily, monthly	NCDC
	Downpours (precipitation rate/ hour)	Kennedy Airport	1949–present	Hourly	NCDC
		La Guardia Airport	1948–present	Hourly	NCDC
	Days with rainfall > X in	Central Park	1944–present	Monthly	NCDC
	Number of consecutive days[b]	Central Park	1876–2001	Monthly, annual	NCDC
		Kennedy Airport	1949–present	Monthly	NCDC
			1949–2001	Monthly, annual	NCDC
		LaGuardia Airport	1948–present	Monthly	NCDC
			1948–2001	Monthly, annual	NCDC
Sea level rise and coastal storms	Sea level rise: mean water level	The Battery	1856–present	Monthly	NOS
		Sandy Hook, New Jersey	1932–present	Monthly	NOS
	Hourly height water level	The Battery	1958–present	Hourly	NOS
	Extreme winds	Sandy Hook, New Jersey	1910–present	Hourly	NOS
	Tropical cyclones	Central Park	1900–present	Daily	NCDC
		New York	1851–present	Annual	NCDC
Other	Greenhouse gas index	Global values	1979–present	Annual	ESRL

[a]Sources of data are the National Climatic Data Center (NCDC), National Ocean Service (NOS), and Earth System Research Laboratory (ESRL), all part of the National Oceanic and Atmospheric Administration (NOAA).
[b]Thresholds preset, requires further processing to customize.

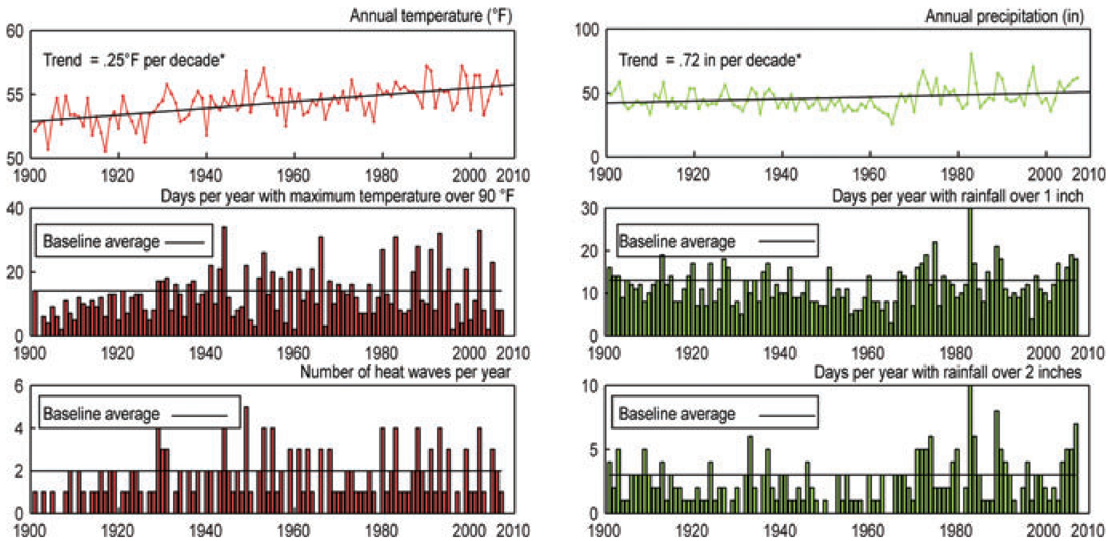

Figure 7.1. **Historic tracking of temperature and precipitation climate change indicators. *The trends for both temperature and precipitation are significant at the 95% level. Data are from the NOAA NCDC United States Historical Climatology Network (USHCN). Heat waves are defined as three or more consecutive days of temperature over 90°F.**

particular climate hazard, it may also be useful to look at the frequency and timing of the events. For example, daily maximum and minimum temperature data can be used to pick out seasonal or annual extremes, which on their own are an indicator. When tracking downpour/precipitation rates, seeing at what time of day the strongest events occur may also be useful for adaptation planning.

The exact definition of some of the climate variables shown in Table 7.1, which may be readily available or newly devised parameters, and the uncertainty bands for each indicator to identify significant changes need to be established. Indicators are either directly observed or derived from archived data. Several of the climate hazards listed in Table 7.1 are further defined in Box 7.1.

Box 7.1 Examples of climate indicators to be tracked

- *Heat stress index:* Sensible temperature that results from combining the actual temperature with the actual relative humidity;
- *Extreme winds:*
  - (a) Wind gusts—sudden, rapid fluctuations of wind speed. Gusts are determined from the most recent 10-min wind speed data. The speed of the gust is the maximum instantaneous wind speed in the 10-min interval. Standard U.S. weather observing practice is to report these gusts when the peak wind speed is 18.4 mph or higher and the wind speed variability between the peaks and lulls is at least 10.35 mph. Gust duration is typically about 20 sec or less;
  - (b) The number of days per year with either sustained wind or wind gusts exceeding certain threshold values. These thresholds values will have yet to be determined for the New York City region. This could be done for stations at JFK and LGA airports for thresholds of 40, 60, 80, 100, and 120mph; and
- *Tropical cyclone:* An area of low pressure that forms in the tropical ocean and develops into a major storm that can travel to extratropical regions. When winds exceed 73 mph, they are known as hurricanes in the Atlantic and Eastern Pacific.

Many archiving and delivery systems of selected indicators for New York City will need to be established and/or institutionalized, where not already in existence. The objective is to guarantee longevity of records, consistency, and quality control, and, if

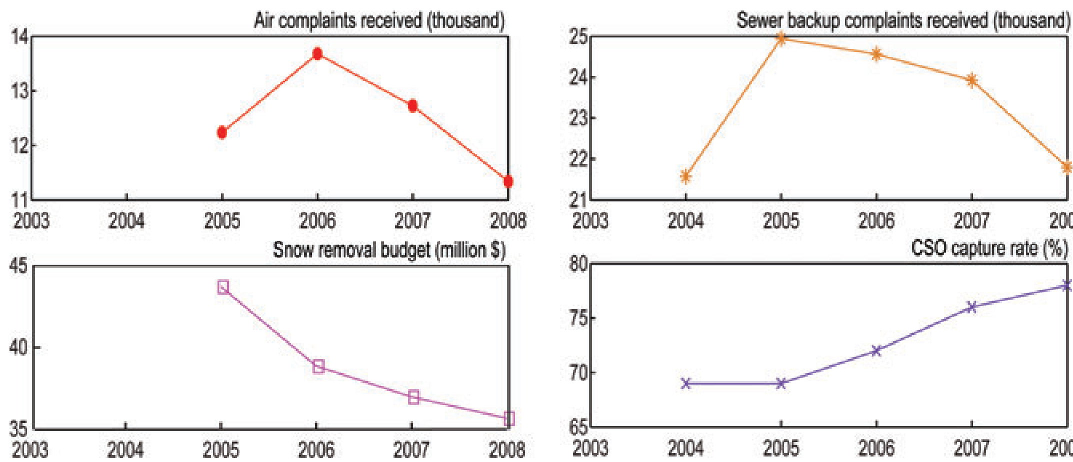

Figure 7.2. **Some of the indicators currently being tracked in New York City. The CSO capture rate is the percentage captured for treatment before released to the waters surrounding the city. Data are from NYCStat, managed by the Mayor's Office of Operations.**

needed, development of new indicators. A group of qualified experts should be charged with the responsibility to oversee reliable data monitoring, archiving and analysis, calculation of derived indicators, and their distribution.

Detection of significant trends is challenging, and the interpretation of such trends depends on how the trends affect the resulting risks and vulnerabilities. This information will help to determine whether adaptation strategies and their timing should be modified. It is unlikely that the relationships among hazards, risks, and vulnerabilities can be established at the outset of monitoring efforts, or even in the near future. If the definition of a significant trend cannot be linked to associated impacts, then, for the time being, the climate indicators will at least measure the observed trends and can be used to determine how they compare to their originally projected values. Statistical measures of confidence need to be calculated for the given indicators, and criteria can be defined to flag "thresholds" or "trigger points." These criteria, which vary by indicator, need to be decided through a documented consensus process involving both scientists and stakeholders.

Risk exposure, vulnerability, and impacts

While information is more readily available for the climate change variables, information tracking the potential impacts of climate hazards is more difficult to find. These indicators, especially those that describe severe impacts on society, have not been consistently collected and archived, nor are the records, to the extent they exist (e.g., insurance records), always readily available to the public. However, these impact indicators are just as important to track as the climate hazard data. They will help to reveal what effects, if any, climate change is having on infrastructure and other aspects of society.

Table 7.2 and Figure 7.3 present an overview of some of the potential indictors related to impacts of climate change on New York City, the functioning of its infrastructure, and its life and economy. The table lists the agency that is currently monitoring the indicators or that would likely be able to undertake such monitoring in the future. Although not comprehensive, the table lists climate impacts that could be tracked in New York City and is based on the projected variables developed by the NPCC. For these and other climate impacts, there needs to be further vetting for their feasibility as indicators, to explore which agencies could be charged to collect, maintain, and analyze the data, and to determine the resources needed to sustain such monitoring, archiving, and analysis functions. Such impact indicators may include already measured climate effects (e.g., number and location of combined sewer overflows per year and losses from extreme weather events), as well as those that will have to be developed.

Examples of indicators that can be tracked are the number and dollar value of claims per year for FEMA flood insurance and commercial

Table 7.2. Climate-related impact indicators[a]

	Climate-related impact	Is it currently tracked?	By which agency?	How long is the series?
Temperature	Electrical outages (frequency/extent)	Yes	EDC	2000–present
	Emergency service calls (fire and ambulance)	Yes	FDNY	1998–present
	Transit service interruptions (electrical outage/rail buckling)	Yes	MTA	2004–present
	Cooling equipment purchases	Yes	IBO	NA
	Extreme heat- or cold-related illness/death	Yes	DOHMH	1999–present
	Unhealthy air quality days	Yes	DOHMH	1995–present
	Roadway pavement condition	Yes	DOT	2003–2007
	Swimming pool usage	Yes	DPR	2003–present
Precipitation	Reservoir capacity	Yes	DEP	2003–present
	Roadway traffic/accidents	Yes	DOT	1987–2007
	Combined sewer overflows	Yes	DEP	2004–present
	Water quality	Yes	DEP	1997–present
	Winter road maintenance	Yes	DSNY	1999–present
	Pumping equipment purchases	Yes	IBO	NA
	Parking suspensions	No		
	Sewer backup complaints	Yes	DEP	2004–present
	Transit service interruptions (flooding)	Yes	MTA	2004–present
Sea level rise and coastal storms	Brownfield cleanup acreage	Yes	MOER	No data
	Flight delays	Yes	PANYNJ	1996–present
	Beach erosion	No		
	Ferry service interruptions	Yes	DOT	2005–present
	Salt water intrusion	Yes	USGS	1988–present
	Water treatment plant operations	Yes	DEP	2006–present
	Emergency services preparedness	Yes	OEM	2004–present

[a]Sources include documents released by New York City, such as the Mayor's Management Report (MMR), Citywide Agency Performance Reports (CPRs), and PlaNYC/sustainability reports. Much of the raw data found in these reports is available online in a statistical database NYCStat, managed by the Mayor's Office of Operations. http://www.nyc.gov/html/ops/nycstat/html/home/home.shtml.

wind insurance. To sort out the coastal storm surge flood insurance versus the inland, noncoastal urban street flooding, different typical communities for either flood environment may be selected. For coastal floods, Rockaway, in Queens, may be selected as representative since it is one of the most vulnerable coastal communities in New York City; for urban inland flooding, data may be collected from low-lying portions of the Bronx located along the Bronx River.

Many of the climate-related impacts on Table 7.2 may have alternative indicators that are currently tracked or should be monitored in the future. For example, the table suggests that monitoring climate impacts on electricity supply and demand can be accomplished by tracking the frequency of electrical outages. Other indicators of the impact of climate on electricity include the number of customers without electric service or the peak demand on days with the highest load due to heat.

A knowledge hurdle exists, as well. For the most part, the climate-related impact indicators shown in Table 7.2 are tracked without taking climate into consideration. A given agency may monitor a particular climate-related impact, but the agency may not currently analyze it in regard to climate as a causative factor. For example, take the climate-related impact of road closures due to heavy rainfall and flooding. While the New York City Department of Transportation has a record of the road closures, the records do not include concurrent precipitation or flooding. Combining the physical climate data with the impact data is necessary to fully understand and successfully monitor changing climate risk exposures. Making the data adaptation relevant will demand careful processing.

Adaptation measures and their effectiveness

In addition to tracking indicators related to climate hazards and impacts, data also need to be collected and analyzed to track the implementation of adaptation strategies and their effectiveness. These provide quantitative insight into the effectiveness of climate adaptations (or other policy actions and societal developments) in regard to climate change risk reduction. These types of indicators can help to inspire communities to support these actions. Included in this category are public policies related to climate change adaptation and those policies that otherwise can influence the coping capacity of the city.

Monitoring adaptation activities and their effectiveness in New York City requires indicators that show whether adaptation is taking place, at what pace, and in what locations. Among the relevant evaluation criteria to track are: cost, feasibility, efficacy, co-benefits, and institutional considerations. Adaptation activities also need to be monitored at the New York State and U.S. government levels, and in other regions of the country and the world, to ensure that New York City has the opportunity to adopt the “best practices” in use worldwide.

An example for how intertwined the relationships can be between physical climate parameters and adaptation measures (or in this case policy measures not directly aimed to adapt to climate change, but which were aimed primarily at other environmental sustainability and economic objectives, such as reducing excessive water consumption in New York City, not only during droughts, but at any time), and therefore must be analyzed synoptically to understand their complex relationships, is well demonstrated in Figure 7.3.

Adaptation measures to track may include:

- The number of building permits issued in any given year by New York City that (a) are located in current FEMA coastal flood zones, and (b) are located in areas likely to be coastal flood zones by the 2080s as projected by the NPCC CRI sea level rise projections (including the rapid ice-melt scenario);
- The percentage of building permits issued in any given year by New York City that have LEED certifications or other measures to reduce precipitation runoff (whether by green roofs, water retainment, and/or gray-water usage, or by creating permeable ground surfaces on their properties);
- An index based on insurance data that measures the insurer’s perception of New York City’s infrastructure-coping capacity vis-à-vis climate change, based on the prices insurers charge to take on the climate change risks, or on their inclination to withdraw from insuring such risks, whether from climate change physical damage or business interruptions;
- An index that measures the rating of bonds solicited by New York City or infrastructure operators for capital projects with climate change risk exposure. Bond ratings typically affect their interest rates, and if they are too high, the related infrastructure projects cannot be financed and may be delayed, often with broader economic consequences;
- The trend of weather-related emergency/disaster losses (whether insured or uninsured, relative to the total asset volume) (i.e., their decrease or increase with time and their relation to climate parameters, such as sea level rise); and
- The number of days with major telecommunication outages (if possible preferably distinguished by wireless versus wired service outages), and their coincidence with weather-related power outages. The latter correlation provides an indication of adaptation measures by the communication sector to arrange for sufficient backup power supply.

Because other cities, municipalities, and organizations are also creating climate change adaptation

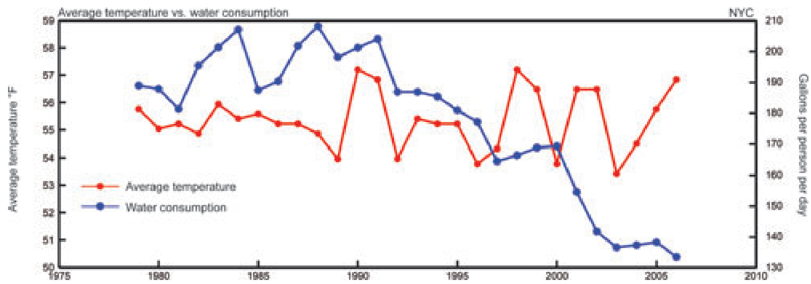

Figure 7.3. **Temperature and water usage for New York City. Data are from the NOAA NCDC USHCN and Mayor's Office of Management.**

plans, part of tracking adaptation strategies should also include following the creation of other plans so that New York City can incorporate the "best practices" from elsewhere.

Finally, nonclimate change-related factors that might influence climate change adaptation plans should be tracked as well. These include socioeconomic and demographic factors, and federal, state, and local adaptation policies.

New research findings and information

Apart from monitoring the three categories of climate change, impacts, and adaptation effectiveness, changes in knowledge and scientific progress need to be tracked as well. This final aspect of monitoring involves tracking of advances in climate change theory, observations, climate change impacts (including both risk exposure and vulnerability), and adaptation strategies and their effectiveness.

Keeping track of new research findings may require periodically revisiting the basic foundations, assumptions, policies, and implementation methods used at the beginning of the City's and the NPCC's processes, and comparing them to new findings and projections. Determining how these new findings may need to be incorporated into revised strategies and policies and their implementation will be a significant task. A body of assigned experts, such as the NPCC, could periodically review the pertinent professional literature and determine its implications. This process is also likely to lead to the identification of critical new indicators.

Tracking of new climate change research findings may alter future projections and their associated uncertainties, including how global greenhouse gas emissions or carbon capture and storage or other technologies may potentially change global climate change scenarios, or whether new methods of downscaling climate model results will improve specification for the New York City region. We need to track both global and regional information with potential consequences for the region's climate change scenarios and for the City's ability to develop appropriate and timely adaptation methods. New research and data on climate change risk assessment and management methods, effective adaptation strategies developed for New York or other cities, and on urban land-use practices to manage climate change risks can be monitored and evaluated for their utility to New York City and the surrounding region.

7.3 Institutional process and requirements

A proposed structure of how a climate change indicators and monitoring process or system could be developed is shown in Figure 7.4. Under such a framework, data from stakeholders who monitor climate-related impacts (such as those listed in Table 7.2) would be combined with climate hazard data (such as those listed in Table 7.1), in a central climate change data-processing center. The output of the analysis could be in the form of an online database of climate change adaptation indicators. To track ongoing research and new knowledge, an online repository of references and resources can also be created using a database searchable by time period, topical category, and key words. The usefulness of such an archive can be measured in a number of ways, including by the number and kind of "hits" it receives.

While many indicators are either already tracked, or easily could be, significant resources and person-hours are required to turn raw data into useful products. Data content and formats need to

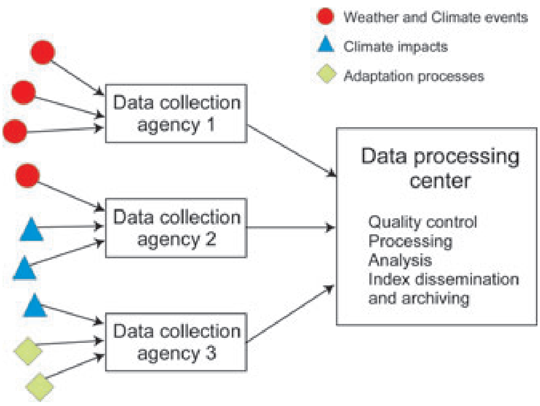

Figure 7.4. **Schematic of proposed structure and process of monitoring climate change, impact, and adaptation parameters, and for translating them into indicators for New York City.**

be standardized, and quality controls implemented. A decision support tool can combine database features, such as queries with visualization tools (e.g., Geographic Information Systems). All of these features require database management as well as computer processing and storage. Additional considerations include: (1) the extent to which raw data can be provided instead of processed data, and (2) how statistical features, such as linear correlation, and trends are included. The greater the number and complexity of indicators included, the greater the need for centralized coordination and data storage.

Risk assessment tracking

When the interactions of climate hazards and impacts are combined into indicators, stakeholders are able to track the risks of climate change. Evaluating the effectiveness of adaptation measures involves monitoring whether the exposure to risk of societal assets is increasing or decreasing. Changes in risk may be due to the climate change trends, changes in the locations of the assets, or changes in the assets. For example, if a sea wall is built to protect a wastewater treatment plant, the treatment plant's vulnerability to sea level rise decreases.

Rates of change of such risks need to be tracked through time and with respect to climate trends. The analysis of climate change impact indicators needs to be coordinated with stakeholders so that they are based on the physical vulnerabilities of the built environment and of the societal environment as a function of time. This will contribute to regional understanding of climate change and to the development and implementation of adaptation strategies.

Issues and considerations

Part of the appeal of indicators is their apparent straightforwardness, since as traditionally defined indicators are based on observations, rather than projections. However, interpretation of indicators can be quite complex, and there are a variety of potential pitfalls. For example, a discrepancy between an observed climate indicator in the short term and a climate change projection for the same period might be used to adjust the climate change projection over the longer term. For a variety of reasons though, a few new observations may be of limited value in modifying projections. Many observations have known errors, and "new" errors may be identified in the process of analyzing a seemingly noteworthy observation. Second, without a long observational record, it is difficult to discern whether a few new observations represent a scientifically meaningful change, or whether they represent natural variability. Finally, an indicator needs to be considered in a broad context before any conclusions are reached. For example, are other relevant indicators consistent with the new result? Is there a strong body of research supporting or contradicting the new interpretation?

While the benefits of monitoring indicators are clear, there may be arguments against full dissemination of some results. The revelation of some vulnerabilities could potentially pose a future security threat. Disclosure of certain information may be beyond the mandate of some agencies and might expose them to fiduciary, legal, and public relations risks. Proprietary concerns, such as who owns the data and the derived indicators, also need to be addressed.

Producing useful climate, impacts, and adaptation indicators, and keeping track of pertinent new research findings requires institutions that have the knowledge, personnel, and resources to fulfill these tasks. Without them, monitoring of climate change to enhance effective adaptation in New York City will at best occur on an *ad hoc* basis and/or lose momentum with time as other concerns come to the public's attention. Without such a monitoring effort, there is no way of knowing whether public and private resources are being spent efficiently, adaptation measures are effective, practices are improving over time, and vulnerabilities are reduced. The overall goal is to develop Flexible Adaptation Pathways that contribute to the sustainability of New York City and the surrounding region with respect to climate change.

New York City–based climate hazard monitoring network

In addition to standard weather stations, tide gauges, and climate-archiving efforts as maintained by NOAA (via the National Weather Service, NOS, and the NCDC for instance), additional special monitoring networks in the New York City region are desirable to gather pertinent data at higher spatial and temporal resolution. For example, it would have been beneficial to have more detailed precipitation data for August 8th, 2007, the day a tornado struck Brooklyn and intense precipitation temporarily disabled much of the public transportation system throughout the entire city. However, higher temporal resolution data at finer spatial scales are not available that would help to elucidate the rates of rainfall that were associated with most of flooding impacts throughout the drainage and transportation systems.

Current data-gathering efforts include NOAA-CREST at City College, CUNY and its New York City MetNet, other CUNY institutions, scores of public and private middle and high schools in New York City, Stony Brook University, Stevens Institute of Technology, Princeton University, and Columbia University. NOAA-CREST, for example, is involved in the Science Playground project, which is focused on developing weather station capacity at schools and other community sites throughout the city. The group has participated in this project through the installation of a WeatherBug weather station in MS/PS 394 in Crown Heights Brooklyn, NY, and the group plans to participate with the school in other climate-related educational programs. Additionally, NOAA-CREST reinstalled and networked the weather station at THE POINT Community Development Corp in Hunts Point, Bronx NY. The station data are posted at THE POINT website (http://www.thepoint.org/) and the New York City MetNet website (http://nycmetnet.ccny.cuny.edu). Working with vibrant community groups like THE POINT is one successful mechanism of generating and maintaining local interest in climate data collection and climate indicator monitoring.

Figure 7.5 highlights some of the atmospheric monitoring equipment that is a part of the New York City MetNet. The New York City MetNet is already used to monitor weather patterns and extremes, some parameterizations of which could be useful as climate change indicators, such as extreme temperatures, precipitation rates, and wind speeds.

The MetNet provides:

- Measurements in real time;
- A permanent and expandable facility;
- Secure two-way data-flow communications;
- Quality-assured data;
- Permanent data archive;
- Secure access to an archive;
- Transparent graphical user-interface developed with end-user input;
- Dynamic forecasts for emergency response; and
- Decision support system.

The network's key elements of communications robustness, quality assurance, data assimilation, processing and archiving, and its real-time display for decision making enable successful integration into an indicator and monitoring system for climate change. Besides providing climate change indicators, it currently supports air quality assessment efforts, provides valuable input in weather forecasting, provides data useful for emergency response, restoration and recovery, and supports numerous ongoing, planned, and future research efforts in atmospheric science.

Additionally, in the New York City region, Stevens Institute Maritime Center[6] maintains a forecast/monitoring and forecast system for harbors and coastal waters. Outside the New York City region, another example of a localized monitoring network is *Mesonet*[7] in Oklahoma, comprised of 110 automated stations that sample several meteorological variables every 5 minutes and transmit the information to a central hub where it is verified and released within 5–10 minutes. This type of localized monitoring networks in urban regions could be useful in developing, tracking, and analyzing hazard indicators for climate change adaptation. Figure 7.6 shows various locations within the environs of New

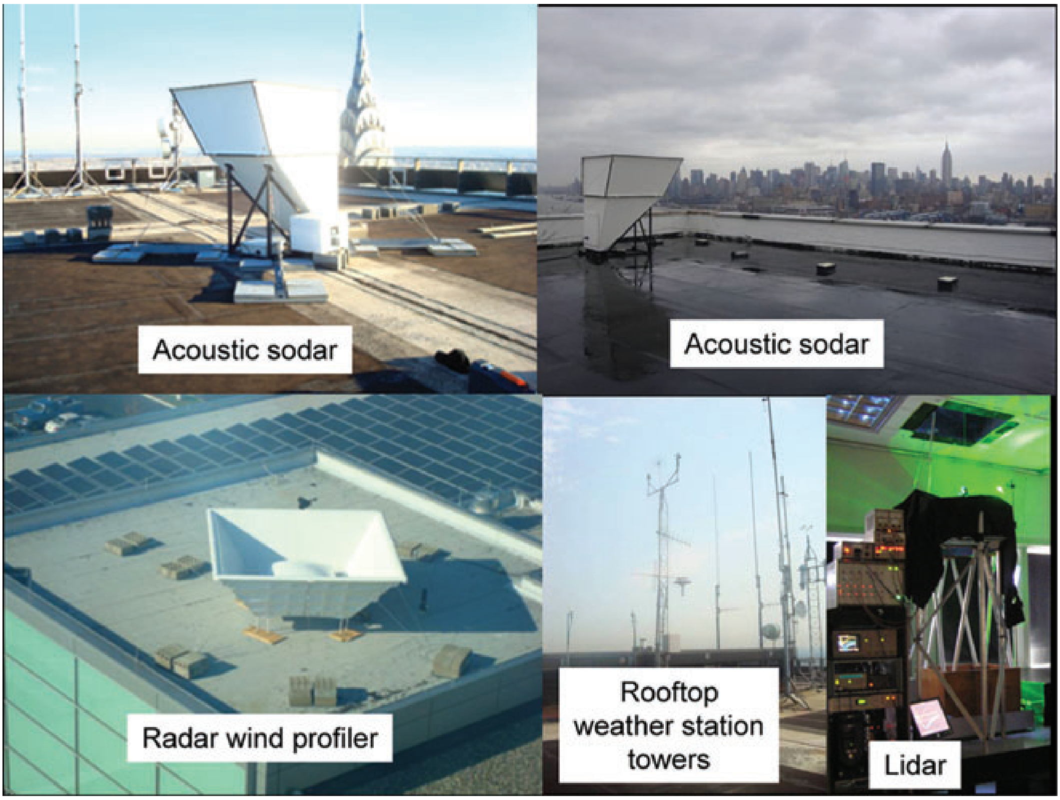

Figure 7.5. **New York City MetNet instruments: weather station, acoustic sodar, lidar, and radar wind profiler.**

York City where NYC MetNet instrumentation is already in place. The network is currently being expanded to cover more of the region.

7.6 Summary and recommendations

The goal is to help foster a research and political environment in which adaptation measures have a sound and up-to-date scientific/technical foundation that includes assessing the inherent uncertainties in climate science, climate impacts, and its adaptation. To fulfill this goal, New York City should create an indicators and monitoring program to:

- Provide a vehicle for keeping New York City's adaptation decision makers and stakeholders informed about important new climate change information and knowledge. The efforts should include coordinating the community and regional/local climate indicator monitoring initiatives that are currently being undertaken;
- Engage stakeholders and communities to include climate change adaptation measures in their daily decisions and alert them to missed opportunities. The distribution of the monitoring results and their discussion with stakeholder communities should be aimed at making adaptation an ongoing, living process rather than a one-time or occasional effort;
- Alert stakeholders of the timing and imminence of trigger points and thresholds at which decisions between distinct climate change adaptation paths become urgent. This will help stakeholders avoid entering into situations where inaction or misguided actions lead to over or under adaptation;
- Present what, on scientific/technical grounds, appear to be better or worse adaptation strategies vis-à-vis evolving climate patterns. Such presentations should complement, enlighten, and enhance the engineering and political decision process needed to arrive at the adaptation decisions that best serve the city, its stakeholders, and its affected communities. Where possible, the efforts should strive to quantify the costs and benefits of climate change adaptation strategies; and

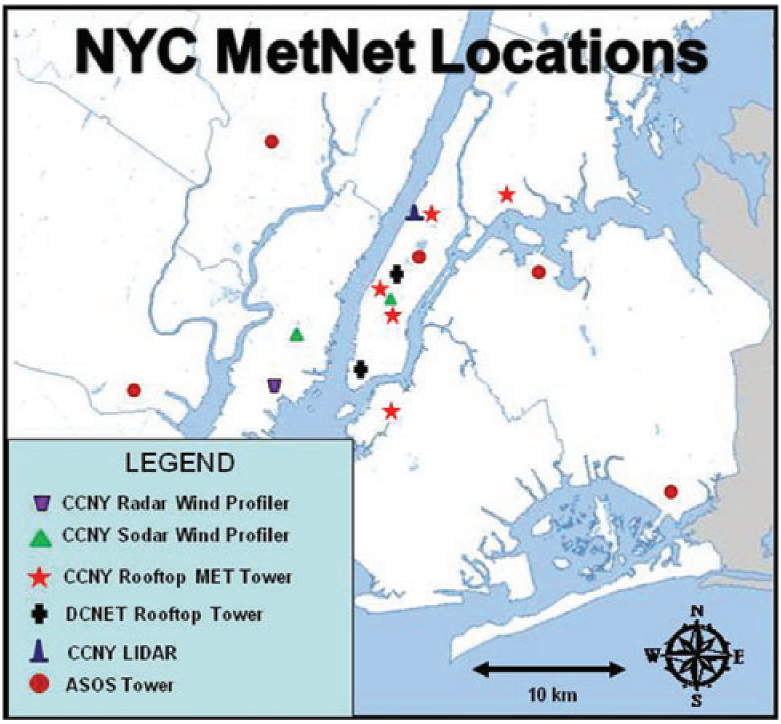

Figure 7.6. New York City MetNet locations. CCNY, City College of New York; DCNET, a monitoring network run by NOAA/OAR; ASOS, Automated Surface Observing Systems.

- Sustain this monitoring and indexing effort through commitment and funding, including institutionalization within city agencies to take on the tasks of monitoring and preparing indicators of climate change science, impacts, and adaptation trends, with the specific aim of fostering strong stakeholder and community involvement.

New York City specifics

Examples of climate change adaptation indicators include:

- The percentage of building permits issued in any given year in current FEMA coastal flood zones, and in projected 2080 coastal flood zones;
- An exact tally of building permits that have measures to reduce precipitation runoff;
- An index based on insurance data that measures the insurer's perception of New York City's infrastructure-coping capacity vis-à-vis climate change;
- An index that measures the rating of bonds issued by the City or infrastructure operators for capital projects with climate change risk exposure;
- The detailed trend of weather-related emergency/disaster losses (whether insured or uninsured, relative to the total asset volume); and
- The number of days with major telecommunication outages (wireless versus wired), correlated with weather-related power outages.

Such indicators and others arrived at in a sound stakeholder-based process create a set of data analysis and processing needs:

- Long-term data sets that span a range of disciplines;
- Indicators tailored to New York City, based on accessible, verifiable data;
- Readily available online climate risk information, citywide and by neighborhood;
- Exact definition of some climate variables, with uncertainty bands for each;
- An appropriate body should set the threshold values for the indicators;

- Many more archiving and delivery systems of the selected indicators;
- Criteria defined to flag “thresholds” or “trigger points,” decided through a documented scientist-stakeholder consensus;
- Designated groups, such as the NPCC, to evaluate the indicators;
- For coastal floods, Rockaway, in Queens, may be selected as representative; for urban inland flooding, low-lying portions of the Bronx;
- Careful processing to combine the physical climate data with the impact data, to fully understand and successfully monitor changing climate risk exposures;
- Tracking the implementation of adaptation strategies and their effectiveness;
- Build on the work already being done by Met-Net: extreme temperatures, precipitation rates, and wind speeds; and
- Synoptic analysis of relationships between physical climate parameters and adaptation measures.

Implementing these measures will require strengthened organizations and institutions:

- Creation of an online repository of resources using a database;
- Sufficient resources to turn raw data into useful products, with professional database management as well as computer processing and storage; and
- Additional special monitoring networks, localized for New York City, to gather data at higher resolution.

At a more general level, additional tracking would be most beneficial. In an effort to provide the City with the best and most up-to-date advice, the NPCC could continue to monitor:

- The adaptation plans of other places for relevant “best practices”;
- Nonclimate change factors that might influence climate change adaptation plans;
- Changes in knowledge and scientific progress; and
- The basic foundations, assumptions, policies, and implementation methods used, comparing them to new findings and projections.

Endnotes

[1] http://destinet.ew.eea.europa.eu/policies_resources/fol955810/OECD_P-S-R_indicator_model.pdf/.

[2] M. S. Reed *et al.* (2006).

[3] Dessai and van der Sluijs (2007); Pew Center (2009); and Fraser *et al.* (2006).

[4] http://www.nrcc.cornell.edu/.

[5] http://lwf.ncdc.noaa.gov/oa/climate/normals/usnormalsprods.html.

[6] http://hudson.dl.stevens-tech.edu/.maritimeforecast/ and http://hudson.dl.stevens-tech.edu/maritimeforecast/info/.

[7] http://www.mesonet.org.

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ANNEX—useful resources and websites:

Useful examples of indicators for physical climate change parameters are:

- For the Northeastern United States: http://www.cleanair-coolplanet.org/information/pdf/indicators.pdf.
- Online climate data for the Northeastern United States: http://neisa.unh.edu/Climate/index.html.

Annual sea-level rise data for NYC:

- http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8518750%20The%20Battery,%20NY. Example of national scale climate change data (for the United Kingdom):
- http://www.ecn.ac.uk/iccuk/ and related links. Examples of global-scale indicators:
- NASA: http://climate.jpl.nasa.gov/keyIndicators/.
- European Environmental Agency: http://www.eea.europa.eu/themes/climate/indicators.

Criteria for indicator development:

- Organisation for Economic Co-operation and Development (OECD)—pressure-state-response model and the development of indicators for environmental sustainability: http://destinet.ew.eea.europa.eu/policies_resources/fol955810/OECD_P-S-R_indicator_model.pdf/.

Climate *normals* for the United States:

- http://lwf.ncdc.noaa.gov/oa/climate/normals/usnormalsprods.html.
- http://lwf.ncdc.noaa.gov/oa/climate/normals/usnormalsprods.html#CLIM81.
- http://lwf.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

Monthly station *normals* for New York:

- http://cdo.ncdc.noaa.gov/climatenormals/clim81/NYnorm.pdf – PDF Format.
- http://cdo.ncdc.noaa.gov/climatenormals/clim81/NYnorm.txt – ASCII Format.

Other sites for climate change indicators:

- http://lwf.ncdc.noaa.gov/oa/ncdc.html.
- http://lwf.ncdc.noaa.gov/climate-monitoring/index.php.
- http://lwf.ncdc.noaa.gov/oa/climate/severeweather/extremes.html.
- http://www.nrcc.cornell.edu.
- http://nysc.eas.cornell.edu/ with NYC summary at:
- http://nysc.eas.cornell.edu/newyork_c20.html.

Websites for sea level rise data, tides and currents, and extremes:

- http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ny.
- http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic±Tide±Data.
- http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic%20Tide%20Data&state=New±York&id1=831&id2=851&id3=905&id4=906300&id5=906301&id6=906302&id7=9063032.
- http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8518750%20The%20Battery,%20NY&type=Extremes.