Climate Ready Boston?: Identifying indicators to evaluate the City of Boston's efforts to implement its climate change adaptation initiatives

by

Kara Runsten

B.A. in Public Policy
Stanford University
Stanford, California (2013)

Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degree of

Master in City Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2018

Author____
Department of Urban Studies and Planning
May 22, 2018

Certified by ____
Professor Lawrence Susskind
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by____
Professor of the Practice, Ceasar McDowell
Chair, MCP Committee
Department of Urban Studies and Planning

Climate Ready Boston?: Identifying indicators to evaluate the City of Boston's efforts to implement its climate change adaptation initiatives

by

Kara Runsten

Submitted to the Department of Urban Studies and Planning on May 22, 2018 in partial fulfillment of the requirements for the Degree of Master in City Planning

Abstract

As a leader in municipal climate change adaptation, the City of Boston has recently updated its climate projections, completed a climate vulnerability assessment, and identified several resilience initiatives. To understand whether these initiatives are leading to a less vulnerable, more resilient Boston, I offer a set of indicators the City can use to start monitoring and evaluating its adaptation efforts.

To create these indicators, I analyzed Boston's vulnerability assessment and resilience plans to understand the types of hazards, risks, and actions the City intends to emphasize. I also interviewed the authors of six recently published indicator frameworks for urban resilience developed by other cities, federal agencies, and nongovernmental groups. I combine the results of these inquiries into an explicit set of 20 indicators that Boston can use with its 2018 *Climate Action Plan* (CAP), and update regularly thereafter. For each indicator, I identify a specific proxy metric and data source and include details on data collection, available scales, and limitations. Because many of my indicators are high-level and citywide, I also include sub-metrics that the City may use for a more in-depth analysis on the impacts of preparedness actions. Finally, I present several key findings for Boston and other cities thinking about creating, publishing, and maintaining their own set of indicators.

In addition to helping the city government monitor its efforts, the indicators I provide can be used by Boston citizens to hold elected and appointed officials accountable for their promises to create a more resilient city. Boston has taken a leadership role on climate change issues by positioning itself to be among the first cities (in the U.S. and internationally) to publish a monitoring and evaluation framework it will use to track the success of its adaptation efforts.

Thesis Supervisor: Lawrence Susskind
Title: Ford Professor of Urban and Environmental Planning

Acknowledgments

I would like to thank my advisor Professor Larry Susskind and my reader Alison Brizius for their support in my endeavor to use this thesis to connect academia to practice. I have learned so much from their thoughtful input and hope the ideas put forth will prove useful in the City's upcoming *Climate Action Plan* update. I would also like to thank Mia Mansfield for being a wonderful mentor and encouraging me in the thesis writing process. Finally, I am grateful to my family and friends and everyone I met in the 6th floor lounge of Building 9 during my residency there.

Table of Contents

Definitions……………….......……………………………………………………………………5
Part I: Introduction and Background…..7
Part II: The Boston Context……………………………………….……………………….…….20
Part III: Methodological Approach………………………………………………………………30
Part IV: Overview of Boston's Vulnerability Assessment………………………………………34
Part V: Review of Existing Adaptation Indicator Frameworks………………..………………..38
Part VI: Suggested Indicators and Metrics for Boston…………………………………………..69
Part VII: Key Findings and Conclusion……………………………………………………...…113

References…………………………………………………………………………………………128
Interviews…………………………………………………………………………………….134
Appendix A: Interview Guide……………………………………………….………………….135
Appendix B: Compiled List of Indicators from All Frameworks…………...………………….136

Definitions

Adaptation: "The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (Intergovernmental Panel on Climate Change [IPCC], 2012).

Adaptive Capacity: "The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities" (IPCC, 2012).

Evaluation: The "use of social research methods to systematically investigate the effectiveness of social intervention programs" (Rossi, Lipsey, and Freeman, 2004)

Exposure: "The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected" (IPCC, 2012).

Hazard: "The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources" (IPCC, 2012).

Indicator: A quantitative or qualitative variable that measures a particular phenomenon or attribute (adapted from U.S. Agency for International Development [USAID], 2009).

Metric: A standard of measurement (Merriam-Webster, 2018). For the purposes of this thesis, a metric is a proxy measure that is used to operationalize a higher-level indicator.

Monitoring: The consistent, periodic measurement of process and outcome results over time.

Resilience: For the purposes of this thesis, the terms "resilience," "adaptation," and "preparedness" will be used interchangeably; however, readers should note that resilience often is defined to encompass more than the response to climate change events and stresses. The Rockefeller Foundation's 100 Resilient Cities program defines it as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" (100 Resilient Cities, n.d.)

Risk management (outcome) indicator: An indicator that measures the proximal and distal effects of implementing resilience actions. It is often only able to be measured after a shock or compounding number of chronic stressors.

Risk reduction (process) indicator: An indicator that monitors the progress in implementing resilience actions taken in anticipation of the worsening effects of climate-related hazards.

Sensitivity: "The conditions, circumstances, and drivers that make people vulnerable to natural and economic stressors" (IPCC, 2012).

Vulnerability: "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2001). For the purposes of this thesis, vulnerability is the opposite of resilience.

Part I: Introduction and Background

The state of adaptation planning in the U.S.

With increasing numbers of high-profile extreme weather events (including recent hurricanes Harvey and Irma being felt in Houston and the southeast and Winter Storm Grayson along the Eastern seaboard), U.S. cities' ability to adapt to climate change impacts is more important than ever. In recent years, cities have begun to come to terms with the fact that there is a certain amount of climate change that is locked into the system from past accumulation of emissions, even if every city in the world were able to reduce its emissions today. This realization has spurred at least 75 U.S. cities to focus more seriously on adaptation (or resiliency) planning (Innovation Network for Communities, 2017).

Likely impacts of climate change on U.S. communities include flooding, extreme temperatures, drought, wildfires, and severe storms, among others. In the last 10 to 15 years, interest in climate change adaptation has skyrocketed. It has become a major topic in international negotiations (as well as on the state and city-levels), a target of billions of dollars of funding from development agencies, and a source of new projects and initiatives in the nongovernmental organization sector (Vogel et al., 2016). Studies have shown that cities with greater commitment from elected leaders, higher municipal expenditure per capita, and high levels of public awareness of climate change are more likely to start adaptation planning (Shi, Chu, & Debats, 2015).

While there have been many studies and reports about the factors that lead to a city's decision to engage in climate adaptation planning as well as how to craft climate adaptation plans and programs, there has been less research on how to define and evaluate the success of adaptation efforts (Hansen et al., 2013). The lack of research in this area is often attributed to the relative newness of the field and the fact that many city adaptation plans are either currently being developed or have only recently been initiated. Indeed, "there are no widely accepted and used measures for cities to monitor progress in adaptation and to create accountability for implementation" (Innovation Network for Communities, 2017).

Thus, few cities have begun to evaluate their climate change adaptation work. New York City, recognizing that it is on the forefront of this research, published adaptation targets and indicators in its *OneNYC* strategic plan, even though it is still figuring out how to operationalize some of them. Many of the New York City indicators are also not backed up by consistent data. Other cities, like Chula Vista, California have published metrics with their plans, but do not appear to be utilizing them because of time and resource constraints (Plovnick, 2016).

In addition to these city-led evaluation efforts, there are a number of frameworks for assessing urban adaptation initiatives that have been developed by entities like Arup/100 Resilient Cities, the Notre Dame Global Adaptation Initiative (ND-GAIN), the Environmental Protection Agency (EPA), the Urban Sustainability Directors Network (USDN), and U.S. Green Building Council (USGBC)/STAR Communities. Many of these frameworks have recently been launched or are still under development, but they offer insight into how a city might go about monitoring and evaluating its progress.

Overview of monitoring and evaluation

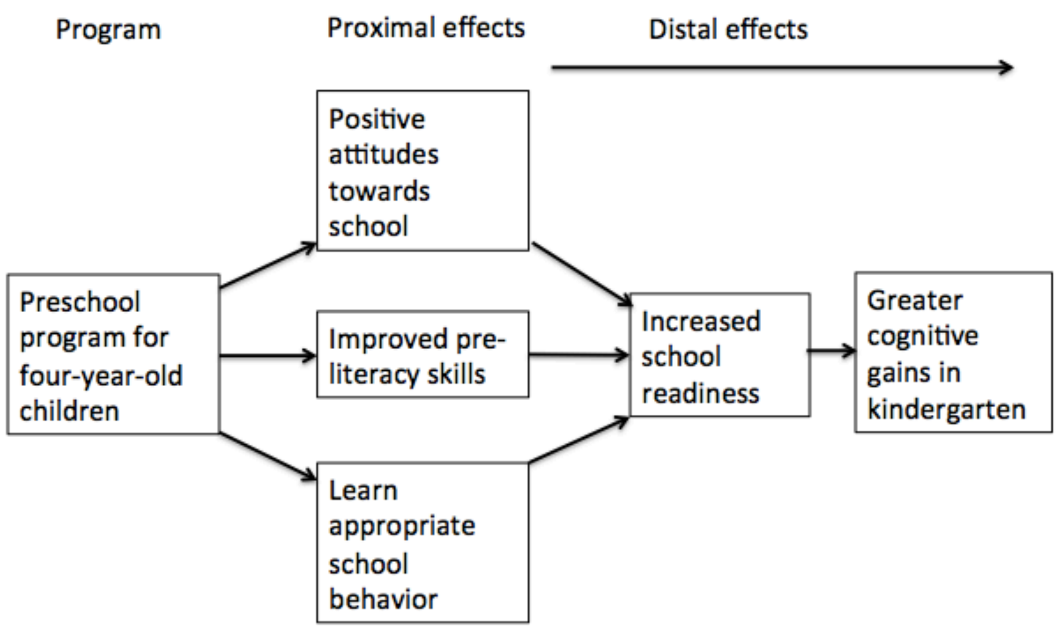
In their seminal text on the subject, Rossi, Lipsey, and Freeman (2004) describe program evaluation as the "use of social research methods to systematically investigate the effectiveness of social intervention programs." Evaluations gauge program performance and assess performance against relevant standards. Possible purposes of evaluation include identifying ways to improve programs, increasing accountability to funders and the public, and generating new knowledge.

The first social programs to be targeted by rigorous evaluation were in the fields of education and health. The topic of evaluation received a large boost from many major federal and private programs launched after World War II that provided "urban development and housing, technological and cultural education, occupational training, and preventive health activities" (Rossi, Lipsey, & Freeman, 2004). Federal agencies and private foundations also made large contributions in family planning, health, and rural development in the Global South. Investment in these programs increased funders' desires to understand their impacts; and thus, program monitoring and evaluation became more widespread (Rossi, Lipsey, & Freeman, 2004).

According to Rossi, Lipsey, and Freeman (2004), there are several contextual factors that should guide the design of an evaluation, including the particular program and circumstances, the purpose and audiences, and the political and organizational environment. Evaluation should provide information on important issues in a timely and meaningful way and communicate it in a form appropriate for its audiences. It should provide information that will be both "useful and used." The authors caution that relatively new programs, like climate change adaptation initiatives, are among the most difficult to evaluate because expected outcomes are often long-term and/or ill-defined. Thus, it will likely be hard to detect any impact on social conditions in the first few years.

Because of this, it is important to distinguish between process and outcome evaluation. Process evaluation is designed to show how effectively a program is being operated and how well it achieves its intended goals. It might address such questions as how many people are participating in a program and whether it is reaching its intended audience. Outcome evaluation, on the other hand, is designed to show how well a program produces a particular improvement in a set of social circumstances. Outcomes can be both “proximal” (near-term) and “distal” (long-term) as demonstrated in Figure 1.

Figure 1: Example of program proximal and distal outcomes (Rossi, Lipsey, & Freeman, 2004)



While proximal outcomes are often not the ultimate goals of a program, they can be important signals of what is to come. If these immediate outcomes are not showing success, this is often a strong sign that long-term outcomes will not be reached by the program as it currently stands (Rossi, Lipsey, & Freeman, 2004). Because the effects of many climate change hazards will largely be felt long-term, assessment of the implementation of adaptation efforts may be dominated in the near-term by process and proximal outcome evaluation, while at the same time identifying indicators for distal outcomes that may describe impacts. Program monitoring, or the periodic measurement of process and outcome results over time, will facilitate both process and outcome evaluation in the long-term by providing consistent and reliable data from which to draw conclusions.

The process of monitoring and evaluation necessitates the identification of appropriate indicators, or quantitative or qualitative variables that provide reliable means to measure a particular phenomenon or attribute (USAID, 2009). While the definitions of metrics and indicators are often disputed, for the purposes of this thesis metrics are the particular quantitative proxy measures that are used to operationalize higher-level indicators. Available metrics are constrained by available data sets. In terms of defining process and outcome indicators, it can be useful to look at an example from the parallel field of climate mitigation. A common outcome indicator for a mitigation program is reduction in greenhouse gas emissions and a common metric associated with this indicator is tons of carbon dioxide emitted (J. Cleveland, personal communication, November 30, 2017). An example of a process indicator is the amount of renewable energy installed, which might be approximated by the megawatts of solar installed citywide (Plovnick, 2016).

In this thesis, process indicators are specifically called "risk reduction" indicators. These indicators monitor the progress in implementing resilience actions taken in anticipation of the worsening effects of climate-related hazards (e.g., the number of trees planted to reduce the risks of extreme heat). These actions are designed to "reduce risk by reducing exposure and sensitivity or increasing recovery potential and adaptive capacity to prepare for expected climatic changes or events" (EPA, 2017). On the other hand, I call outcome indicators "risk management" indicators. These indicators measure the proximal and distal effects of implementing resilience actions (e.g., the prevalence of heat-related illness).

Also important are context indicators, or "indicators which may be useful for understanding the background situation or context related to a specific issue" that "are typically not under the direct control or influence of the entity seeking to use them" (Arup, 2014). Indicators that measure the frequency and intensity of climate hazards are important context indicators because they show how the climate is changing, which provides important information for interpreting the risk reduction and risk management metrics.

In terms of what constitutes a good indicator, Doran (1981) coined the widespread SMART principles that he originally proposed to evaluate corporate goal-setting but can equally be used to craft robust indicators and metrics in the adaptation arena. SMART refers to:

- Specific- target a clear and well-defined attribute
- Measurable- quantify (or qualitatively describe) the attribute
- Assignable- specify who will do it
- Realistic- state what can be achieved given available resources

- Time-related- specify when results can be generated

Embedded in this list of criteria is the importance of creating indicators that are robust as well as practical. Identifying available (or low-cost) data sets and parties that will be able to collect and monitor the metrics associated with indicators can be just as (or more) important than identifying the most appropriate or robust measure. Additionally, programs related to complex problems may require bundles of indicators, as one indicator that adequately describes the whole phenomenon or attribute may be impossible to locate (Plovnick, 2016).

Sustainable development indicators

Another topic that has been researched longer than climate adaptation (and that has some of the same barriers that make it hard to evaluate) is sustainable development. Researchers have been struggling to develop a set of widely agreed upon indicators of sustainability since that concept first became popular in the latter part of the 20th century. There is still substantial debate on the set of indicators that ought to be used. Parris and Kates (2003) conducted a study of some of the more than 500 efforts to measure sustainable development and concluded that no indicator sets are universally accepted. Bossel (1999) notes the problems in developing sustainability indicators start with the issue of adequately defining “sustainable development.” In a parallel fashion, the concepts of “vulnerability” and “resilience” have many different meanings in today’s literature on climate change adaptation (Gallopín, 2006; Downing et al., 2005). For the purpose of this study, and for the sake of simplicity, my thesis assumes that resilience is the flip side of vulnerability (IPCC, 2001).

Meadows (1998), who explores the creation of sustainable development indicators in particular, notes that most groups that publish lists of characteristics of good indicators include such items as clear in value, clear in content, compelling, policy-relevant, feasible, sufficient, timely, appropriate in scale, democratic, supplementary, participatory, hierarchical, physical, leading, and tentative. She notes that strict adherence to these high standards makes it almost impossible to come up with indicators. Instead, she suggests making the task manageable by concentrating on just ten indicators that seem important, and subsequently refining this set. In addition, Moldan, Janoušková, and Hák (2012) emphasize the importance of setting targets and measuring the distance to those targets as a key component in developing sustainability indicators.

While no indicator frameworks for sustainability are universally accepted, there are several frameworks that have caught on more than others, depending on which scale of measurement is desired. The Global Reporting Initiative and the Carbon Disclosure Project provide a framework for organizations and cities to report on climate change and carbon emissions indicators. The USGBC has two rating programs related to sustainability that are particularly widespread in the United States. While both measure and score sustainability, the Leadership in Energy and Environmental Design (LEED) system rates buildings, while the STAR Communities system rates communities.[1] In addition, several city sustainability plans like the Sustainable DC Plan include specific targets to be tracked via indicators (Plovnick, 2016).

[1] The STAR Community Rating System includes climate change adaptation as one of its subsections. See Part V of this thesis for a discussion of this framework.

Current municipal efforts to create climate adaptation indicators

While adaptation programs, and thus efforts to evaluate them are relatively new, the increasing numbers of academic papers and evaluation frameworks in recent years highlight their importance and popularity. Ford, Berrang-Ford, Lesnikowski, Barrera, and Heymann (2013) develop a typology of methods to track adaptation at the national level. They highlight the need for evaluation, noting "As adaptation financing increases and initiatives are developed, the need to monitor and evaluate progress on climate change adaptation is being increasingly recognized, as a means of evaluating the effectiveness of adaptation support, informing governance at various levels on adaptation needs, justifying funding allocation, and communicating to the public on adaptation." Similarly, Preston, Westaway, Dessai, and Smith (2009) suggest that climate change adaptation evaluation is important to ensure reductions in vulnerabilities, learn and adaptively manage, and promote accountability.

Climate adaptation experts agree that municipal evaluation of these efforts is lacking. Vogel et al. (2016) conducted 17 intensive case studies of cities taking climate preparedness actions and found that while monitoring and evaluation is often touted as a key piece of these planning efforts, most cities do not have a formal evaluation system, and none are comprehensive in nature. A report by the USDN (2016) identified that a number of nongovernmental groups are developing adaptation indicators, but that they lack "consistent, organized input from urban adaptation practitioners." Plovnick (2016) analyzed climate adaptation plans in nine large coastal cities, finding that only two included indicators in their climate adaptation plans, and only one is actually reporting on them. Of the 37 indicators from these two cities, only five are risk management (outcome) oriented. The rest are risk reduction (process) indicators that measure the degree to which city actions are underway.

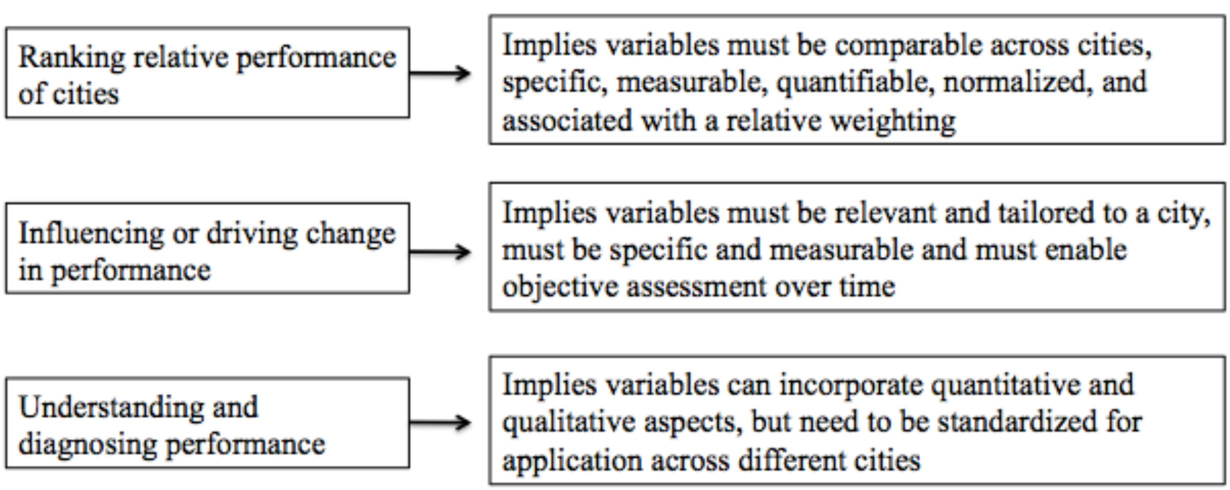
While most published city plans in the U.S. do not include adaptation indicators, New York City's *OneNYC* plan is a notable exception. This indicator set appears to be particularly promising for cities looking to select and track their own measures because it contains indicators that have been approved by a municipality despite data limitations and other constraints common to cities.

Other non-municipal attempts to create indicator frameworks like those generated by 100 Resilient Cities and Arup's recently released City Resilience Index, ND-GAIN's Urban Adaptation Assessment, USDN's guide to selecting urban adaptation indicators, EPA's Multi-Sector Evaluation Tool for Identifying Resilience Opportunities, and USGBC/STAR Communities' sustainability rating system may also provide promising indicators and metrics for cities to consider.

Plovnick (2016) identifies three categories that these non-governmental and city-driven frameworks fit into. These include **top-down frameworks,** which involve external evaluation of city efforts; **bottom-up frameworks** where cities conduct the analysis with proscribed or internally developed metrics, and **guiding frameworks** that give cities instructions on how to craft their own indicators. I gained insight from analyzing examples from each type of framework before making suggestions for Boston in Part VI of this thesis. Boston City staff communicated a desire to develop indicators specific to the local context, suggesting that the latter two types of frameworks are most relevant for my purposes.

These three types of frameworks map onto what Arup (2014) considers the three primary motivations for developing adaptation indicator sets (see Figure 2). Top-down frameworks are often motivated by the desire to rank relative performance of cities, whereas bottom-up and guiding frameworks are often motivated by the desire to understand and influence performance. City-born indicator sets like NYC's (that fit into the bottom-up framework category) are almost always related to the second motivation listed in Figure 2 (i.e., influencing change), with measures "tailor-made to their needs" (Arup, 2014). Julie Wormser, Principle of North Cambridge Consulting and long-time City of Boston partner on climate preparedness issues, emphasized the importance of this motivation, noting that developing indicator sets that "drive action" should be the main focus of the City's efforts on climate change adaptation monitoring and evaluation (J. Wormser, personal communication, January 10, 2018).

Figure 2: Motives for developing indicators (Arup, 2014)



Challenges to climate adaptation monitoring and evaluation

There are several barriers to developing adaptation indicators identified in the literature on the subject. These include a lack of agreement over what defines success, long time-horizons and shifting baselines, potential for maladaptation, invalid measures, and resource constraints (Plovnick, 2016; USDN, 2016; Ford, Berrang-Ford, Lesnikowski, Barrera, & Heymann, 2013; Pringle, 2011). Each are explained in more detail below.

Defining success

Terms like "vulnerability" and "resilience" have different meanings to different groups and localities. Definitions can vary based on the hazards facing a particular community as well as community values. Without common definitions of what constitutes a resilient city, it is hard to figure out what measures will indicate success. This, combined with the relative newness of monitoring and evaluation of these efforts, means that practitioners and academics do not have a robust list of potential indicators for cities to use.

Long time-horizons and shifting baselines

The impact of many adaptation initiatives might not be discernible for a long period of time. The success of many measures to combat sea level rise, for example, might not be apparent until a major storm event or until sea levels have risen by a significant amount. Conditions will also change over time (i.e., baselines will shift) because climate change is a dynamic phenomenon. Knowing what success means in the face of constantly changing climate hazards is a difficult task.

Potential for maladaptation

Because urban systems are complex, it can be hard to detect if adaptation initiatives have unintended negative impacts (e.g., disproportionately burdening communities of color).

Invalid measures

Metrics are proxies for the phenomenon or characteristic that one would like to measure, which means they may not accurately reflect the success of a program. For example, measuring the number of feet of flood mitigation barriers installed may not accurately reflect a reduction in flood risk if the barriers are not in the appropriate locations to block flood pathways.

Resource constraints

Just because a community discovers a robust indicator to track a particular measure of success does not mean that it is feasible to monitor with the resources it has available. Robustness must be balanced against practicality in terms of staff capacity, money, data availability, and time.

It will be important to keep these barriers in mind when crafting a set of indicators for the City of Boston to use in monitoring and evaluating implementation of its climate adaptation initiatives.

Part II: The Boston Context

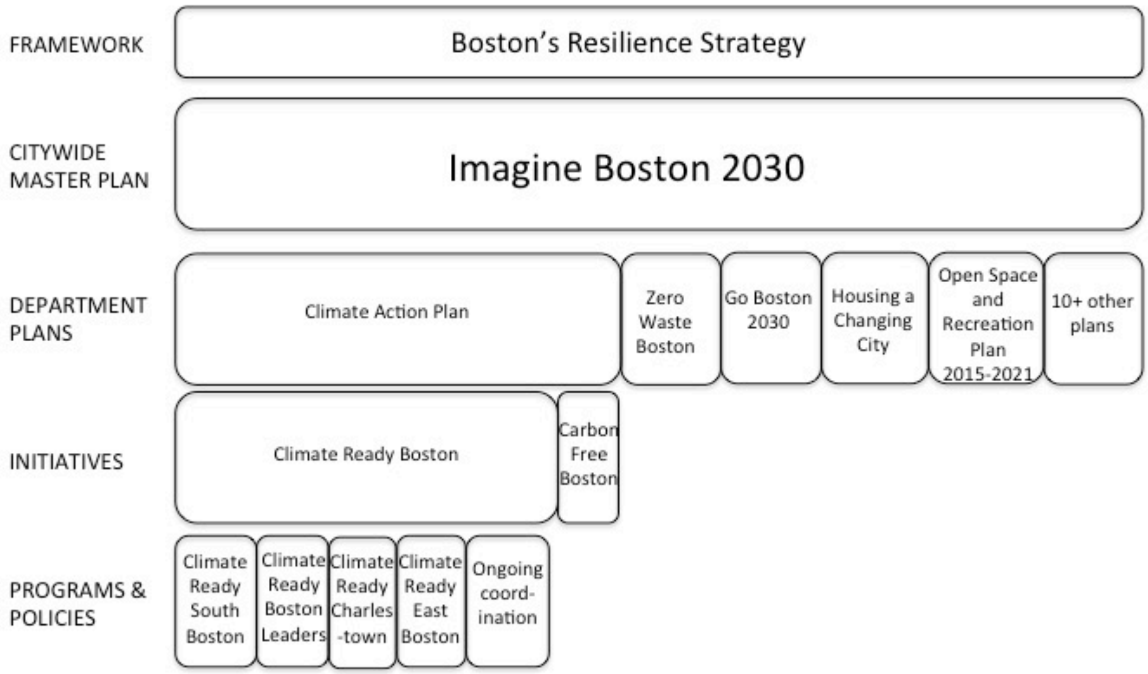
Overview of Boston's climate change adaptation efforts

In recent years, under the direction of Mayor Martin J. Walsh who took office in 2014, the City of Boston has been ramping up its climate change preparedness efforts, which began during Mayor Thomas Menino's administration. *Imagine Boston 2030,* the City's first comprehensive plan in 50 years, is perhaps Mayor Walsh's signature achievement of his first term. This document outlines the key goals that Boston would like to accomplish leading up to its 400th birthday, including "encouraging continued economic growth, becoming more affordable and equitable, and preparing for climate change" (City of Boston, 2017f).

In support of the latter goal, Boston has been working to reduce its greenhouse gas emissions and become more resilient since a 2007 executive order that instigated action (City of Boston, 2007). In 2011, Boston released its first plan dedicated to addressing these issues entitled *A Climate of Progress* (City of Boston, 2011). The *2014 Climate Action Plan (*CAP*) Update* continues this work. These efforts are housed in the Environment Department and branded as Greenovate Boston.

As part of this climate action work, the City launched an effort specifically aimed at climate adaptation and preparedness called Climate Ready Boston (CRB). A chart that describes how CRB fits within all of the City of Boston's planning processes can be seen in Figure 3 below. This image makes it clear that the purpose of CRB is to operationalize the City's high-level climate preparedness goals identified in *Imagine Boston 2030* and the *2014 Climate Action Plan Update*.

Figure 3: Relationship between the City's climate work and other efforts (image adapted from Greenovate Boston)



CRB released its full foundational report in December 2016, which includes updated climate projections, a vulnerability assessment (discussed further in Part IV), five overarching goals, and 39 recommended resilience initiatives to address these vulnerabilities (City of Boston, 2016b). While overall project management is situated within the Environment Department, the report identifies at least 10 other City departments that will be involved in carrying out the recommendations. For example, the Boston Public Health Commission (BPHC) is tasked with conducting outreach campaigns to facilities serving vulnerable populations, the Boston Planning and Development Agency (BPDA) is tasked with crafting new development guidelines for resilient buildings, the Office of Emergency Management (OEM) is tasked with creating a new heat emergency plan, and the Boston Water and Sewer Commission (BWSC) is tasked with developing design guidelines for green infrastructure. The Office of Workforce Development, Office of Economic Development, Office of Resilience and Racial Equity, Department of Parks and Recreation, Boston Transportation Department, and the Office of Neighborhood Services also play key roles in carrying out actions. Finally, the report recommends that the City coordinate with state-level agencies like the Massachusetts Department of Transportation and private communications and energy companies, especially related to matters of infrastructure resilience.

In recognition of climate change as a cross-cutting issue, several other City departments have incorporated climate preparedness as a key component of their planning documents. Released in July 2017, *Resilient Boston* (created with the support of the Rockefeller Foundation's 100 Resilient Cities program) focuses on racial equity and identifies several actions related to the intersection of equity with climate readiness (City of Boston, 2017h). Released in March 2017, the *Go Boston 2030 Vision and Action Plan*, the citywide transportation plan, identifies the need for analysis of climate impacts when issuing City transportation contracts (City of Boston, 2017e). Finally, many of the BPDA's neighborhood planning processes are beginning to incorporate climate impacts and preparedness into their thinking. The final drafts for the Dot Ave and JP/Rox plans include actions for resiliency, and the Glover's Corner plan emphasizes climate as a main consideration (City of Boston, 2018b).

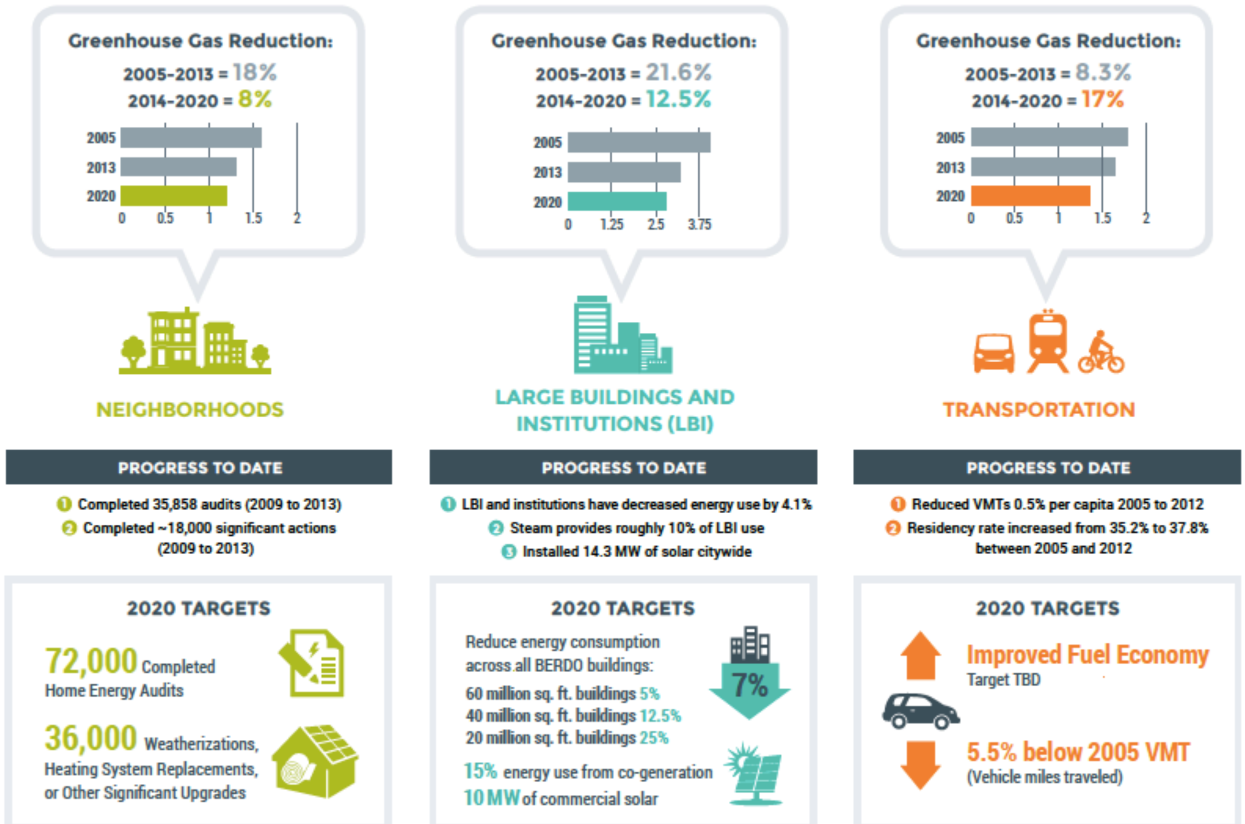
City data collection and monitoring efforts

In addition to the proliferation of planning documents, the City has also started to explore tracking its performance in new ways and publishing open source data on its website. Launched in April 2017, the "Analyze Boston" webpage currently houses about 130 data sets (City of Boston, 2017a). It includes data collecting efforts like CityScore that tracks key performance metrics, including time taken to fill potholes and emergency services response time (City of Boston, 2018a).

Additionally, the *Imagine Boston 2030* webpage includes a "metrics dashboard" which is meant to be updated annually with measures related to the goals in the report. For example, in the area of "walkability" the goal is to "increase Walk Score® rankings by neighborhood, including reducing the number of households classified as car-dependent by half" (City of Boston, 2017g). The dashboard displays Boston's current Walk Score® and includes informative maps and charts.

The "Reduce Emissions" section of this dashboard presents the current overarching goals for climate change mitigation in both *Imagine Boston 2030* and the 2014 CAP update, namely to reduce emissions by half by 2030 (from 2005 levels) and become carbon neutral by 2050. More specific mitigation goals, targets, and metrics are included in the 2014 CAP update (see Figure 4).

Figure 4: 2014 CAP update progress and targets by sector (City of Boston, 2014a)



One of the sections on the dashboard also attempts to address adaptation. The identified goal is to “reduce economic loss and number of people exposed to climate-related flooding,” and it includes baseline metrics from the CRB vulnerability assessment on the number of people, percent of land, and economic value of property exposed at nine inches of sea level rise (City of Boston, 2017g). It is unclear how the City plans to update these numbers year to year; the analysis that went into producing them is quite extensive and involves multiple data sets that would need to be revised. Also, exposure “by definition does not consider site-specific conditions such as structure elevations and flood elevations, but simply identifies structures that may be exposed to a number of flood impacts such as structural damage, contents loss, property value degradation, and access issues" (City of Boston, 2016a). Thus, these numbers do not include benefits from site-specific adaptation measures. When developing the dashboard, there were conversations about including additional indicators that might provide more insight into adaptation progress, including amount of tree canopy and economic recovery time after a severe weather event, but these were left off the final product because of data limitations and/or the fact that the metric values might not change from year-to-year (e.g., there might be a year without an extreme weather event) (M. Mansfield, personal communication, January 12, 2018).

Previous attempts to develop indicators for Boston's climate adaptation efforts

In recent years, there have been efforts related to how Boston, specifically, might establish indicators to evaluate its progress on climate adaptation. In 2014, a Fellow in the Environment Department conducted a study that resulted in a memo on this topic. The Fellow identified the need for multiple indicators because of the complex impacts of climate change on many sectors. As such, she identified several indicators under nine categories (Deas, 2014). These indicators are listed in Table 1 below.

Table 1: List of indicators from a memo drafted for the City of Boston Department of Environment (Deas, 2014)

Category	**Indicator**
Government leadership	Number of City plans referencing climate change preparedness.
Education and public outreach	Number of individuals pledging to make key preparedness measures in their homes and businesses.
Critical services	• *Water and wastewater:* Volume of combined sewer overflows. • *Energy facilities:* Percentage of electricity generated within the 500-year floodplain able to remain online after a 500-

	year flood event. • *Liquid fuels:* Percentage of gas stations with quick-connects for generators. • *Telecommunications:* Percentage of Boston's telecommunication system transitioned to fiber optics or coaxial cables. • *Transportation infrastructure:* Number of or percentage of transportation assets adapted for climate change resilience. • *Food systems:* Number of grocery stores or food markets per square mile, with special attention to low-income neighborhoods. • *Natural systems and green infrastructure:* Square miles of green space or vegetative cover.
Building stock	Number of renovations or new construction that incorporate resilience measures.
Coastal risks and flooding	Funding secured for flood protection projects.
Heat risks	Percentage or number of buildings with cool or green roofs.
Emergency management- the public sector response	Number of emergency workers undergoing City coordinated hazards training.
Emergency management- the private sector response	Number of businesses with disaster continuity plans.
Public health	Percentage of adults who meet current federal physical activity guidelines *or* percentage of population with medical insurance.

In January 2015, SeaPlan and the Boston Harbor Association, in collaboration with the City of Boston, released a report called *Draft Climate Adaptation Indicators Framework for the City of Boston, MA*. The report identifies six high-level indicators and potential ways to think about measuring them (see Table 2).

Table 2: List of indicators from *Draft Climate Adaptation Indicators Framework for the City of Boston, MA* (Lipsky & Starbuck, 2015)

Indicator 1	The degree to which planning, capacity and coordination to effectively prepare for and respond to climate change and extreme weather events is in place. Climate change is mainstreamed into city plans and programs. Finances and resources are available to adequately address climate change and related events. Government is able to continue operating and providing critical services during climate-related events.
Indicator 2	The degree to which information and data are available and used to adequately address climate change and related events.
Indicator 3	The degree to which the public and specific stakeholders are aware of and provide input into preparing for climate change and related events.
Indicator 4	The degree to which Boston residents are vulnerable to climate-related health risks and have access to needed services and amenities.
Indicator 5	The degree to which natural ecosystems in Greater Boston are able to withstand impacts of climate change and related events. Green/gray infrastructure is expanded to address climate vulnerabilities. Protective infrastructure (e.g., ecosystem components and coastal infrastructure - dikes, levees and seawalls) exist and are adequate to protect against climate-related events and risks.
Indicator 6	The degree to which public/private buildings and utilities are adequately prepared to withstand climate change and climate-related events.

Despite these efforts, the City has not yet actively pursued implementing any of these indicators and did not include any indicators or metrics in the 2016 CRB report. Boston's Environment Department leadership notes that previous evaluative studies have limitations that make them hard for the City to implement. For example, some prioritized comprehensiveness over practicality and/or went beyond locally appropriate concerns and considerations (C. Spector, personal communication January 24, 2018). Others did not identify data sources. There has been significant progress made by the City in assessing vulnerability and crafting and implementing resilience actions in the past couple years, meaning that a reassessment of previously developed indicator sets to determine their applicability and connectedness to current efforts is needed.

In an interview, Commissioner of the Environment Carl Spector outlined several key considerations that those developing indicators for Boston's adaptation initiatives should keep in mind. Overall, indicators should be both meaningful and relatively easy to track, implying that data should either already be tracked or be readily attained. He also emphasized the importance of developing a small set of indicators to start with, trying them out for a few years, and then re-evaluating them based on this experience. He noted that more indicators could be added over time to build toward a comprehensive set, but that efforts right now should be focused on identifying a few that are "reasonable places to start" and explaining why they are reasonable. Finally, he pointed out that setting targets is not the priority at this stage, unless there are very clear standards already developed in the literature (e.g., EPA quality standards). Identifying the general direction that the quantitative variable should move is important (e.g., number of flood protection measures should increase), and targets can be added in later once the city has more information from implementing resilience actions and metrics (C. Spector, personal communication, January 24, 2018).

Renewed interest in adaptation indicators

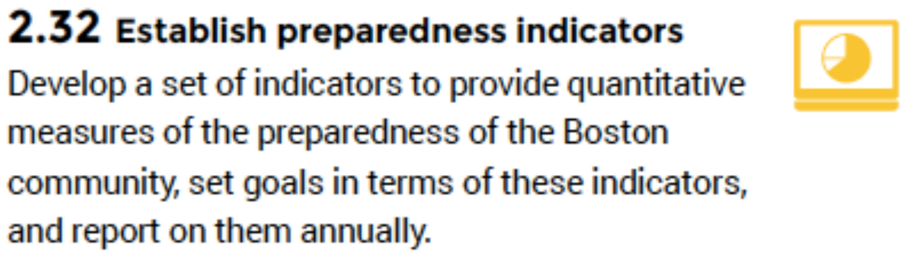
There is renewed interest in the topic of indicators at City Hall. As mentioned previously, the Environment Department is currently readying itself to update its CAP. This update will need to report on progress toward implementing the City's climate adaptation initiatives since the last update in 2014 and since the 2016 CRB report. The last CAP update in 2014 noted the following:

> *"Unlike climate change mitigation, where the total amount of greenhouse gases emitted serves as the overriding measure of progress, there is no single indicator that measures*

climate preparedness. The City will continue to monitor measures of risk, including sea-level averages, average annual temperature, number of days over 90 degrees Fahrenheit, and precipitation patterns. Some useful metrics are available in specific areas, such as the size of the city's tree canopy, the proportion of impermeable pavement, and the number of people who have participated in outreach programs. The City is working with local researchers and other cities to understand and develop better indicators of urban and community preparedness that can be used to establish more concrete goals" (City of Boston, 2014a).

Furthermore, Action 2.32 (one of 28 actions identified in the "climate preparedness" section of the plan) is dedicated to establishing preparedness indicators (see Figure 5).

Figure 5: Action 2.32 (City of Boston, 2014a)



2.32 Establish preparedness indicators

Develop a set of indicators to provide quantitative measures of the preparedness of the Boston community, set goals in terms of these indicators, and report on them annually.

As referenced above, the sections of the 2014 CAP pertaining to mitigation identify specific targets, goals, and metrics while there is no such information in the climate adaptation section. I think it is reasonable to assume that the public will expect adaptation indicators to be included in the next CAP update. In this thesis, I move a step farther than previous studies developed for the City by recommending specific indicators and metrics and connecting them to existing data sets with an eye toward practicality of implementation.

Part III: Methodological Approach

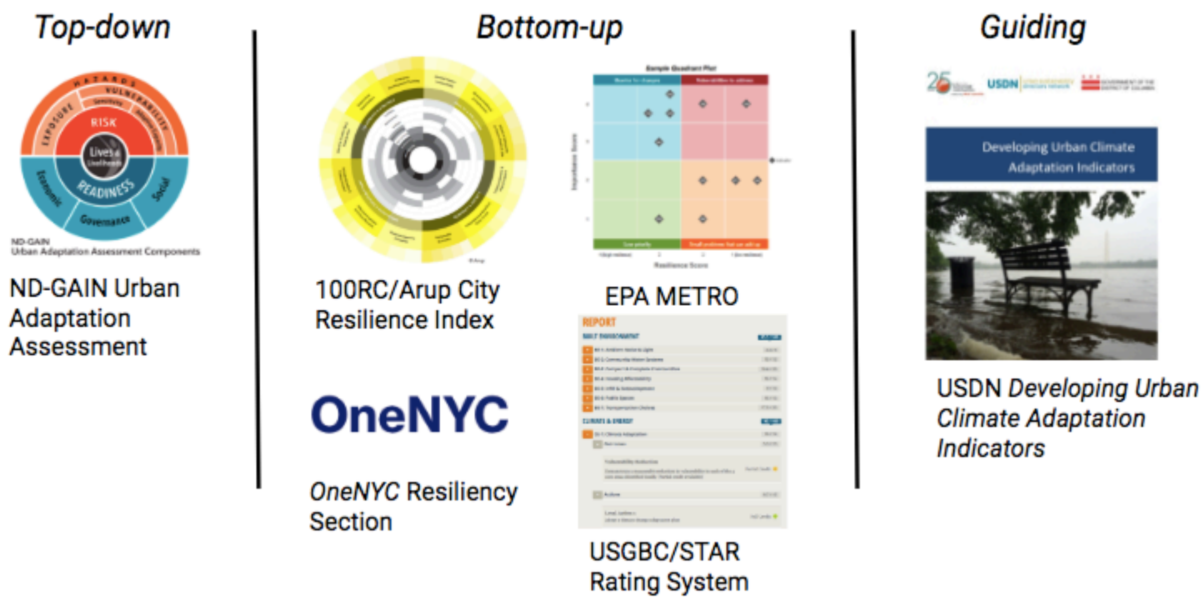
To create a set of indicators for the City of Boston to include in the next CAP update, I took a four-pronged approach that included reviewing Boston's climate vulnerability assessment, analyzing major frameworks in the field and interviewing experts associated with these frameworks, ensuring that each of the City's five resilience goals from the CRB report is well-represented, and identifying potential data sets. These steps are further outlined below.

First, I used the City of Boston's vulnerability assessment, along with interviews with City staff and other Boston resiliency experts (i.e., funders, advocates, and consultants) to ascertain the City's main climate vulnerabilities and resilience goals, gather information about past efforts to identify metrics, and glean advice for how to increase the likelihood of the City adopting the indicators I recommend through this report.

Next, I undertook an analysis of six indicator frameworks developed by cities and other groups (see Figure 6). I selected these frameworks based on their focus on the city level, their popularity, their potential application to Boston, and their representativeness of the three types of frameworks discussed in Part I (top-down, bottom-up, and guiding). In a study conducted by Plovnick (2016), New York City is the only large coastal city in the U.S. that currently publishes indicators related to climate change adaptation (through annual updates to its *OneNYC* comprehensive plan). As a peer city to Boston, reviewing this framework was a high priority because of its ability to identify the types of indicators that a large coastal city might be able to publish and track. Boston officials were involved in the development of USDN's report *Developing Urban Climate Adaptation Indicators*, EPA's Multi-Sector Evaluation Tool for

Identifying Resilience Opportunities, and USGBC/STAR Communities' rating system, which made these prime candidates to include. Finally, City officials mentioned interest in learning more about the City Resilience Index (developed by Arup and the Rockefeller Foundation's 100 Resilient Cities) and ND-GAIN's Urban Adaptation Assessment.

Figure 6: Six indicator frameworks reviewed



All of these indicator frameworks are less than five years old, emphasizing the newness of this line of inquiry and its current importance to cities. USGBC/STAR Communities' rating system is the oldest; its first city was certified city in 2013. ND-GAIN's assessment is the newest, with its online platform expected to roll out later this year, although pilot assessments have already been completed in several cities (P. Regan, personal communication, January 11, 2018). I conducted semi-structured interviews with staff members involved in each of these projects to identify how they constructed the evaluation framework, why they chose the specific indicators they did, and how they went about measuring them, although specifics varied by interview (see Appendix A for an interview guide). Through these conversations, I was able to compile a list of important considerations as I developed a set of indicators for Boston.

I also compiled a spreadsheet of all the indicators listed in each framework and categorized them based on the structure of the City's vulnerability assessment, first by risk and then by association with people, infrastructure, buildings, and economy (see Appendix B).[2] Many indicators applied to more than one hazard, so they were included in more than one place. Indicators related to education & engagement and information & governance were listed separately because they were not hazard-specific. This categorization exercise helped me uncover the overlap between Boston's climate risks as identified in the vulnerability assessment and those indicators selected by the six frameworks reviewed. Subthemes emerged within each of the categories and are identified in the spreadsheet. I gave indicators included by multiple frameworks more weight in my final recommendation process, and I identified how many of the frameworks included such a measurement in my description of the indicator in Part VI of this thesis. One caveat is that because many of these frameworks were developed through reviewing other indicator sets, replication across frameworks may indicate a prevalence of groupthink in the field rather than totally independent valuation of each indicator.

Next, I re-categorized promising indicators based on the five goal areas identified in the CRB report (which closely resemble the categories in the vulnerability assessment): updated climate projections, prepared and connected communities, protected shores, resilient infrastructure, and

[2] Indicators from Lipsky & Starbuck (2015) and Deas (2014) are also included, along with suggested metrics identified (though not published) via Imagine Boston 2030. Hazard risk indicators from Susskind, Rumore, and Field (2015) are also included.

adapted buildings. This re-categorization was necessary to match the structure of the CAP update and ensure that each of Boston's goals is well represented with both risk management and risk reduction indicators.

Finally, I conducted research online and through conversations with City staff to understand which indicators from the list above might already have data sets (or proxy data sets) associated with them. If data does not exist but seems relatively easy to collect based on existing City activities or processes, I included the indicator and identified how that data might be collected in Part VI.

Part IV: Overview of Boston's Vulnerability Assessment

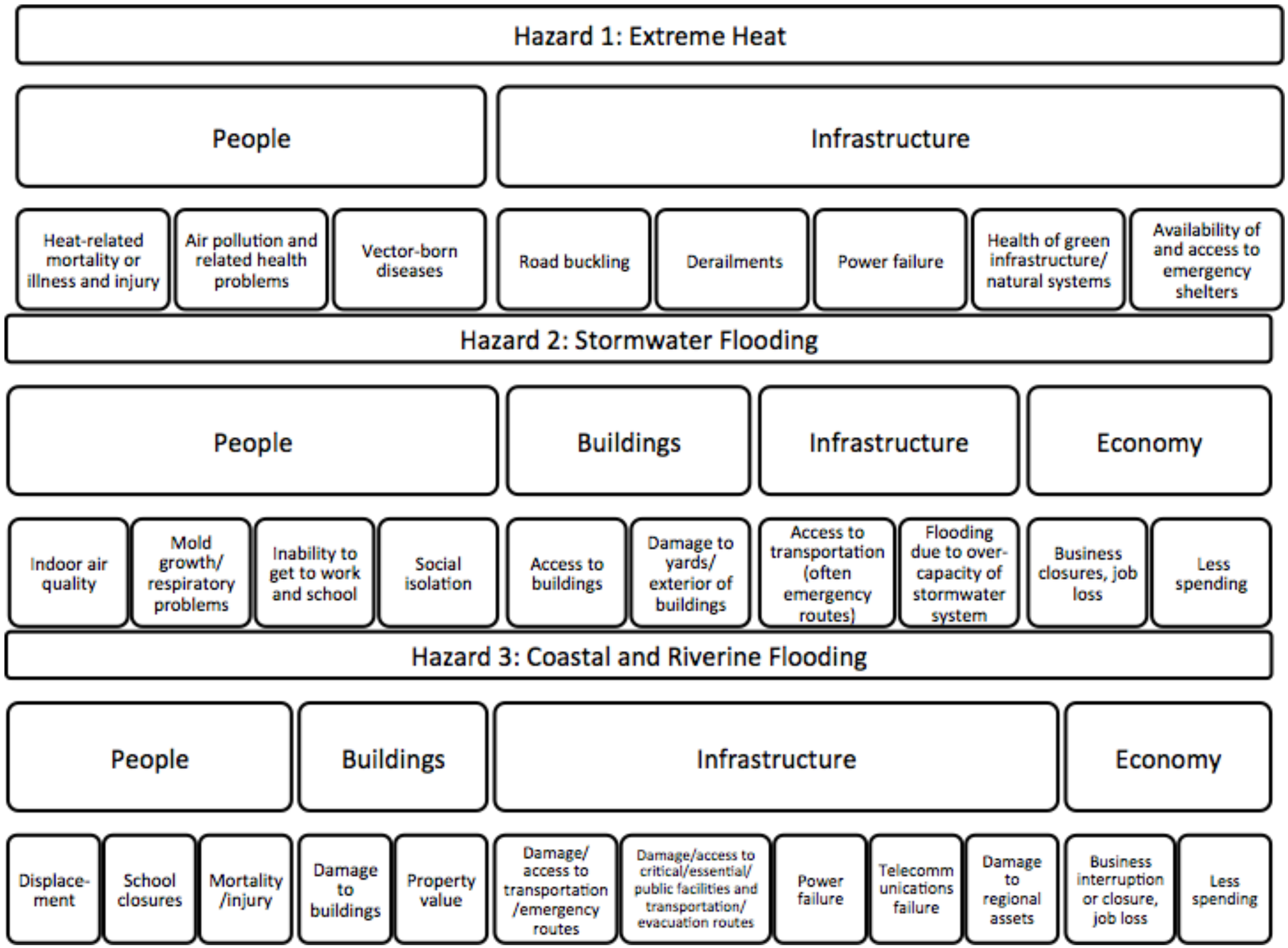
Boston's vulnerability assessment identifies three main climate hazards: extreme heat, stormwater flooding, and coastal/riverine flooding. Each of these hazards impacts people, buildings, infrastructure, and economy in different, but often overlapping, ways.

Extreme heat is a chronic stress that the city experiences every year, and, as such, may be particularly amenable to monitoring and evaluation. Climate change will cause average temperatures to rise and increase the duration, frequency, and intensity of extreme heat events. Boston residents can expect the number of days above 90 degrees Fahrenheit to as much as quadruple (from 11 to as many as 40 days) by 2030. The urban heat island (UHI) effect, or the higher temperatures observed in densely developed areas, creates differentiated risks of extreme heat throughout Boston, with neighborhoods with little tree canopy often at greatest risk. The vulnerability assessment is careful to point out, however, that the whole city will be exposed to the impacts of extreme heat to some extent. It identifies negative health impacts (e.g., mortality and illness) and infrastructure problems (e.g., road buckling and train derailment) as key vulnerabilities that climate change will exacerbate in the future. The vulnerability assessment did not analyze heat risks to buildings and the economy because of a lack of available data (City of Boston, 2016b).

Stormwater flooding due to increased precipitation is another key hazard for Boston. Rainfall could increase by 20 percent by 2060, which would mean water levels exceeding the height of city curbs during storms. Due to limited data, the vulnerability assessment only assessed frequent stormwater flooding, or 10-year, 24-hour events. The assessment asserts that the existing stormwater system struggles to convey the current 10-year, 24-hour precipitation event, much less those of greater intensity (City of Boston, 2016b). Evidence of this was recently experienced during Winter Storm Grayson, where many places in South Boston experienced flooding due to stormwater system problems (City of Boston, 2018c). Upgrades to the system combined with green infrastructure solutions will be needed to combat stormwater flooding and reduce the risks associated with it (e.g., decreased access to buildings and transportation) (City of Boston, 2016b).

Finally, coastal and riverine flooding is a grave risk for Boston and is "expected to lead to the most significant climate hazard consequences" (City of Boston, 2016b). According to the assessment, sea levels could rise to three feet or more during the second half of this century, meaning more daily nuisance flooding as well as more flooding during extreme weather events (e.g., the one percent annual chance coastal storm). Vulnerabilities associated with this hazard include such risks as displacement due to home loss, physical damage to buildings, power failure, and business interruption or closure, among others (City of Boston, 2016b). The vulnerabilities mentioned in the assessment are summarized in Figure 7 below.

Figure 7: Summary of hazards and vulnerabilities identified in the CRB report



The indicators I suggest in Part VI are informed by this analysis. The risk management indicators included in my suggested list are proxies for many of the risks identified in Figure 7. The risk reduction indicators, on the other hand, primarily measure progress on implementing the 39 resilience actions included in the CRB report that address these vulnerabilities. All are related to the City's overarching resilience goals: updated climate projections, prepared and connected communities, protected shores, resilient infrastructure, and adapted buildings.

Part V: Review of Existing Adaptation Indicator Frameworks

I conducted an analysis of six existing indicator sets to aid in producing my suggested set for Boston. These frameworks fit into the three categories discussed in Part I, namely top-down, bottom-up, and guiding. An overview of each framework is included below along with guidance I gleaned from their creators about crafting an indicator set for Boston.

Top-down frameworks

Top-down frameworks are not created with specific city goals and circumstances in mind. Instead, a group picks a set of indicators to apply to many different cities and the final result is often a ranking of the cities examined. These features can be disempowering to cities hoping to make progress in this arena; thus, they should not be the primary assessment tools utilized to understand performance. Nevertheless, some of the indicators and other components of these frameworks may be applicable to a specific municipality, so reviewing them can be helpful to cities crafting their own assessments.

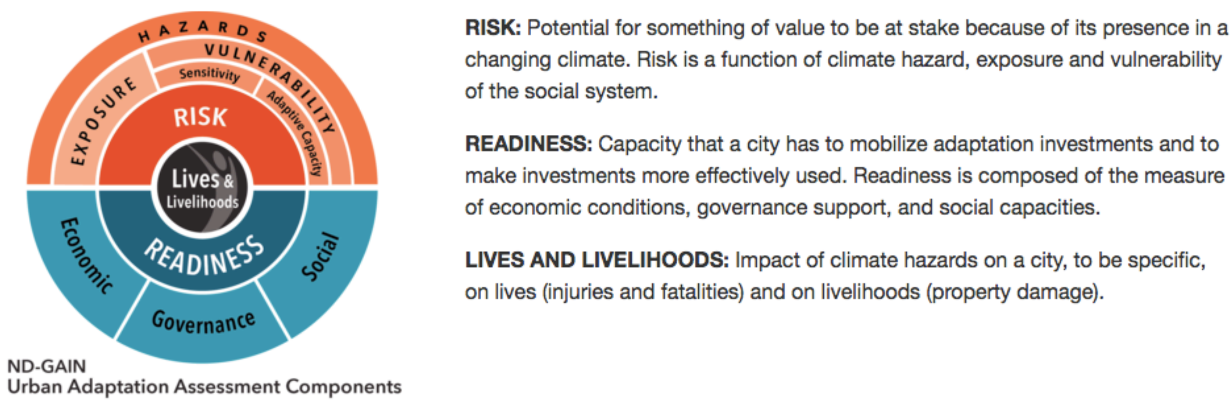
ND-GAIN's Urban Adaptation Assessment

Overview

ND-GAIN, originally known for its country index that ranks nations based on their vulnerabilities and readiness to adapt, is in the process of expanding that work to the city level via the Urban Adaptation Assessment (UAA) (ND-GAIN, 2018). Recognizing a need to measure cities' capacity to take on adaptation action in addition to understanding climate risks, the ND-

GAIN team developed a framework to understand these complex concepts and hopes to apply it to 278 cities in the U.S. with populations above 100,000 people (see Figure 8).

Figure 8: Urban Adaptation Assessment components (ND-GAIN, 2018)



In a nutshell, ND-GAIN sees risk as a function of climate hazard (e.g., inland flooding measured through monthly maximum consecutive 5-day precipitation), sensitivity (e.g., percent of area that is impervious surface), adaptive capacity (e.g., percent of population with health insurance), and exposure (e.g., percent of population living in flood plains). These types of risks are measured by a variety of metrics (see Figure 9) and aggregated into a score that ranks cities on their overall vulnerability and readiness to adapt. The scores will be updated annually and reported out on a publically available website. The project is still under development, but the team hopes to release the first iteration soon (P. Regan, personal communication, January 11, 2018).

Figure 9: ND-GAIN's draft framework with indicators (ND-GAIN, 2018)

COMPONENTS OF RISK

VULNERABILITY Measures the degree to which an urban area is unable to cope with the impacts of climate hazards on its human population.

HAZARD Potential occurrence of a biophysical event, trend or impact caused by climate change	SENSITIVITY Extent to which an urban area will be affected by, or responsive to, a climate hazard	ADAPTIVE CAPACITY Ability of an urban area to prepare for or cope with a climate hazard	EXPOSURE Lives and assets that could experience a climate hazard
INLAND FLOODING Rx5day: Monthly maximum consecutive 5-day precipitation	Percent of area that is impervious surface	Quality of drinking water	Number of cars on roads in flood zone
	Percent of buildings built after 1999		
	Percent of population residing in mobile homes	Number of acute care hospital beds available per 1,000 residents	Percent of population living in flood plains
	Percent of population that is 65 years old or older		
	Percent of population that is 18 years old or younger	Percent of population with health insurance	Number of buildings in the flood plain
	Percent of workers without access to a vehicle		
EXTREME HEAT WSDI: Warm Spell Duration Index Annual count of days with at least 6 consecutive days when daily maximum temperature higher than the 90 percentile of the maximum temperature in the base period	Percent of buildings built after 1979	Percent of land covered by tree canopy	Number of people in city
	Percent of population that is 65 years old or older		
	Percent of population that is 18 years old or younger	Number of acute care hospital beds available per 1,000 residents	
	Percent of population spending over 50% of income on rent		
	Percent of population that is chronically sick (12 seperate diseases)	Percent of population with health insurance	
	Outdoor workers		
EXTREME COLD CSDI: Cold Spell Duration Index Annual count of days with at least 6 consecutive days when the daily maximum temperature lower than the 10 percentile of the maximum temperature in the base period	Percent of buildings built after 1979	Percent of houses with heating	Number of people in city
	Percent of population spending over 50% of income on rent		
	Percent of population that is 65 years old or older	Number of acute care hospital beds available per 1,000 residents	
	Percent of population that is 18 years old or younger		
	Percent of population that is chronically sick (12 specific diseases)	Percent of population with health insurance	

Please note: Indicators on drought and coastal flooding hazards are forthcoming.

COMPONENTS OF READINESS

ECONOMIC READINESS	GOVERNANCE READINESS	SOCIAL READINESS
City revenue per resident	Total number of federal public corruption convictions by district	Percent of population with less than 12th grade education
City deficit per resident	Civic Engagement	General innovation capabilities
Readiness to accept adaptation investment	Community rating system (CRS)	Estimated percent of adults who think global warming is already harming people in the US now or within 10 years
Tax incentives for renewable energy		

Notre Dame political science professor Patrick Regan, who is Associate Director of the Environmental Change Initiative and oversees the UAA, emphasizes that the UAA is not designed to measure success of cities' adaptation actions.

> *"...if somebody in Boston says 'so has our adaptation strategy been effective?' you might look at changes over time in some of our indicators, but we don't have any behaviors that we call adaptation. We are really making the assumption, and I think the literature is making the assumption, that if we were better on these indicators under conditions of climate stress, we would have some better outcome. You could get to those better indicators in a multitude of ways that are unrelated to the political decision to adapt to the expectation of future climate change."*

He notes, however, that some of the indicators included could be improved through adaptation actions, like increasing the amount of tree canopy or the number of hospital beds.

Lessons for Boston

Because the indicators in the UAA are designed to measure current risk conditions and readiness to adapt rather than success of adaptation actions, the approach is quite different from the one Boston needs. Boston has a solid understanding of its risks as a result of the extensive vulnerability assessment that was undertaken as part of the planning process. However, many of the metrics in the UAA might be applicable to helping Boston understand if those risks are declining based on its actions (e.g., property damage per capita and per hazard occurrence), and some of them might be applicable to measuring the actions themselves, particularly those identified as "adaptive capacity" metrics (e.g., percent of land covered by tree canopy). Additional insights from this framework are listed below.

Pay attention to the distribution of risks across the city

One unique piece of the UAA will be its "sub-city" analysis. Available for each city via the web platform that will house the index, the viewer will be able to see the data included in the assessment spatially. This can help decision-makers understand, for example, if hospital beds are accessible to at-risk areas, rather than just the total number of hospital beds in the city. One could also toggle on demographic data to "see where the distribution of adaptation efforts would have the highest pay off from a social equity point of view" (P. Regan, personal communication, January 11, 2018).

Focus on theory over correlation

In the process of cutting down the original list of over 60 indicators to about half that amount, Regan emphasized that his main decision criterion was a theoretical argument.

> *"I would always say does it make theoretical sense? ...Tell me about a logical argument that says if you have more of x you'd have less of y. And I think that's the strongest way to go. If I was standing up in front of a group of people giving a talk about this, I'd want a good reason for every indicator and the good reason would not be high correlation."*

He also noted that the team had to make tough decisions on reasonable proxy indicators when they could not get data for the particular indicator they desired to include.

Match your precision to your audience

Regan said that some of the experts the UAA team worked with were concerned about the precision of the data included in the assessment. He notes, "The level of precision should be consistent with the level of precision in the usage." Because the main audience of the UAA is decision-makers, precision is not as important a factor as it would be for a hydrologist developing models of water flow, for example (P. Regan, personal communication, January 11, 2018).

Bottom-up frameworks

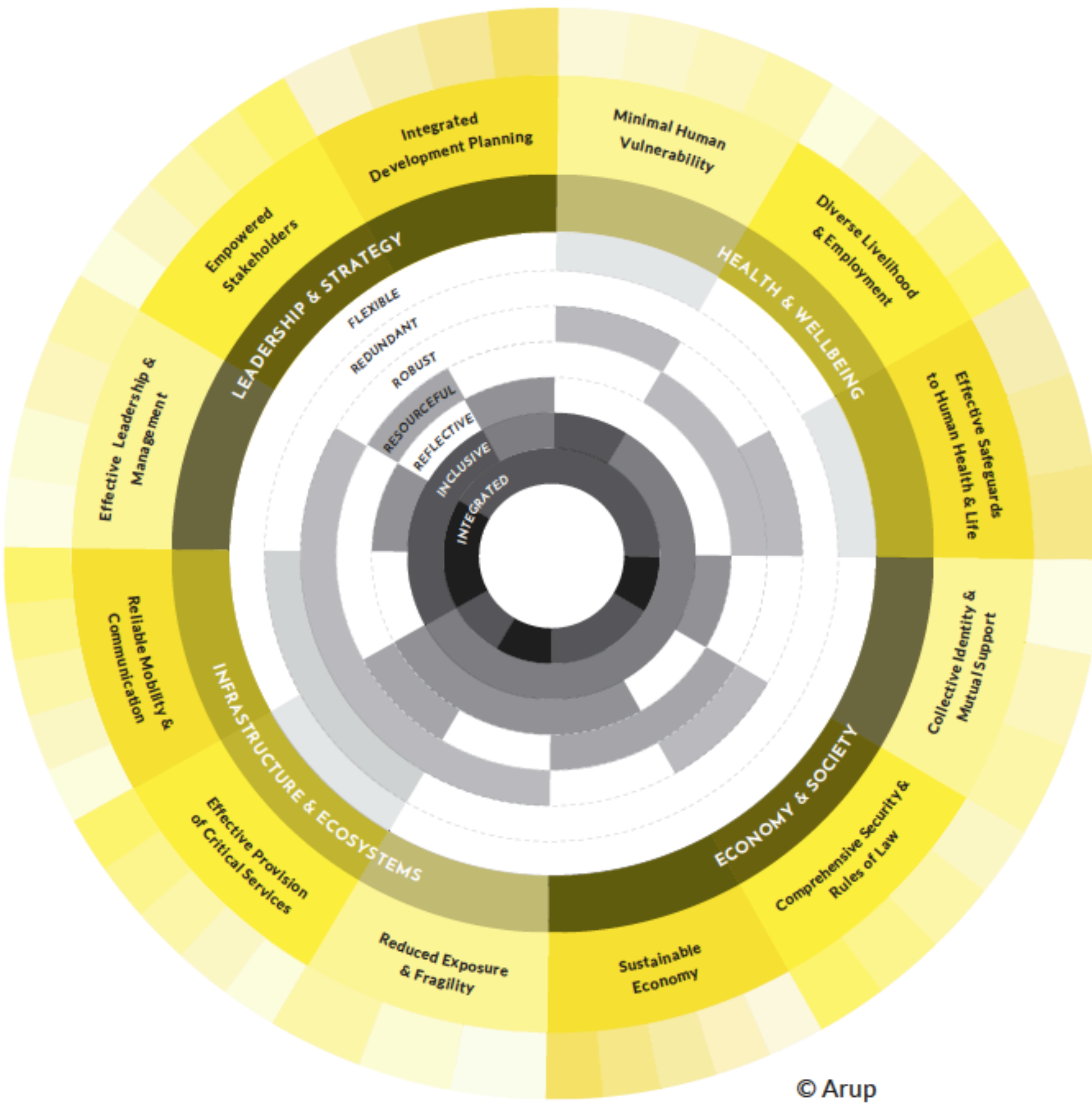
Bottom-up frameworks include both those developed by groups that give cities a proscribed set of indicators to measure on their own and those directly developed by a city. Arup and 100 Resilient Cities' City Resilience Index, EPA's Multi-Sector Evaluation Tool for Identifying Resilience Opportunities, and USGBC/STAR Communities' rating system are all examples of the former. The indicator set used in NYC's *OneNYC* plan is an example of the latter. These frameworks provide many potential indicators and metrics that could be applied to the Boston context.

100 Resilient Cities and Arup's City Resilience Index

Overview

Arup, with the support of The Rockefeller Foundation's 100 Resilient Cities program, started the process of creating the City Resilience Index (CRI) in 2013. With four dimensions (Leadership & Strategy, Health & Wellbeing, Economy & Society, and Infrastructure & Ecosystems), 12 goals (e.g., minimize human vulnerability), 52 high-level indicators (e.g., protection of livelihoods following a shock), 156 qualitative and 156 quantitative variables, the tool takes an extremely comprehensive approach to all aspects of resiliency, which includes but goes far beyond climate change adaptation (see Figure 10). The process for creating the index included a "literature review, 14 city case studies and primary data from six cities globally which focused on identifying the multitude of factors that contribute to a city's ability to be able to function in the event of an extreme event or chronic stresses" (Arup, 2016b). Recognizing the importance of a bottom-up approach, CRI "is a way for cities to self-assess how resilient they are" (S. Nadkarny, personal communication, February 20, 2018).

Figure 10: Organization of the City Resilience Index (Arup, n.d.)



Data limitations proved a significant hurdle both while crafting the indicators and metrics for the tool and while implementing the tool in the five pilot cities (Hong Kong, China; Liverpool, England; Arusha, Tanzania; Concepción, Chile; and Shimla, India) during the summer and fall of 2015. Arup (2016) notes that the researchers were unable to "identify existing metrics that were directly relevant based on what is measured already" for approximately half of the 156 variables. In those cases, Arup relied on in-house experts to craft appropriate metrics (S. Nadkarny, personal communication, February 20, 2018). Related to the difficulty in crafting these metrics was pilot cities' inability to match data sets to them. Hong Kong, described as having a strong data culture, did not have data for 32 percent of the metrics and Liverpool had no data for 56 percent. The magnitude of the data availability problem is illustrated in the fact that in addition to the qualitative and quantitative resilience profile outputs, a third output for the assessment is a quantitative data availability profile, detailing where cities lacked adequate measures. Arup (2016) describes the problem this way:

> *"In addition to not being familiar with the quantitative metrics beforehand, the roots of this challenge generally laid in a lack of understanding regarding whether data existed (especially between different sectors or departments), and – where data did exist – who might actually have it."*

Lessons for Boston

Based on conversations with Boston City staff who emphasized starting with a handful of indicators, the 156 that the CRI delivers is a magnitude unlikely to be practical for Boston at the current time. Additionally, because the CRI definition of resilience extends beyond climate change and is meant to be widely applicable to a range of cities around the world, only a portion of the indicators in the CRI are relevant for the project in Boston. Finally, it is likely that Boston would have similar difficulties as CRI's pilot cities in finding existing data sets that are routinely updated to measure many of the indicators included in this framework. Despite this, there are several key lessons Boston can take away from the CRI.

Tie monitoring and evaluation to existing planning benchmarks

Arup is currently in phase three of the CRI project, which is focused on making the tool scalable and sustainable. One goal of this phase is to understand from cities how often it would be helpful for them to repeat the CRI assessment. So far, feedback from cities suggests that assessments should "align with existing planning benchmarks in the city like starting a new development plan cycle or a change in the administration that has a different spatial planning policy." Additionally, Arup suggests that cities may want to monitor a subset of these metrics between full assessments (S. Nadkarny, personal communication, February 20, 2018).

Focus on capacity

The CRI frames resilience as "capacity," which focuses on a review of performance beyond just evaluation "in the moment" of a shock or stress (S. Nadkarny, personal communication, February 20, 2018). To that end, CRI does not try to measure resilience outcomes that "can only be truly measured based on actual performance following an extreme event, or during chronic stresses." Instead, it focuses on the "likelihood of a city being resilient in the event of any acute shock or chronic stress" (Arup, 2016b). Because of this, many of the risk management indicators included measure vulnerability based on the overall performance of the system (e.g., average length of electrical interruptions (hours per year per customer)) rather than the performance of the system only during times of stress (e.g., average length of electrical interruptions after a shock) (Arup, 2016a). This is an important approach to keep in mind when crafting metrics for

Boston, since many shock-related climate change outcomes may be hard to measure in the near-term.

Include qualitative information to supplement quantitative data

Several of the indicator frameworks reviewed include qualitative indicators as well as quantitative ones. CRI staff note that they deemed it necessary to include both because of the problem with "leading" versus "lagging" indicators. Quantitative indicators are lagging because "certain changes to practices, mechanisms, and policies don't necessarily show an outcome until much later" (S. Nadkarny, personal communication, February 20, 2018). Qualitative indicators, on the other hand, are leading because they help assess whether the mechanisms are in place to lead to a particular resilience outcome. Each variable in the CRI has both a qualitative and quantitative indicator to try to catch both leading and lagging information. Qualitative information could theoretically help cities find a problem before it shows up in the quantitative data. Nadkarny illustrates an example of the importance of collecting both kinds of information:

> *"...There was a city in north India where we did the pilot and on a particular indicator related to the city's ecosystem the city scored a five on the quantitative side but a two on the qualitative side. One of the things that was influencing the high score on the quantitative side was just how much forest cover was present within city boundaries. If I was seeing it as a snapshot in time I would say this is fantastic; the city is in the 80th percentile and above of cities around the world. But when you speak to stakeholders who are familiar with what direction policies and processes are taking, they give it a score of two because they are concerned that a new land use policy is going to lead to deforestation. So the qualitative response is recorded not just as a score but a rationale to the score, and that gives you some indication of where you could expect improved or unimproved outcomes down the line."*

Understand the limitations of assessment

A key piece of advice that Nadkarny would give to cites is that data can only take you so far.

> *"...data are not going to tell you what to do, which seems to be an unfortunate jump that some cities tend to make. If you have a fever, the thermometer is going to tell you what your temperature is, but it's not going to tell you what pills to take… A data-driven approach doesn't mean that you don't consult stakeholders, that you don't follow transparent, inclusive processes of planning. It doesn't mean that it gives you shortcuts to anything, but it makes whatever outcomes you are looking at more robust, more thoughtful."*

Bridging the gap from reporting metrics to identifying course corrections will be a key step for Boston after it begins to consistently monitor adaptation indicators.

EPA's Multi-Sector Evaluation Tool for Identifying Resilience Opportunities

Overview

In 2017, EPA released a report entitled *Evaluating Urban Resilience to Climate Change: A Multi-Sector Approach*. The tool created through this report, since named the Multi-Sector Evaluation Tool for Identifying Resilience Opportunities (METRO), contains quantitative and qualitative indicators to help cities understand areas where they should focus on improving their resilience. It identifies indicators in eight municipal management sectors affected by climate change, including (1) water, (2) energy, (3) transportation, (4) people (public health and emergency response), (5) economy, (6) land use/land cover, (7) the natural environment, and (8) telecommunications. The tool contains 88 quantitative indicators and 169 qualitative indicators (see Figure 11 for examples) that are intended to reveal the city's "ability to reduce exposure and sensitivity to and recover and learn from gradual climatic changes or extreme climate events" (i.e., the report's working definition of resilience). Each indicator is assigned an importance score as well as a resilience score. For the quantitative indicators this resilience score is based on thresholds established in the literature, when available. Indicators assigned high importance scores and low resilience scores in a city are identified through the tool as "critical areas of focus" and are represented in the upper right-hand corner of the quadrant plots for the city (see Figure 12) (EPA, 2017).

Figure 11: Example qualitative and quantitative indicators from the EPA tool (EPA, 2017)

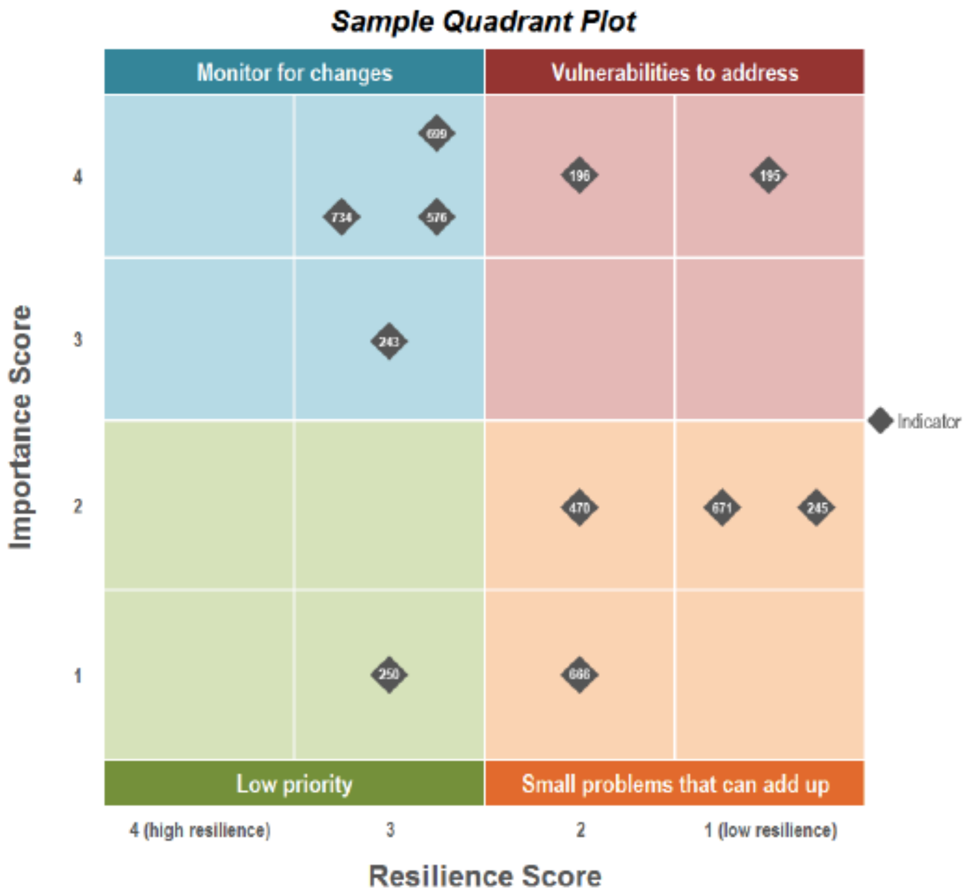
a. Example qualitative indicator

Sector	ID#	Question	Score = 4 (highest resilience)	Score = 3	Score = 2	Score = 1 (lowest resilience)
Economy	1	Is the economy of the urban area largely independent, or is it largely dependent on economic activity in other urban areas?	Largely independent	Somewhat independent	Somewhat dependent	Largely dependent

b. Example quantitative indicator

Sector	ID#	Indicator	Definition	Value
Economy	1437	Percentage of city area in 500-year floodplain	This indicator reflects the percentage of the metropolitan area that lies within the 500-year floodplain.	11.0%

Figure 12: Example of how the EPA tool prioritizes action areas through a quadrant plot (EPA, 2017)



Two communities, Washington, DC and Worcester, MA, have used the tool so far, and lessons from each case study are included in the report. Specific challenges to implementing the tool included gathering city-specific knowledge, data availability and quality, and threshold-setting for quantitative indicators.

Lessons for Boston

The main purpose of this tool is to use indicators to identify and prioritize sectors that need resilience improvements within a city, and Boston can learn a lot from this approach when trying to understand where to focus additional resources in the future.[3] Additionally, the EPA report's extensive documentation of its data sources and processing steps are particularly illuminating when crafting a set of indicators for Boston.

Consider data availability and limitations when selecting quantitative indicators

When selecting indicators, the steering committee (made up of over 50 experts from the various focus sectors) used a literature review and its diverse expertise to select the comprehensive list included in the final tool. An additional criterion was whether data would be available in a broad range of cities for the particular indicator.

Julie Blue, Principal Climate Scientist at Eastern Research Group and the project manager, also described how the group acknowledged data limitations, recognizing that the data collected for the various indicators would not be consistent in terms of timing (e.g., year last collected) and other factors. "We tried to be reasonable; if we were expecting big jumps in the data we were especially careful not to use an outdated data set that was unlikely to reflect current conditions." The report includes a robust summary of the types of data quality issues that the group confronted (see Figure 13).

[3] In Part VII, I show how the EPA quadrant plot can be used with my set of suggested indicators for Boston to help the City prioritize future action.

Figure 13: Types of data quality issues identified in the EPA report (EPA, 2017)

Data limitation	Description
Data not available	No data were available for the indicator.
Significant postprocessing	Data were available but required significant processing to obtain the value of the indicator for the city.
Multiple data sets	Calculating the indicator value required more than one data set; in some cases, combining data sets was challenging due to different spatial and temporal resolutions.
Modeled data	Extensive modeling efforts were required to calculate the indicator value.
Ongoing data collection	Data collection efforts were proposed or ongoing and therefore incomplete.
Outdated data	Available data were out of date and inappropriate for measuring the current resilience of the city.
Regional-scale data	Data were available only at a regional scale (e.g., county), not at the municipal scale.

Think about incorporating the spatial distribution of data

The report also notes that the spatial distribution of data was an important limiting factor.

> *"Within a city and within a sector, service quality and vulnerability may vary, even from block to block, depending on a host of factors (e.g., elevation, maintenance schedule, districting). Aggregating data at a city level may hide problems that are only severe in specific instances, or in the opposite case, make problems that are limited to small areas appear much worse than they are"* (EPA, 2017).

Thus, like ND-GAIN's UAA, the EPA report suggests that spatially mapping these indicators via a geographic information system (GIS) approach could be an important step in resilience assessment.

Include qualitative as well as quantitative indicators

Like in CRI, this report emphasizes the importance of including qualitative indicators in the assessment, both due to limited data availability and "sometimes because it is impossible to develop an indicator that provides more objective information than the city managers' responses regarding a specific question or issue" (EPA, 2017). Blue describes it this way:

> *"I think that is really what's special about the tool— that we used this mixed methods approach, meaning we could use hard data when it was available or we could just use the professional knowledge of the people working in the city. In all cases data availability is a huge issue even in really big metropolitan areas that are very well funded. So we felt that to get at the really important issues and to do this evaluation properly we didn't want to be hindered by the lack of available hard data sets."*

<u>Focus on monitoring, rather than a singular assessment</u>

Blue emphasizes the importance of using the tool "iteratively within the same city to track progress and to make adjustments on what the priorities should be as things change." She adds, "Part of what you have to do for adaptation is keep your monitoring programs going because if you don't know what is happening you can't react to it as changes occur." Thus, the project team focused on selecting indicators for which data are collected on a regular basis.

USGBC/STAR Community Rating System

Overview

Operated through a collaboration of the U.S. Green Building Council and STAR Communities and created with the input of 200 sustainability experts, the STAR Community Rating System was "built by and for local governments seeking a common framework for sustainability and standard metrics to benchmark progress" (STAR Communities, 2017). Almost 70 communities are certified through the system, which evaluates outcomes and community actions in eight goal areas, one of which is "climate and energy." This goal area contains a subsection (called an "objective") on climate adaptation.

Originally, the system was designed around measuring outcomes (i.e., metrics that demonstrate progress toward achieving a sustainability goal), but communities also wanted to get credit for actions (i.e., steps taken that may contribute to achieving outcomes), so the final result is a framework that combines the two. Because it is a rating system, points are assigned to each subsection and because climate adaptation is a growing practice, communities need to demonstrate success in outcomes and actions in order to obtain full credit for that objective (see Table 3). Other, more established, objectives allow communities to obtain 100 percent of the points available for that section from outcomes alone (K. Wamstad-Evans, personal communication, November 29, 2017).

Table 3: Outcome and action indicators from the climate adaptation section of the STAR Community Rating System (STAR Communities, 2016a)

Community Level Outcomes
Outcome 1: Climate Resilience Demonstrate a measurable reduction in vulnerability and/or increase in resiliency to three communitywide risks and one at-risk population group.
Local Actions
Action 1: Inventory, Assessment or Survey Conduct a local climate risk and vulnerability assessment
Action 2: Plan Development Adopt a local plan that incorporates potential climate change impact scenarios and identifies specific actions to reduce risk and exposure from identified hazards
Action 3: Policy and Code Adjustment Adopt building codes or land use ordinances that address specific climate impacts in the community
Action 4: Practice Improvements Demonstrate that internal decisions by local government departments use the most current climate science and that staff monitor climate change impacts
Action 5: Partnerships and Collaboration

Develop an interdisciplinary committee for the purpose of understanding and addressing climate vulnerabilities
Action 6: Education and Outreach Create an education and outreach campaign to engage residents, businesses, and local government staff in climate change vulnerability reduction efforts
Action 7: Programs and Services Create or enhance programs and services that specifically address the community's greatest climate threats
Action 8: Practice Improvements Develop metrics for measuring the success of adaptation actions to prepare for a changing climate
Action 9: Enforcement Incentives Enforce regulations or offer incentives to encourage residents and businesses to shift behaviors to prepare for future climate change impacts
Action 10: Facility and Infrastructure Improvements Improve facilities and infrastructure throughout the community to be better prepared for climate change threats

To complete the outcome piece of the climate adaptation objective, communities are encouraged to use their own vulnerability assessments to pinpoint key hazards and risks associated with those hazards and then explain how they are avoiding, addressing, or adapting to these risks. The technical guide lays out a table of example risks based on climate hazards under five key heading areas: human health, ecosystem vitality, economic well-being, social dynamics, and infrastructure. For example, risks related to extreme heat under the human health category include such items as air pollution and heat-related illness and injury. Additionally, communities are required to explain how they are reducing risks to at least one vulnerable population group, recognizing climate change's disproportionate impacts on young, elderly, and low-income people (STAR Communities, 2016b).

This framework is technically a hybrid of top-down and bottom-up frameworks, although the requirement for communities to collect their own data and the significant flexibility in the outcomes and actions they choose to report on justified its inclusion in the bottom-up list. It is top-down in the sense that they submit information to USGBC/STAR for review and final decisions on certification and scores.

Lessons for Boston

Pay special attention to at-risk population groups

Because climate change adaptation was still an emerging practice when the first version of the STAR rating system was released in 2012, a committee convened to review the system in 2016 decided to update this subsection. Kristi Wamstad-Evans, Technical Director for USGBC/STAR Communities, reflects on the decision to include equity considerations:

> *"...one of the things that came up in many of our discussions around equity was that risks are not always being addressed for all in the community. If you've put together a flooding plan and you are protecting properties, what is the potential that that flooding plan also then leads the water to run downhill into the lower income area? ...we also need communities to start considering at-risk populations and differentiations in risk."*

Rely on the expertise of other groups

Wamstad-Evans emphasizes that indicator systems should not try to reinvent the wheel. The STAR Community Rating System tries to serve as "an umbrella for data holders and thought leaders." For example, Wamstad-Evans points to the Trust for Public Land as experts on public parks. STAR encourages local governments to use their data and methodology rather than trying to come up with something new.

Include outcome and action indicators

As mentioned above, the entire rating system is designed around "outcome" and "action" (or process) reporting. With regard to the impetus behind the decision for this structure, Wamstad-Evans notes:

> *"On the local government scale the outcomes are interesting, good, and important for local governments to be tracking and benchmarking against others, but typically the bigger questions are about what is supposed to be done. That's when we started populating the framework with actions."*

As more data are collected both through certifying more communities and re-certifying existing communities, Wamstad-Evans also hopes to complete another important step—a "grander analysis of whether the actions lead to achievement of outcomes."

City of New York's *OneNYC*

Overview

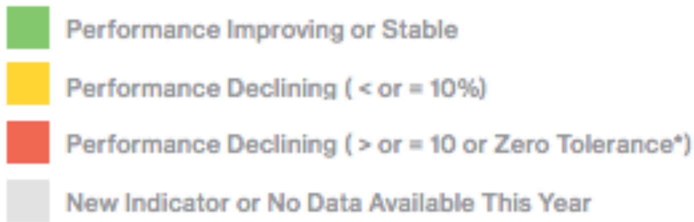
The City of New York is a leader in publishing and monitoring climate change resilience indicators. Its deep history of performance-based management rooted in the fiscal crisis of the 1970s means that metrics have infiltrated all aspects of the City's operations. Every year, the City releases its mandated Mayor's Management Report, which "uses indicators to measure and track the City's progress on a variety of goals and the implementation of services associated with those goals" (City of New York, 2017).

The City of New York published its first set of public-facing resilience indicators in its 2015 comprehensive plan, *OneNYC*, and has reported on progress in its 2016, 2017, and 2018 plan updates. Unsurprisingly for a plan created just a few years after Hurricane Sandy, resiliency is one of the four overarching visions. Success in this area is defined as "neighborhoods, economy, and public services...ready to withstand and emerge stronger from the impacts of climate change and other 21st century threats" (City of New York, 2015). This vision has three overarching indicators and eleven sub-indicators related to four goal areas: neighborhoods, buildings, infrastructure, and coastal defense (see Figure 14).

Additional indicators like "reduce risk of stormwater flooding in most affected communities" in the sustainability section of the plan also have adaptation relevance (City of New York, 2018). This is a good illustration of how the line between sustainability indicators and resilience indicators can be fuzzy.

Figure 14: NYC resiliency indicators from the *OneNYC 2018 Progress Report* (City of New York, 2018)

ID	Indicator Name	Latest Data	Previous Data	Target
4.0.1	Eliminate disaster-related long-term displacement of New Yorkers from homes by 2050	Data Not Available	Data Not Available	Eliminate (2050)
4.0.2	Reduce the Social Vulnerability Index for neighborhoods across the city	Data Not Available	Data Not Available	Reduce
4.0.3	Reduce average annual economic losses resulting from climate related events	Data Not Available	Data Not Available	Reduce
Vision 4: Neighborhoods				
4.1.1	Capacity of accessible emergency shelters	38,000 (2018)	10,000 (2017)	120,000 (2018)
4.1.2	Rate of volunteerism among New Yorkers	Data Not Available	17.4% (2015)	25% (2020)
Vision 4: Buildings				
4.2.1	Number of flood insurance policies across the city	55,000 (2018)	55,700 (2017)	Increase
4.2.2	Square footage of buildings upgraded against flood risk	21,534,000 (2018)	7,692,000 (2017)	Increase
4.2.3	Number of elevated homes in the Build It Back program (cumulative)	1,315 (2018)	957 (2017)	Increase
Vision 4: Infrastructure				
4.3.1a	System Average Interruption Frequency Index (SAIFI), the number of outages per 1,000 customers[1]	84.5 (2017)	85.9 (2016)	Decrease
4.3.1b	Customer Average Interruption Duration Index (CAIDI) , the average duration of an outage in hours[2]	3.22 (2017)	2.89 (2016)	Decrease
4.3.2	Percentage of hospital and long-term care beds benefitting from facility retrofits for resiliency	84% (2018)	84% (2017)	100% (2020)
Vision 4: Coastal Defense				
4.4.1	Linear feet of coastal defenses completed	133,140 (2018)	104,100 (2017)	Increase
4.4.2	Acres of coastal ecosystems restored	38.5 (2018)	22.0 (2017)	Increase
4.4.3	Number of residents benefiting from coastal defenses and restored ecosystems	Data Not Available	Data Not Available	Increase



City officials noted that the New York City Panel on Climate Change (NPCC), an independent body that advises the City on climate change issues, played a key role in developing the resiliency indicators included in *OneNYC*. In fact, chapter six of the *New York City Panel on Climate Change 2015 Report* is dedicated to the topic of indicators and monitoring. NPCC created a framework that separates indicators into four groupings: climate indicators, impact indicators, social vulnerability indicators, and resilience indicators (see Table 4). Indicators were selected based on "policy relevance, analytical soundness, and measurability" (Solecki et al., 2015).

Table 4: Candidate indicators for the New York City Climate Resiliency Indicators and Monitoring System (Solecki et al., 2015)

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

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

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:
    o Heat Vulnerability Index in census block groups experiencing relatively higher heat stress
    o Social Vulnerability Index scores related to access to green space
    o Social Isolation Index in census block groups in flood evacuation zones

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
- 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

Lessons for Boston

Boston can glean a great deal from New York City's experience to date.

Match indicators to the structure of the City's plan

City officials emphasize the importance of making sure the metrics selected for *OneNYC* reflected the structure and logic of the plan. To this end, each overarching vision and goal have associated metrics (see Figure 14). This approach ensures clarity in communication to the public and helps relate progress on resilience actions (generally measured through process indicators), to the overarching vision (measured through outcome indicators).

Leverage existing metrics and data when selecting resilience indicators

City officials note the importance of leveraging NYC's long history of performance management to address data collection resource constraints. When selecting indicators, officials look at what metrics are already in use and whether they could be helpful in the context of the *OneNYC* plan. They underscore, however, that because resiliency is a relatively new area of focus many desired data sets do not yet exist.

Focus on indicators able to be operationalized and consistently updated and leave room for flexibility

As noted above, because the desire to measure resilience is a relatively new phenomenon, the City of New York has had difficulty operationalizing and finding consistently updated data sets at the appropriate scale for many of the desired indicators in that part of the plan. Officials noted the tension between being aspirational and practical in terms of indicator selection. None of the three vision-level indicators have data.

For those indicators with data problems, flexibility has been the name of the game. Many of the indicators and/or data sources have been tweaked since the plan was originally published in 2015. City officials note that the original indicator "customer hours of weather related utility and service outages" was changed to "System Average Interruption Frequency Index" and "Customer Average Interruption Duration Index" due to data limitations. Additionally, the original data source for the indicator related to flood insurance was a 2013 study that was not replicated. Thus, the City pivoted and began to use a slightly different indicator that was tracked more consistently through the National Flood Insurance Program (NFIP). This suggests a key consideration in picking indicators should be whether the data will be updated on a frequent enough basis to ensure consistent reporting.

Besides resource constraints, it is also important to leave room for flexibility as values or priorities change. For example, officials point out that in the past, the City measured and reported on air quality at the citywide level. Due to increased attention to equity issues, *OneNYC* established new metrics that helped show the disparities in air pollution between neighborhoods (e.g., “disparity in SO2 across city neighborhoods”). Changing the indicator helped steer air pollution reduction efforts in a more targeted, equitable direction.

City officials also express faith that many of the current data problems will be fixed with technological advances. Related to neighborhood flooding, for example, they said that one day there may be sensors in sewers to quantify which neighborhoods have the most stormwater flooding problems, but right now the city is using less specific proxy indicators, like “backlog of catch basin repairs.”

<u>Obtain help from partner groups</u>

City officials note the importance of NPCC’s contributions to crafting resilience indicators. The NPCC and the City continue to work on operationalizing these indicators and searching for useful proxies. The results of this effort will likely be born out in subsequent plan updates.

Find ways to make indicator values interpretable to the public

NYC shares its progress with the public by including both the new and previous data for each indicator in its progress reports. Stoplight colors show if performance is improving/stable (green), declining by less than ten percent (yellow), or declining by more than 10 percent (red) (see Figure 14).

Guiding frameworks

The last type of framework takes the form of a guidance document. These frameworks give cities advice on how to craft their own indicators based on their goals and activities, but do not proscribe specific indicators or metrics to be used (Plovnick, 2016).

USDN's *Developing Urban Climate Adaptation Indicators*

Overview

Recognizing a need to expand cities' assessment of their progress on climate change actions beyond mitigation to adaptation, USDN established a working group of sustainability officers from seven cities (led by Washington, DC) to "assess leading climate adaptation indicator frameworks, determine their relevance and feasibility from a city perspective, and identify gaps" (USDN, 2016). This project started out as an endeavor with the goal of either adopting a particular set of indicators already in existence or creating a new set of indicators informed by those frameworks. After reviewing over 50 frameworks, however, it became clear that in many cases, the motivations for developing them did not necessarily match the motivations of local governments (M. Crowley, personal communication, February 7, 2018).

Michael Crowley, then a Senior Program Officer at the Institute for Sustainable Communities charged with working on the project, says this raised "some flags" from the municipal perspective, particularly related to those frameworks that focused on ranking cities. He notes, "every city has unique conditions, and it's very difficult if not impossible to compare cities and especially to rank cities against each other." He also notes that some frameworks reviewed were very academic with no guidance about how to make them useful planning tools. The team realized that instead of trying to come up with a set of indicators that could be universally applied, "the most prudent course of action was to develop guidelines for creating indicators that were relevant to the realities on the ground" (M. Crowley, personal communication, February 7, 2018).

The resulting document includes a survey of seven leading adaptation indicator frameworks, an explanation of how various indicator types (e.g., indicators that measure exposure, sensitivity, process, adaptive capacity, and transformative capacity) may fit in a city's overall planning process, and guidance for linking planning goals to metrics. The complete set of outputs from this study also includes a list of potential indicators, drawn from cities and other sources.

Lessons for Boston

<u>Stick to what is relevant</u>

As detailed above, instead of trying to adapt indicators from well-known frameworks often created with motivations beyond tracking city-level progress on adaptation actions, local officials should select indicators that align with their planning goals and priorities. The report also emphasizes a need to consider the indicators' audience in both selection and communication, pick indicators that will inspire action, and assign responsibility for indicators to specific government agencies to "provide accountability and make use of indicators more likely" (USDN, 2016).

Build off of what exists

Crowley emphasizes the importance of working off of the data that already exists both within city departments and externally. He mentions that if city officials are measuring something different than external groups, they should endeavor to understand why that difference exists, as it might stem from conflicting values. He also mentions that part of the process of selecting indicators should include sitting down with stakeholders to understand their priorities.

Select a variety of indicators, but not too many

The report also notes that because adaptation success is "holistic in nature" single indicators are not likely to show the entire picture. Cities must learn to walk the fine line between including a variety of indicators and including too many to implement effectively.

Think about the values conveyed through the indicators selected

Crowley advises cities to think about the values inherent in their indicators. As an example, measuring the amount of sea wall built may prioritize coastal defense over, say, community access to the waterfront. Crowley says, "doing this kind of measurement analysis is a very good way to uncover hidden assumptions in the planning process." The report adds, "indicators that do not account for inequalities may actually serve to make inequality worse" (USDN, 2016). Ensuring that that disparate effects on vulnerable populations are highlighted is important.

Focus on consequence, where possible

Finally, the report points out that indicators should "address specific adaptation performance goals and answer the question 'resilience to what?'" For example, instead of including an indicator about the number of trees planted, a better one might be number of heat-related illnesses because it "may reveal the impact of heat island adaptation strategies," including the beneficial effects of increased tree canopy (USDN, 2016). This closely aligns with what constitutes a risk management indicator in my analysis in Part VI below.

Part VI: Suggested Indicators and Metrics for Boston

In this chapter, I draw on lessons learned from the six frameworks I reviewed, interviews with Boston City staff and other experts, and a compiled list of example measures to suggest 20 quantitative indicators (and two qualitative indicators) for the City to report on in the 2018 CAP update. Each of the City's five main climate change adaptation goals is well-represented, including (1) updated climate projections, (2) prepared and connected communities, (3) protected shores, (4) resilient infrastructure, and (5) adapted buildings. The indicators are organized by these goals.[1] Both risk reduction and risk management indicators are incorporated, underscoring the importance of both. Also included are hazard indicators, or indicators that provide context on the current level of risk for extreme heat, stormwater flooding, and coastal flooding. Table 5 lists the indicators by type. Table 6 then summarizes each indicator, including information on its related hazards; suggested metrics, targets, and data sources; and how the data is collected. There is also a column in Table 6 on sub-metrics designed to disaggregate the data in ways that may be helpful to understanding different types of impact.[2] A narrative with detailed descriptions and limitations for each indicator follows these tables.

There are three common threads that run through all the indicators selected: (1) they relate to one of the City's five main resilience goals (informed by Boston's vulnerability assessment), (2) their importance is supported through their inclusion in multiple reviewed frameworks, and (3) data either already exists or could be easily obtained to measure these indicators. Many of these initial suggestions are also included because of their relationship to initiatives from the CRB report that

[1] City staff indicated that the adaptation part of the CAP update will likely be organized by these goals, further emphasizing the importance of this structure in displaying the indicators.
[2] Part VII includes discussion on how these sub-metrics can be utilized.

are already being implemented. Taking Commissioner Spector's charge to heart and understanding that a set of 20 indicators may be too large for the City to implement all at once, I highlight seven that might be particularly "reasonable places to start" in Table 6. Over time the City could add more indicators to create an increasingly comprehensive and informative evaluation of its efforts to implement its climate adaptation initiatives.

Table 5: List of suggested indicators by indicator type

Risk management indicators	Risk reduction indicators	Context indicators
-Prevalence of heat-related illness -Reliable emergency response -Resilient electricity system -Reliable public transit -Adequate stormwater system -Economic losses due to flood events	-Adequate health insurance coverage -Access to critical services for vulnerable populations -Community awareness of hazards and need for adaptation -Residents and businesses guarded via coastal flood protection measures -Amount of vulnerable coastline secured -Increased tree canopy coverage -Amount of green space -Increased flood insurance coverage -Resilience components incorporated into new development -Prepared municipal facilities -Climate risk considerations included in neighborhood planning processes	-Current level of heat hazard -Current level of stormwater flooding hazard -Current level of coastal flooding hazard

Table 6: Summary table of suggested climate adaptation indicators for Boston

Indicator	***Related hazard/ context indicator***	***Type***	***Metric***	***Data source***	***Target***	***Data collection***	***Scales available***	***Impact sub-metrics***
Goal one: Updated climate projections								
This goal should be evaluated qualitatively and include a description of the number of years since city hazard projections and maps have been updated. The goal from the CRB report is to update them every five years.								
Goal two: Prepared and connected communities								
Prevalence of heat-related illness	Extreme heat	Risk management indicator	Heat-related illness emergency department visits during warm-weather months per 100,000 residents	Massachusetts Center for Health Information and Analysis and BPHC's Health of Boston Report	Decrease	Collected annually by the Commonwealth, most recent data available from 2015	Citywide and by certain social vulnerability indicators	Emergency department visits by socially vulnerable group; emergency department visits by those in tree deficient areas versus those with plentiful trees
Adequate health insurance coverage	Extreme heat and flooding	Risk reduction indicator	Civilian non-institutionaliz-ed population without health insurance	American Community Survey 5-year estimates	Increase	Annually, most recent data from 2016	Citywide and census block group level	Health insurance by socially vulnerable group

Reliable emergency response	Extreme heat and flooding	Risk management indicator	Average annual Emergency Medical Service (EMS) response time- EMS priority 1 responses triggered by 911 calls related to life-threatening illness or injury	Boston CityScore	< 6 minutes	Daily, data up-to-date	Citywide	Average response time during/after extreme events; average response time in areas with large percentages of socially vulnerable groups; average response time for areas particularly vulnerable to heat or flooding
Access to critical services for vulnerable populations	Extreme heat and flooding	Risk reduction indicator	Number of facilities and community organizations serving vulnerable populations with continuity of operations plans	BPHC's effort to develop continuity of operations plans for facilities and community organizations	Increase	Data not currently collected systematically because program has not started; ability to work with BPHC to implement appropriate data tracking	Could be collected citywide and by neighborhood	Number of facilities and groups with continuity of operations plans in areas particularly vulnerable to extreme heat or flooding
Community awareness of hazards and need for adaptation	Extreme heat and flooding	Risk reduction indicator	Number of Climate Ready Boston Leaders trained and number of people reached by these Leaders	Boston Environment Department data on the Climate Ready Boston Leaders program	Increase	Annually, data up-to-date	Citywide and by neighborhood	Number of people reached in areas with high percentages of socially vulnerable groups; number of people reached in areas particularly vulnerable to heat or flooding

Goal three: Protected shores								
Residents and businesses guarded via coastal flood protection measures	Flooding	Risk reduction indicator	Number of residents and businesses expected to be protected due to new coastal defense measures from the CRB neighborhood -level planning processes	Boston Environment Department neighborhood-level resilience studies	Increase	Data not currently collected systematically, could be collected annually with limited additional effort	Could be collected citywide and by neighborhood	Number of residents and businesses expected to be protected in areas with high percentages of socially vulnerable groups; number of residents and businesses expected to be protected under various sea level rise scenarios
Amount of vulnerable coastline secured	Flooding	Risk reduction indicator	Feet of coastal defenses completed	Massachusetts Department of Conservation and Recreation 2007 study and other City department data on flood protection measures installed since 2007	Increase	Data not currently collected systematically and consistently, would require additional data collection efforts and processing	Could be collected citywide and by neighborhood	Feet of coastal defenses installed in areas with little protection; feet of coastal defenses installed in areas of low elevation; feet of coastal defenses installed in areas with high percentages of socially vulnerable groups; feet of coastal defenses installed in critical flood pathways
To accomplish this goal, the City is also studying how it could use zoning law to address coastal flooding (initiative 5.1 in the CRB report). While not amenable to quantitative tracking, the City should include qualitative updates related to this point in each CAP update.								

Goal four: Resilient infrastructure								
Resilient electricity system	Extreme heat and flooding	Risk management indicator	1) Average number of months between interruptions 2) System average time in minutes to restore service to customers	Eversource yearly sustainability report	1) Increase 2) Decrease	Annually, most recent data available from 2017	Regional, includes Eversource coverage area in MA, CT, and NH	Average number of months between outages and average time to restore service in areas with high percentages of socially vulnerable groups; average time to restore service after extreme events
Reliable public transit	Extreme heat and flooding	Risk management indicator	Reliability of buses, subway, and commuter rail (yearly average)	Massachusetts Bay Transportation Authority (MBTA)	MBTA reliability targets: *Bus:* 75% *Subway:* 90% *Rail:* 90%	Daily, data up-to-date	Citywide	Reliability of transit during/after extreme events; reliability for routes that service high percentages of socially vulnerable groups
Increased tree canopy coverage	Extreme heat and flooding	Risk reduction indicator	Net number of new trees per year (plantings minus removals)	City Arborist data	Increase	Annually, data up-to-date	Citywide and potentially by neighborhood	Net number of new trees in tree deficient areas; net number of new trees in areas particularly vulnerable to heat or flooding; net number of new trees in areas with large percentages of socially vulnerable groups

Amount of green space	Extreme heat and flooding	Risk reduction indicator	Park land as a percentage of city area	The Trust for Public Land ParkScore®	Increase	Annually, most recent data available from 2017	Citywide and by neighborhood	Percentage of new park land in green space deficient areas; percentage of new park land in areas particularly vulnerable to heat or flooding; percentage of new park land in areas with high percentages of socially vulnerable groups
Adequate stormwater system	Flooding	Risk management indicator	Volume of sanitary sewer overflows (SSOs)	BWSC	Decrease	SSO events updated as they occur	Citywide and by neighborhood	Volume of SSOs in areas with high percentages of socially vulnerable groups; volume of SSOs in areas particularly vulnerable to flooding; volume of SSOs in areas with large percentages of trees or green space versus those without

Goal five: Adapted buildings								
Increased flood insurance coverage	Flooding	Risk reduction indicator	Number of flood insurance policies across the city	Federal Emergency Management Agency (FEMA) and Boston's Hazard Mitigation Plan (HMP)	Increase	Every five years through the HMP, possibility that FEMA may track and share more regularly	Citywide	Difference in flood insurance coverage for those in the 100-year floodplain by income and other social characteristics; percentage of people in particularly vulnerable areas with flood insurance
Resilience components incorporated into new development	Extreme heat and flooding	Risk reduction indicator	Number of buildings incorporating resilience measures from Article 80 Climate Resiliency Checklist	BPDA	Increase	Data not currently collected systematically, could be collected annually with limited additional effort	Could be collected citywide and by neighborhood	Number of buildings incorporating resilience measures in areas with high percentages of socially vulnerable groups; number of buildings incorporating resilience measures in areas that are particularly vulnerable to flooding

Economic losses due to flood events	Flooding	Risk management indicator	FEMA dollars spent on repetitive loss properties	FEMA and Boston's HMP	Decrease	Every five years through the HMP, possibility that FEMA may track and share more regularly	Citywide	FEMA dollars spent in areas with high percentages of socially vulnerable groups; FEMA dollars spent in tree deficient areas versus those with plentiful trees; FEMA dollars spent in green space deficient areas versus those with plentiful green space; FEMA dollars spent in areas with high percentages of resilient development versus other areas
Prepared municipal facilities	Extreme heat and flooding	Risk reduction indicator	Budgeted investments in resilience projects through the capital planning process	Office of Budget Management	Increase	Data not currently collected systematically, could be collected annually with limited additional effort	Could be collected citywide and by neighborhood	Investments in resilience projects in areas particularly vulnerable to heat or flooding; investments in areas with high percentages of socially vulnerable groups; investments in high development areas that could motivate the private sector

Climate risk considerations included in neighborhood planning processes	Extreme heat and flooding	Risk reduction indicator	Percentage of neighborhood plans released annually that contain climate change preparedness recommendations	BPDA	Increase	Data not currently collected systematically, could be collected annually with limited additional effort	Could be collected citywide and by neighborhood	Percentage of neighborhood plans with preparedness recommendations in areas with high percentages of socially vulnerable groups; percentage of neighborhood plans with preparedness recommendations in areas particularly vulnerable to heat or flooding
Context indicators								
Current level of heat hazard	Extreme heat	Hazard indicator	Average summer daily maximum temperature--May through September	National Oceanic and Atmospheric Administration (NOAA)'s NOWdata	N/A	Daily, data up-to-date	Citywide	Level of heat hazard in areas with high percentages of socially vulnerable groups
Current level of stormwater flooding hazard	Flooding	Hazard indicator	Annual mean precipitation (inches)	BWSC	N/A	Daily, data up-to-date	Citywide and by neighborhood	Level of stormwater flooding hazard in areas with high percentages of socially vulnerable groups
Current level of coastal flooding hazard	Flooding	Hazard indicator	Number of days per year in which coastal waters rose above the local threshold for minor flooding	NOAA's Center for Operational Oceanographic Products and Services (CO-OPS)	N/A	Daily, data up-to-date but would require processing	Citywide	Level of coastal flooding hazard in areas with high percentages of socially vulnerable groups

Goal one: Updated climate projections

Making sure decision making in Boston is informed by up-to-date, localized hazard predictions is a main goal in the CRB report. According to the report, the Boston Research Advisory Group (BRAG) should reconvene every five years to update these projections and "assist local and state agencies in applying those conclusions to policy, design, and regulation" (City of Boston, 2016b). This latter mission is related to initiative 1.2 "Create future flood maps to support planning, policy, and regulation." These flood maps should also be updated every five years.

This goal and related actions are more compatible with a qualitative report out than a quantitative one. The CAP update should include a description of the status of these projections and maps, including whether or not they have been updated in the last five years as recommended. Two of the six frameworks reviewed plus the SeaPlan report recognize keeping climate projections updated as a key task for cities.

Goal two: Prepared and connected communities

The second overarching goal outlined in the CRB report is aimed at empowering communities to improve "operational preparedness, adaptation planning, and emergency response" (City of Boston, 2016b). Sub-goals include expanding outreach and education on climate issues and leveraging climate adaptation as a tool for community development.

Risk management indicator: Prevalence of heat-related illness
Metric: Heat-related illness emergency department visits during warm-weather months per 100,000 residents

Description

Prevalence of heat-related illness is an important risk management indicator related to how well the city deals with the impacts of extreme heat and the UHI effect. It is also called out in the vulnerability assessment as a key indicator, which makes it especially important to include (City of Boston, 2016b). It should provide information on whether risk reduction actions like increasing tree canopy or the capacity of cooling centers are actually decreasing vulnerability in the face of rising temperatures and an increasing number of heat emergencies. The City is currently preparing to launch an initiative to update that City's heat annex of its emergency response plan (in fulfillment of initiative 2.4 in the CRB report), and this could be an important indicator for that project.

Four of the six frameworks reviewed include indicators related to the health impacts of heat. While New York did not include it in their *OneNYC* plan, the NPCC (the independent group of experts that works with the City on developing its indicators) did recommend such an indicator (Solecki et al., 2015). The SeaPlan report also includes a related indicator.

Importantly, data related to this metric are already collected by the Massachusetts Center for Health Information and Analysis and were included in BPHC's *Health of Boston Report, 2016-2017* (see Figure 15). Reliable data sets for risk management indicators are hard to find, making this indicator especially exciting. Because the effects of extreme heat are already being felt consistently in Boston and its health effects have a history of documentation, it may be easier to measure ultimate success of actions related to this hazard than actions related to hazards with longer-term time-horizons like coastal flooding.

In addition to communicating the raw value of the metric, the City should consider adopting a coloring system (green, yellow, and red) that will help the public make sense of the City's performance. For this metric, an analyst could compare the rate of emergency department visits in Boston to other cities with similar average summer temperatures when assigning colors. The metric could be colored green if Boston is doing well compared to these other cities (indicating good performance), yellow if Boston is doing about average (indicating that it would benefit from improvement), and red if it is doing worse than average (indicating poor performance). I suggest comparison among cities for this metric because comparing performance only within Boston from year-to-year does not factor in changes in the level of heat hazard, which could skew interpretations of results.

This indicator's ability to supply information about the effectiveness of various risk reduction strategies, its inclusion in four of the six case studies, and its association with a data set that already exists makes this one of the seven priority indicators I highlight in Table 6.

Limitations

While this metric has many positive qualities, there are a few limitations to keep in mind. First, the recently released *Health of Boston Report, 2016-2017* was the first time this metric was reported through BPHC. It is unclear if BPHC will continue to report on this metric consistently in the coming years. Second, the data included in that report were from 2015, suggesting a lag.

Finally, as mentioned in Figure 15, while the second table included in the report is helpful in identifying differences in heat illness across social vulnerability factors, the sample sizes are low, meaning the ability to draw conclusions from these numbers is limited.

Figure 15: Heat-related illness data published in BPHC report (BPHC, 2018)

Table 4.24 Heat-Related Illness Emergency Department Visits During Hot-Weather Months† by Year

	2011	2012	2013	2014	2015	Change over time
Boston	6.7	13.1	8.3	6.6	10.1	↔

Data values ED visits per 100,000 residents.

† Age-adjusted rates

NOTE: Warm-weather months are defined as May, June, July, August, and September.

DATA SOURCE: Acute hospital case-mix databases, Massachusetts Center for Health Information and Analysis

Table 4.25 Heat-Related Illness Emergency Department Visits During Warm-Weather Months by Selected Indicators, 2012-2015

	Rate	Comparison to reference
Boston†	9.5	N/A
Sex†		
Female	8	↓
Male	11.2	Reference
Race/ethnicity†		
Asian	6.6 §	↔
Black	12.5	↔
Latino	8.2	↔
White	9.4	Reference
Age††		
0-17 years old	8.1	↓
18-44 years old	8.5	↓
45-64 years old	9.4	↓
65+ years old	15.2	Reference

Data values are ED visits per 100,000 residents.

† 4-year average annual age-adjusted rates
†† 4-year average annual rates
§ Rates are based on 20 or fewer cases and should be interpreted with caution.

NOTE: Comparisons are made within each selected indicator. Warm-weather months are defined as May, June, July, August, and September.

DATA SOURCE: Acute hospital case-mix databases, Massachusetts Center for Health Information and Analysis

Risk reduction indicator: Adequate health insurance coverage
Metric: Civilian non-institutionalized population without health insurance

Description

The extent of health insurance coverage is a common risk reduction indicator; three of the six frameworks reviewed include such an indicator. The report conducted by a City of Boston Fellow in 2014 also includes this as a suggested indicator. The justification for inclusion is that people who have health insurance will be better able to respond to health risks from heat and flooding, whether it be a physical injury from an extreme event or a chronic illness related to climate stressors (e.g., asthma due to mold growth in homes due to increased precipitation). Because data on this indicator are published yearly through the American Community Survey 5-year estimates, it is easy to obtain and can also be broken down by census tract level, giving a better picture of what areas of Boston are ripe for targeted action on health insurance.

In terms of a grading scale for this indicator, green could mean Boston is performing well compared to other similarly-sized cities in terms of health insurance coverage, yellow could mean it is performing about average, and red could mean Boston is performing worse than average.

Limitations

There are many factors besides the City's resilience initiatives that may create demand for health insurance, making it hard to ascertain a causal effect between the City's actions on adaptation and increased health insurance coverage. Regardless of the motives behind coverage fluctuations, it is an important metric to keep track of because of its ability to reduce the consequences of climate change health impacts.

Risk management indicator: Reliable emergency response
Metric: Average annual Emergency Medical Service (EMS) response time- EMS priority 1 responses triggered by 911 calls related to life-threatening illness or injury

Description

Emergency response is an important component of climate risk management for all climate hazards. Slow emergency response times during an extreme weather event could indicate a number of issues with the City's current adaptive capabilities, including lack of emergency response capacity, an insufficient emergency response plan, and/or inadequate access to emergency sites due to vulnerable road networks. Boston's vulnerability assessment identifies inability to access emergency routes as a key flood risk and emphasizes that road buckling is a possible problem under conditions of extreme heat, which could affect emergency response (City of Boston, 2016b). Three of the six frameworks, as well as the SeaPlan report, include a related indicator.

Boston's CityScore dashboard that reports out daily on the adequacy of various government services includes a metric on EMS response time with a set target of fewer than six minutes (City of Boston, 2018a). Because this information is collected and logged daily, this information could be easily compiled into a yearly average and reported out via the CAP update.

This metric already has a target, so a grading scale could be designed around this goal. Environment department staff should work with those who created the target to define further thresholds for performance. Assuming six minutes is a robust target, green could mean the average emergency response time is meeting or exceeding the target, yellow could mean it is off by less than 10 percent, and red could mean it is off by more than 10 percent, for example.

Limitations

While annual average response time may give some indication of the City's overall ability to respond to emergencies, a more informative metric for these purposes may be average response time during and after extreme weather events. Because this metric is collected daily, this type of analysis would be possible but would need a standard definition of an emergency event for each hazard and would require more processing time to average only those days that meet this emergency event definition.

Additionally, the spatial distribution of these data is not reported, meaning internal analysis of specific locations in the city where emergency response time is especially problematic (and whether it differs across social groups) is not possible. Changing the way these data are processed may be an area for improvement in the future.

Risk reduction indicator: Access to critical services for vulnerable populations
Metric: Number of facilities and community organizations serving vulnerable populations with continuity of operations plans

Description

Community organizations and certain facilities provide critical social services to vulnerable populations after emergencies. Municipal and healthcare facilities licensed by the Massachusetts Bureau of Healthcare Quality are already required to maintain preparedness and evacuation plans, but there are many other facilities (e.g., privately-owned affordable housing complexes, daycare facilities, food pantries, small nonprofits, etc.) that are not subject to these regulations (City of Boston, 2016b). As such, it is important to encourage these groups and facilities to have continuity of operations plans to ensure that vulnerable populations are adequately served.

This metric relates directly to initiative 2.3 in the CRB report "Conduct outreach to facilities that serve vulnerable populations to support preparedness and adaptation." BPHC plans to launch an effort in summer 2018 to help these groups and facilities create continuity of operations plans (City of Boston, 2018b). Data collected related to this program could be folded into CAP updates related to this indicator.

The importance of this indicator is evidenced in the frameworks reviewed. Indicator sets from Arup and SeaPlan contain metrics related to the availability of assistance post-disaster. Arup, the SeaPlan report, and the memo written by a City of Boston Fellow in 2014 all also contain indicators related to continuity of operations planning, although mostly for businesses.

A grading scale for this indicator should be developed in consultation with BPHC and those implementing this initiative. Ideally, that office will have goals for the program, and coloring the indicator green could be defined to mean that the program is meeting or exceeding those annual goals, yellow could mean it is off by less than 10 percent, and red could mean it is missing the target by greater than 10 percent.

Limitations

The main limitation related to this indicator is that the data does not currently exist. It seems unlikely that this metric would be able to be included in the 2018 CAP update because BPHC has yet to launch the program. However, because BPHC is in the planning stages of this new program, now might be an opportune time for the Environment Department to work with that office to ensure that this metric and recommended sub-metrics are tracked from the beginning. This information can then be included in future CAP updates.

Additionally, this metric would likely only include the number of organizations and facilities with continuity of operations plans that participated in the program and would not account for those that already have plans.

Risk reduction indicator: Community awareness of hazards and need for adaptation
Metric: Number of Climate Ready Boston Leaders trained and number of people reached by these Leaders

Description

It is important that the public is aware of the hazards facing their communities and for residents to have conversations about how to contribute to adaptation efforts. Four of the six frameworks reviewed, as well as the SeaPlan report, include an indicator related to community outreach. The Climate Ready Boston Leaders (CRBL) program (an outreach program where City officials train residents in discussing climate change hazards and adaptation opportunities with their friends, neighbors, and coworkers) is the City's main effort to increase comprehensive outreach throughout Boston and is directly related to initiative 2.1 in the CRB report "Expand citywide climate readiness education and engagement campaign." Each Leader is charged with holding an event that reaches at least 30 other city residents. The pilot round of the program was launched in summer 2017 and a second round will be complete by late spring 2018.

Environment Department staff tracked several key data points related to this program, including the number of leaders trained and the number of people reached (through required feedback forms). They also tracked important locational data related to where leaders and their audiences hailed from and where events were held. Analysis of the distribution of leaders and participants could help City staff understand where to target outreach efforts for future rounds of the program.

A grading scale for this indicator should be created in tandem with those running the CRBL program. Assuming the goals for the program are aggressive, green could mean the annual goals for the program are met or exceeded, yellow could mean results are off by less than 10 percent, and red could mean results are off by greater than 10 percent.

Limitations

There are two potential limitations related to this indicator. First, the metric associated with the number of people reached is only a rough estimate because feedback form response rate is not always high. Second, the metric proposed is a rough proxy for the indicator; the number of people in the city aware of climate change risks and adaptation actions would be a more informative metric but would be much harder, if not impossible, to count.

Goal three: Protected shores

This goal relates to protecting Boston against flooding by investing in physical flood protection measures or nature-based solutions. Sub-goals include developing neighborhood-level resilience plans and creating a coastal protection system.

Risk reduction indicator: Residents and businesses guarded via coastal flood protection measures
Metric: Number of residents and businesses expected to be protected due to new coastal defense measures from the neighborhood-level planning processes

Description

For coastal cities, flood protection measures at the coastline (e.g., seawalls, berms, coastal dunes, flood gates, etc.) are very important to mitigating flood risk and protecting the people, buildings, and infrastructure within the city. Three of the six frameworks reviewed include an indicator related to coastal protection, as do NPCC, the SeaPlan report, and the 2014 memo by a City of Boston Fellow. Two of the frameworks include a metric specifically related to the number of buildings or residents secured via coastal protection projects.

The City of Boston is identifying coastal flood protection measures on a neighborhood scale through its local climate resiliency planning efforts (initiative 4.1 in the CRB report). It has completed a plan for East Boston and Charlestown and is currently developing one for South Boston. As these plans are implemented, the amount of flood protection measures will increase. When the East Boston and Charlestown plan was released in October 2017, Mayor Walsh announced that two of the recommendations would be completed in the near-term, including elevating Main Street in Charlestown and installing a deployable floodwall at the East Boston Greenway. The plan outlines the number of residents and approximate number of businesses that would be protected from these measures (City of Boston, 2017b). Any additional commitments made because of these neighborhood planning processes would likely also report on the number of people and businesses safeguarded. As long as the reporting format stays consistent, these commitments could easily be aggregated and included in CAP updates.

Because there is no specific target identified, I suggest using a scale that shows improvement over the years for this indicator. Green could be a 10 percent or greater improvement over the previous year, yellow be a slight improvement over the previous year, and red could represent no improvement or a decline in performance.

Because this metric focuses on capturing the benefits to society of different flood protection measures that the City is implementing and data can likely be collected systematically through the neighborhood planning processes, I identify this as one of the seven priority indicators in Table 6.

Limitations

This indicator has several limitations. First, it would only measure the additional number of residents and businesses protected because of new projects rather than the total number protected from all coastal defense measures that exist in the city. Second, it appears that the coastal defenses announced for Charlestown and East Boston protect against different potential hazard scenarios, so the level of protection afforded differs based on the project (City of Boston, 2017b). These discrepancies would not be apparent in the number of residents and businesses reported through this metric in the CAP update. Third, the City would need to decide whether to report out on these numbers when the projects are committed to, or when they are actually constructed. Because there could be many years between announcement and completion (e.g., the elevation of Main Street is not expected to start construction until 2021) the City may decide to report out on commitments rather than finished projects. The CAP update should make this clear. Fourth, this aggregate metric does not break down where the protected residents and businesses are located, but City officials should analyze the data spatially to make sure efforts are fairly and effectively distributed throughout the city. Finally, this number reflects a prediction of the number of residents and businesses protected, but this can only be verified after a flood event.

Risk reduction indicator: Amount of vulnerable coastline secured
Metric: Feet of coastal defenses completed

Description

This indicator is similar to the one above but gives additional insight into whether the City's goal of "protected shores" is being accomplished. As the City's neighborhood-level plans are implemented, the number of feet of flood protection projects will increase. Three of the six frameworks reviewed include a related indicator, as do the SeaPlan report and the 2014 memo by a City of Boston Fellow. Two of the frameworks and the NPCC paper include a metric specifically on the length of coastline protected.

In 2007, the Massachusetts Department of Conservation and Recreation (DCR) completed a study that documented flood protection measures at the coastline and reported out on key metrics, including the number of feet of coastal defenses in Boston (Bourne Consulting Engineering, 2007).

A grading scale for this indicator could also relate to change over time. Green could be a 10 percent or greater improvement over the previous year, yellow could be a slight improvement over the previous year, and red could mean no improvement or a decline in performance.

Limitations

This indicator has many limitations. First, the DCR study has not been replicated, making it a poor data source for ongoing monitoring. It could be used as a baseline and supplemented with new data, if a practical way to do this is discovered. Second, according to the report, in some cases there might be multiple coastal barriers at one location, resulting in over counting in number of feet of protection measures. Third, this metric does not take into account the condition of the structures and how adequate they are to meet future hazards. Finally, because some flood protection measures (e.g., flood gates) may be short in length but just as effective as lengthier infrastructure interventions, the number of feet of flood protection measures may not sufficiently convey the actual benefits of these projects.

Because both of the metrics proposed in this goal area have significant limitations, measuring both and analyzing them together may be especially important. Another metric the City could think about including under this goal is total City financial investments in these coastal protection measures, identified through the budgeting process. This measure, however, does not give much of an inkling as to how much of the City is protected, which should be a prime goal of this indicator. Still, it might be better to report on this in the short-run if data on either of the other two prove elusive.

Goal four: Resilient infrastructure

This goal relates to retrofitting current and creating new infrastructure to prepare for climate change impacts. The definition of infrastructure in the CRB report includes traditional utilities and the systems that support them, transportation networks, important facilities like hospitals and schools, and green infrastructure and natural systems that can mitigate effects of heat and flooding. Sub-goals in this category include coordinating investments to make infrastructure more resilient, developing district-scale energy solutions, and expanding the use of green infrastructure and natural systems.

Risk management indicator: Resilient electricity system
Metric: Average number of months between interruptions and system average time in minutes to restore service to customers

Description

As identified in Boston's vulnerability assessment, climate-related extreme heat and flooding can both lead to electricity outages, and the utility provider's ability to maintain service or rapidly address outages during events can sometimes be lifesaving. Reliability of the electricity system also prevents large interruptions to residents' daily lives and the economy. Four of the six frameworks reviewed contain an indicator related to reliable electricity. The report conducted by a City of Boston Fellow in 2014 also includes a similar indicator. Eversource, the main electricity provider in Boston, releases a sustainability report every year that includes the average number of months between interruptions and system average time in minutes to restore service to customers (Eversource, 2017). These can be used as proxy metrics.

While there are certain limitations with the scale of the data (discussed below), the importance of this indicator to four of the six case studies recommend its inclusion as one of the seven priority indicators in Table 6.

A grading scale for this metric should be crafted in partnership with Eversource. The company should have annual goals for these metrics. Assuming the goal is robust, green could mean meeting or exceeding the goal, yellow could mean missing the goal by less than 10 percent, and red could mean missing the goal by more than 10 percent.

Limitations

First, these metrics relate to Eversource's entire service area that covers Massachusetts, Connecticut, and New Hampshire. It is unclear if they would release Boston-specific numbers; City staff should consult with the company to understand if that would be possible. The fact that New York City was able to release city-specific numbers from its utilities is perhaps a promising sign for Boston. Second, these numbers technically reflect outages for more than just climate-related events. However, Eversource's 2017 report identifies weather-related events as the main reason for a drop in reliability that year. This justification indicates that these metrics may be an adequate proxy for reliability during and after climate-related events.[6] They should be analyzed in conjunction with the three hazard level context indicators to interpret performance in relation to different levels of risk year-to-year (e.g., if the coastal flooding hazard level increases but these electricity metrics stay the same, this could suggest good performance). Third, the last data reported are from 2016, suggesting a slight lag in data publication. Finally, this indicator does not take into account geographic location or social vulnerability issues; the distribution of power outages is important to understanding if at-risk groups are being disproportionately affected.

[6] The Eversource report states, "During 2016, we experienced twice the number of storm events compared to 2015, and the multiple lightning and wind storms, combined with drought conditions that stressed trees and caused damage to our equipment, led to electric reliability performance behind plan" (Eversource, 2017).

Risk management indicator: Reliable public transit
Metric: Reliability of buses, subway, and commuter rail (yearly average)

Description

The Massachusetts Bay Transportation Authority (MBTA) is a public agency that runs most of the public transit system in Greater Boston. Climate change may cause disruptions to service through extreme weather events (e.g., flooding from a storm) or slow degradation of infrastructure (e.g., road buckling, derailments, etc.) (City of Boston, 2016b). To be resilient, the MBTA must be able to meet a high level of service despite these changes. Public transit may serve an important function during and after extreme weather events, including transporting residents out of town or to emergency shelters. This indicator is important to risk management, as it may show whether investments in adapting transportation infrastructure to climate risks are paying off. Three of the six frameworks reviewed plus the SeaPlan report and the 2014 City of Boston Fellow memo include measurements of transit resilience, although most are risk reduction-related (e.g., number of transportation assets adapted to climate change). The NPCC, on the other hand, takes this risk management approach with its recommendation to track "number of weather-related transit and subway outages per year" (Solecki et al., 2015). The MBTA collects and publishes daily data on the reliability of its bus, commuter rail, and subway lines, so this information could be easily compiled into a yearly average and included in the CAP update. The MBTA also defines its own targets for these metrics (MBTA, 2018).

The MBTA has goals for this indicator, and the City should use these goals when creating a grading scale. Assuming the goals are aggressive, green could mean meeting or exceeding the goal, yellow could mean missing the goal by less than 10 percent, and red could mean missing the goal by more than 10 percent.

Limitations

First, while these data may give some indication of the City's overall transit reliability, a more informative metric for these purposes would be average response time during and after extreme weather events. Because this metric is collected daily, this type of analysis is possible but would depend upon a standard definition of an emergency event for each hazard and would require more processing time. Second, the MBTA serves the Greater Boston area, so this is a regional rather than a city-specific metric, although the city is the focal point of the system. Finally, this indicator also does not take into account geographic location or social vulnerability issues. The distribution of reliability is important to understanding if at-risk groups are disproportionately affected by subpar service.

Risk reduction indicator: Increased tree canopy coverage
Metric: Net number of new trees per year (plantings minus removals)

Description

As mentioned in the vulnerability assessment, increased tree canopy can help mitigate problems related to heat and the UHI effect. Trees can also mitigate urban flooding by retaining water. Three of the six frameworks reviewed include such an indicator. The 2014 report by the City of Boston Fellow, the SeaPlan report, and NPCC also include such an indicator in their recommendations.

While a percentage of the city covered by tree canopy would be a more ideal metric, consistent data are unavailable. A Boston Parks and Recreation Department study from the early 2000s identified tree canopy coverage of 28 percent (City of Boston, 2015) and set a target for 35 percent, but the study was not replicated. The Parks Department recently conducted an updated tree canopy study with the Metropolitan Area Planning Council and the University of Vermont in response to initiative 8.5 in the CRB report "Develop an action plan to expand Boston's urban tree canopy" (City of Boston, 2018), but information is not yet publicly available and is also not likely to be replicated. The most consistently collected metric available may be tree planting and removal data from the City Arborist (M. Mansfield, personal communication, January 12, 2018).

In the absence of specific targets, a grading scale for this indicator should hold the city to improvement over time. Green could be a 10 percent or greater improvement over the previous year, yellow be a slight improvement over the previous year, and red could represent no improvement or a decline in performance.

Because of the importance of trees in mitigating both heat and flooding and this indicator's inclusion in three of the six frameworks reviewed, I include it as one of the seven priority indicators in Table 6.

Limitations

As mentioned above, this metric is a rough proxy; number of trees planted and removed does not provide information on the amount of canopy they provide. Second, this indicator does not take into account social vulnerability issues and spatial distribution, and it is unclear if the data is collected in a way that could facilitate this analysis. The distribution of tree canopy is important to understanding if at-risk groups are being disproportionately affected and if trees are being planted in areas most affected by the UHI effect. Finally, this metric only includes trees that are planted and maintained by the City.

Risk reduction indicator: Amount of green space
Metric: Park land as a percentage of city area

Description

Open space and permeable surfaces are important for mitigating against heat effects and absorbing storm and flood waters (City of Boston, 2016b). Three of the six frameworks reviewed include a measure of green space. The reports conducted by a City of Boston Fellow in 2014 and SeaPlan also include a similar indicator. The Trust for Public Land (TPL) and the City have a strong history of partnership, so using this organization's regularly updated data seems like a good fit. The most recent data are from 2017 and are updated yearly via TPL's ParkScore® Index that rates the 100 largest U.S. cities on the adequacy of their park systems. One of the metrics that makes up the final score is "park land as a percentage of city area," and Boston could leverage this metric instead of trying to collect its own data (TPL, 2018).

A grading scale for this indicator could also be based on improvement over time. Green could mean a 10 percent or greater improvement in amount of green space over the previous year, yellow could mean a slight improvement over the previous year, and red could mean no improvement or a decline in performance.

Limitations

First, this is a rough proxy for the amount of green space/permeable surface because it only includes park land. It does not capture green infrastructure additions (e.g., green roofs) that are also extremely important. Second, this aggregated indicator does not in-and-of-itself convey information on geographic distribution and social vulnerability issues, but TPL does include maps of how parkland is distributed, so these data layers could be utilized by the City to make sure the benefits of open space are reaching vulnerable populations and the areas most at risk to climate impacts.

Risk management indicator: Adequate stormwater system
Metric: Volume of sanitary sewer overflows (SSOs)

Description

To be resilient to flooding, the City must take action to both manage the amount of water going into the stormwater system as precipitation and coastal flooding increase in intensity, duration, and frequency and ensure the infrastructure is adequate to accommodate these new conditions. The frameworks reviewed highlight the importance of selecting a metric related to the adequacy of the stormwater system, with four of the six frameworks including related indicators, as well as the SeaPlan report and the 2014 memo by the City of Boston Fellow. A popular metric used by the frameworks are measures of combined sewer overflows. BWSC reports out data on its version, sanitary sewer overflows (SSOs). In September 2012, BWSC started a program to monitor and report all public and private SSOs to the Massachusetts Department of Environmental Protection and the EPA within 24 hours (BWSC, 2017). This information is also provided to the public via a map and associated data tables on BWSC's website. The description notes that "Some SSOs occur when wet weather events cause inflows to exceed the collection capacity of the system, producing an overflow of sanitary sewerage." (BWSC, 2018a). These data are kept up-to-date and include the volume of the overflow for each SSO. BWSC's map also details where these SSOs occur throughout the city, giving the public and City staff more information on which to base equity and geographic distribution analyses.

For this metric, an analyst could compare the volume of SSOs in Boston to other cities with similar average rainfall and storm events during the year in question. Green could mean Boston is doing well compared to these other cities, yellow could mean Boston is doing about average, and red could mean Boston is doing worse than these other cities. I suggest comparison among cities for this metric because comparing performance only within Boston from year-to-year does not factor in changes in the level of stormwater flooding hazard, which could skew interpretations of progress.

Limitations

There are potential limitations related to the data set, and further investigation with BWSC is required to make sure it is viable. While it would be ideal to report out the SSOs per wet weather event, the data on the causes of each SSO reported out by BWSC do not appear to help in distinguishing which SSOs were caused by storms. Some incidents can definitely be ruled out because they are attributed to such problems as improper fat, oil, and grease disposal, but others are less clear. Additionally, a quick analysis of the data shows no entries from the day of Winter Storm Grayson on January 4, 2016 (a known flooding event), which raises questions about the accuracy of this data set.

Goal Five: Adapted buildings

The last goal identified in the CRB report is related to creating "a regulatory environment and financial and other tools to promote new and existing buildings that are climate ready" (City of Boston, 2016b). Sub-goals include updating zoning and building regulations, retrofitting existing buildings, and insuring buildings against the effects of flooding.

Risk reduction indicator: Increased flood insurance coverage
Metric: Number of flood insurance policies across the city

Description

Flood insurance is an important part of risk reduction because it allows residents the ability to rebound after a flood event by making it financially feasible to repair damages. This indicator is specifically important to evaluating the initiatives related to flood insurance included in the CRB report, including initiative 11.1 “Evaluate the current flood insurance landscape” (City of Boston, 2016b). The uptake of flood insurance policies across the city could also could be an indicator of the success of community outreach programs around resilience; more dissemination about the risks of climate change could lead to increased demand for insurance. Three of the six frameworks reviewed contain metrics related to flood insurance.

The Federal Emergency Management Agency (FEMA) tracks data related to flood insurance under NFIP. Boston’s 2014 Hazard Mitigation Plan (HMP) (that is updated every five years) includes the number of flood insurance policies in force in the city. It is unclear if this statistic would be able to be reported on more regularly, but the City of New York has an updated number of flood insurance policies across the city in its 2018 progress report, which may mean it is possible.

A grading scale for this indicator could be based on improvement over time. Green could be a 10 percent or greater improvement in number of flood insurance policies over the previous year, yellow could be a slight improvement over the previous year, and red could be no improvement or a decline in improvement compared to the previous year.

Assuming the City is able to obtain yearly data on this indicator, I include it as a priority indicator in Table 6 because it is in three of the six frameworks and is heavily emphasized in the CRB report.

Limitations

More information would need to be collected about this data set to ensure its reliability and ability to be included in a monitoring system. It appears FEMA used to publish this data set publically at the city scale (according to the 2014 HMP source citation for these data), but the agency currently only reports this information at the state level (FEMA, 2018). Therefore, it is unclear how often this data set is collected by FEMA at the city level. (Although, as mentioned above, New York City's updated number included in its 2018 progress report lends hope to the idea that it might be possible for Boston to also report out on this indicator annually.) It is also unclear whether the data are broken down by neighborhood to aid in understanding geographic and equity-related distributions.

Risk reduction indicator: Resilience components incorporated into new development
Metric: Number of buildings incorporating resilience measures from Article 80 Climate Resiliency Checklist

Description

Revised in December 2017, all developments that trigger the Article 80 review process (generally developments greater than 50,000 square feet) must complete the Climate Resiliency Checklist (BPDA, 2017). The checklist asks for information about how developers are incorporating resilience components into their projects. It addresses extreme heat, sea level rise, and storms. A current academic project that involves cataloguing checklist data should be helpful in supplying data for this metric (M. Mansfield, personal communication, January 12, 2018). Three out of the six frameworks include a similar indicator, as do the SeaPlan report and the 2014 memo by the City of Boston Fellow.

A grading scale for this indicator could be based on improvement over time. Green could be a 10 percent or greater improvement over the previous year, yellow could be a slight improvement over the previous year, and red could be no improvement or a decline in performance compared to the previous year.

Because this indicator is related to an important focus area for the City, there is the potential for a robust data source, and it is incorporated into several of frameworks reviewed, I include it as one of the seven priority indicators in Table 6.

Limitations

This metric simply conveys information on the aggregate amount of buildings that are taking steps to incorporate resilience measures into their design; it does not indicate how robust these measures are. It could be appropriate to pick specific measures identified through the checklist (e.g., buildings built to a specific flood elevation standard) instead of an overall total number of buildings filling it out. Second, this metric mostly captures new development, while retrofitting existing buildings is also extremely important because Boston is already densely developed.

Risk management indicator: Economic losses due to flood events
Metric: FEMA dollars spent on repetitive loss properties

Description

Economic losses resulting from flood events is an important risk management indicator related to coastal flooding. NFIP tracks total economic losses from repetitive loss properties, which it defines as "any property for which the NFIP has paid two or more flood claims of $1,000 or more in any given 10-year period since 1978" (City of Boston, 2014b). This number is reported every five years through Boston's HMP update. Analyzing this number over time will help to decipher the effectiveness of risk reduction efforts like coastal protection projects and resiliency retrofits for buildings. Three of the six frameworks include specific measures of damages to property from flooding. In addition, the *OneNYC* plan includes an indicator for total average annual economic losses from all sectors (instead of just to property), although this has yet to be operationalized and is left blank in the plan (City of New York, 2018).

For this metric, an analyst could compare FEMA dollars spent in Boston versus other comparatively sized cities facing similar rainfall and storm events in a given year. Green could mean Boston is doing well compared to these other cities, yellow could mean Boston is doing about average, and red could mean Boston is doing worse than these other cities. I suggest comparison among cities for this metric because comparing performance only within Boston from year-to-year does not factor in changes in the level of flood hazard, which could skew interpretations of progress.

Assuming the City is able to obtain annual data on this indicator, I include it as a priority indicator in Table 6 because it is in three of the six frameworks and has the ability to convey information on whether risk reduction measures (like the Article 80 checklist mentioned above) are successful.

Limitations

The limitations associated with this indicator are similar to those for flood insurance claims data because FEMA collects the data associated with both. More information would need to be acquired about this data set to ensure its reliability to be included in a monitoring system. The City does report out on this statistic every five years via its HMP update, and it is possible that FEMA could make this information available to the City on a more regular basis. The City should also check if it can access geographic information about these losses for more detailed analysis.

Additionally, this data set only collects information on repetitive loss properties, not those that experience losses for the first time. This means that if a flooding event occurred in 2018, only those properties that previously successfully filed claims would be counted. As of 2014, there were only 23 repetitive loss properties in Boston (City of Boston, 2014b). Therefore, this metric would likely significantly underestimate the total property damage of a future flood event. According to the FEMA website, the agency also reports out annually on the the total claims payments by state. If they collect this information at the city level, this may be a more desirable indicator because it would include more than just repetitive loss structures (FEMA, 2018).

Risk reduction indicator: Prepared municipal facilities
Metric: Budgeted investments in resilience projects through the capital planning process

Description

Related to initiative 10.2 in the CRB report "Prepare municipal facilities for climate change," the City has recently included climate change resiliency as a stated goal within the capital planning process (M. Mansfield, personal communication, January 12, 2018). An inventory of capital improvement projects is maintained by the City, and new projects are reported out to the public every year as part of the City's budgeting process. The City's website currently lists the FY2018 projected budget broken down by category, with resilience-related projects in the energy and environment category. Two projects in the list, Long Wharf and Climate Ready Boston, have descriptions that highlight climate resiliency as the impetus behind the project (City of Boston, 2017d). Once the budget is adopted, the actual numbers associated with these projects could be added together and reported out to the public via a climate adaptation monitoring system.

While many frameworks mention the need to adapt facilities and infrastructure to climate change, surprisingly only the NPCC and the SeaPlan reports include financial expenditure on resilience projects as a specific indicator. Because these data are easier to collect than the amount of benefits received from these improvements, it may be a reasonable starting metric for the City. A grading scale for this indicator could be based on improvement over time. Green could be a 10 percent or greater improvement over the previous year, yellow could be a slight improvement over the previous year, and red could be no improvement or a decline in improvement compared to the previous year.

Limitations

There are two potential limitations associated with this indicator. First, the definition of a resilience capital planning project is relatively fuzzy. While projects listed in other capital budget categories (e.g., open space) might include some resiliency components, limiting those included in this metric to the energy and environment category may be necessary to keep the task of tracking these projects manageable. Only those that state clearly in the description that their purpose is to increase resilience to climate change or reduce flooding or heat-related vulnerabilities should be counted.

Second, while the funds for capital projects may be allocated for a specific year, they may not all be spent in that year. For simplicity's sake, the City may want to report on the amount of money allocated rather than what is actually spent. This should be made clear to the public, so residents know there may be a lag between the amount of investment reported and the benefits of the project accruing to society. A more robust indicator may include the specific level of protection provided by these investments (e.g., in terms of damage avoided), but there are no current feasible proxies for this.

Risk reduction indicator: Climate risk considerations included in neighborhood planning processes
Metric: Percentage of neighborhood plans released annually that contain climate change preparedness recommendations

Description

An important risk reduction measure relates to the incorporation of adaptation concepts into neighborhood plans within the city. Including climate change considerations as a key part of these BPDA-run planning processes means adaptation actions are more likely to be carried out in these areas. It also increases climate change outreach and awareness, as residents participating in the planning processes will be more informed about their risks. BPDA keeps a database of all of its planning efforts, so annually culling through them to find those with climate change preparedness recommendations should be a feasible task. While no frameworks reviewed include this specific indicator, four of the six, as well as the SeaPlan report and the 2014 memo by the City of Boston Fellow, contain general planning indicators. This measure is directly related to initiative 9.5 in the CRB report "Incorporate future climate conditions into area plans," so it is an appropriate indicator for Boston.

A grading scale for this indicator could be based on improvement over time. Green could be a 10 percent or greater improvement over the previous year, yellow could be a slight improvement over the previous year, and red could be no improvement or a decline in performance compared to the previous year.

Limitations

There are two limitations associated with this indicator. First, it does not measure the level of resilience reached by these plans. Second, as noted above, this data set does not already exist, although it should not require much time to create.

Context indicators

Because of the shifting baselines problem discussed in Part I, it will be important to analyze the above risk management and risk reduction indicators in the context of changing climatic conditions. For example, while in any given year heat-related illness may increase over the previous year, the severity of the summer could have increased by a significant amount. Thus, a few more heat-related illnesses may not actually indicate that actions to reduce heat risk are not being effective.[7] Because of the dynamic nature of climate change, it is important to understand all indicators in context and clarify these types of trends for the public through qualitative explanations of changes in indicator values.

Hazard indicator: Current level of heat hazard
Metric: Average summer daily maximum temperature (May through September)

Description

Temperature is increasing due to climate change, meaning summers will get hotter on average. This creates risks for people, buildings, infrastructure, and the economy. The National Oceanic and Atmospheric Administration (NOAA)'s NOWdata reports high temperatures every day, archived by month. This data would require a small amount of processing, simply using the averages provided in the report-outs to create an annual average (NOAA, 2018c). This metric gives a rough indication of the warming trend and is important context to the heat-related indicators included above. In particular, this metric works well with that of the heat-related illness data because both are averaged from May to September. It is important for these two data sets to align so that the hazard indicator gives maximum context to changes in heat-related emergency department visits, a key indicator of the city's heat risk management.

Limitations

This metric only provides an average temperature and does not contain information on the frequency, intensity, and duration of extreme events, which are important factors to consider

[7] This is also why the recommended grading scale for this indicator compares heat-related illness to other cities with similar levels of heat hazard in a given year.

when analyzing impact. Heat can also differ by geographic location, which has led some cities like Baltimore, Maryland to turn to citizen science projects to measure heat at assigned community hotspots (Baltimore Office of Sustainability, 2018).

Hazard indicator: Current level of stormwater flooding hazard
Metric: Annual mean precipitation (inches)

Description

As precipitation levels increase due to climate change, the amount of rainfall will be an important indicator of the hazard of stormwater flooding. BWSC collects rainfall data via eleven solar-powered rain gauges on public buildings scattered throughout the city. These data are also reported as a yearly average (BWSC, 2018b). This metric provides context for many of the indicators above. For example, if precipitation increases but the volume of SSOs remains constant, this would provide evidence that actions related to reducing stormwater flooding risks are working.

Limitations

This metric only conveys average annual precipitation and does not provide information on the frequency, intensity, and duration of events. Rainfall can also differ by geographic location, meaning City officials should analyze the neighborhood-specific rainfall data that BWSC provides in addition to the citywide average.

Hazard indicator: Current level of coastal flooding hazard
Metric: Number of days per year in which coastal waters rose above the local threshold for minor flooding

Description

Sea level rise related to climate change is a main driver for coastal flooding because as the planet warms glaciers and ice sheets melt and thermal expansion occurs. A localized measure of this impact can be determined by analyzing tide height in feet as compared to a threshold for flooding determined by the National Weather Service (NWS) for Boston.[8] According to the EPA, which selected this indicator to measure coastal flooding in its *Climate Change Indicators in the United States, 2016* report, NWS flood thresholds vary by location based on observed impacts and "depending on land cover, topography, and the presence of flood defenses such as seawalls" (EPA, 2016).

NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) operates a tide gauge at the Fort Point Channel and reports out on tide levels every six minutes via their "Tides and Currents" website (NOAA, 2018b). While a bit labor intensive, scanning through each day of the year for tide levels above 12.5 feet (i.e., the Boston threshold) should be a feasible task. If measured over a number of years, this indicator helps to understand sea level and coastal flooding trends and will be important to understanding whether adaptation actions are adequately addressing the changing severity of this risk.

[8] The flood threshold for Boston is 12.5 feet mean lower low water (MLLW). The moderate flood threshold is 14.5 feet, and the major flood threshold is 16 feet (NOAA, 2018a).

Limitations

The NWS website points out that coastal flooding impacts are dependent on wave action as well as sea level. Intense wave action can cause flooding even if tides do not reach the flooding threshold.

Qualitative indicators

Some important components of resilience may be better served by qualitative explanations than quantitative metrics. As mentioned above, goal one “updated climate projections” is one such component. CAP updates should include a description of how the City is doing on reconvening the BRAG and updating climate projections and maps. Additionally, an essential piece of both Boston’s current strategy and the frameworks reviewed are actions related to amending zoning ordinances and building codes to promote adaptation, and this process is hard to quantify numerically. A written update on the progress toward achieving these actions could be included in the CAP update. Both of these components are included in Table 6.

Part VII: Key Findings and Conclusion

This foray into crafting adaptation indicators for Boston revealed challenges and opportunities, many of which may be faced by others attempting to craft indicators in various locales. In this section, I distill key lessons learned while researching the topic of adaptation indicators and formulating the set presented in Part VI.

Overcoming resistance to indicator adoption is possible

Based on the many challenges to crafting adaptation indicators, it is easy for a city to justify delaying the task. In order to hold itself accountable to the goals it hopes to achieve, however, evaluation is a necessary component of any program. It is no surprise that New York City, with its long history of performance management, is among the first to create and publish adaptation indicators. For most other cities that are not as data-driven, the situation is more challenging, but not impossible to overcome. Starting with just a handful of indicators specifically tailored to the city's priorities may be enough to overcome the status quo. Indicator frameworks like CRI and METRO that contain hundreds of indicators can seem overwhelming to cities struggling with resource and personnel constraints. It is much harder, on the other hand, for a city to justify delaying implementation of a small set of indicators with specific proxy metrics and routinely updated data sets.

Connecting back to the challenges presented in Part I, below I detail how my indicator set suggested for Boston overcomes many of these issues.

- **Defining success-** I attempt to overcome the problem of defining successful adaptation by basing my selection of indicators and metrics off of Boston's vulnerability assessment and the resilience goals and actions that Boston is pursuing. These components have been guiding Boston’s actions in these areas, so evaluating success on their terms is a logical and justifiable place to start.

- **Long time-horizons and shifting baselines-** By including context indictors that will help to showcase changes in the severity of specific hazards year-to-year, I help provide a consistent set of information to show how baselines are shifting in relation to the other risk reduction and risk management metrics. Additionally, implementing a grading scale for some indicators where performance is compared to other cities facing similar levels of hazard is another way to control for climate-related fluctuations. For those actions where success is born out over a long time period, I focused on identifying risk reduction indicators (e.g., number of people expected to be protected from the installation of new flood protection measures) or risk management indicators that measure overall capacity of the system (e.g., reliability of electricity services year-round). The former gives insight into the amount of risk that can be expected to be avoided in the event of a storm, while the latter gives insight into how the system may perform during an extreme weather event (i.e., if it is not performing well overall, it likely will not perform well in a worst case scenario). In addition to monitoring these proxy indicators over time, cities should conduct in-depth analyses in the aftermath of significant events to compare expected to actual performance. If indicators show a high level of expected resilience, but a storm causes major destruction, that would be a sign to reevaluate the indicators used.
- **Potential for maladaptation-** While it may be impossible to predict and thus measure every potential unintended negative impact of an action, by carefully analyzing each indicator in relation to city values (e.g., equity) it is possible to uncover whether an action

is disproportionately burdening a particular socially vulnerable group, for example. Looking at specific sub-metrics and mapping some of the indicator data spatially can help with this analysis (as detailed later in this section).

- **Invalid measures-** Because of the relative newness of the field and data limitations, it currently might not be possible to track the most desirable indicators. Despite this, it is important to start somewhere. By selecting indicators based off of community goals and values and those that have been successful in other frameworks and cities, Boston can hope to avoid the problem of invalid measures. Exploring sub-metrics can also help bolster the adequacy of a measure. If a metric is determined to be invalid or a more desirable metric is available in the future, the City should edit its evaluation accordingly.
- **Resource constraints-** By focusing on data already available or easily collected for my suggested metrics, I attempt to overcome the problem of resource constraints and provide Boston with indicators that will be both useful and used.

Reviewing existing frameworks is helpful but can only take you so far

A common theme heard from both City of Boston officials and many interviewees is that municipal governments and stakeholders desire a set of indicators tailored specifically to the circumstances of their city. Because cities face different climate hazards and have different systems, services, and values, it is not possible to create one set of adaptation indicators that would be appropriate for all. While some frameworks have attempted to create one set, municipal leaders have generally been uncomfortable with that approach, especially when it comes to ranking cities against each other. Other factors unique to cities (e.g., the amount of data available) also make translating metrics used by one city directly to another challenging.

Additionally, multiple interviewees mentioned the importance of tying indicators to a city's existing goals in this arena, as well as actions it is taking to address these goals. By fitting indicators and metrics in with the structure of an adaptation plan, city leadership can better understand if the actions they are taking are improving conditions for residents. Publishing indicators and metrics along with plan updates gives city officials a built-in timeframe for evaluation, so that these measures are reported out to the public on a consistent basis.

Because of the need for a localized approach, this means every city will likely need to undergo a similar exercise to the one undertaken in this thesis, where staff or outside partners craft indicators appropriate for a particular city informed by, but not identical to, those included in other frameworks and plans.

Data is a key limitation, for now

Data availability was a key problem throughout all the frameworks reviewed. Like Boston, many cities have only recently started to make a concerted push to collect data on government functions and activities and distribute these data sets to the public. An additional problem for the adaptation field is that it is relatively new, and there is not yet consensus on what to measure. Or, even if cities know what they would like to measure, there may not be robust methodology or technology for how to measure it (e.g., amount of flooding in a given area). This makes developing indicator sets for resiliency a search for rough proxy metrics often based on what data the City is collecting in other areas. Data limitations can be particularly problematic in small cities with fewer resources.

Even if a data set exists for an ideal proxy indicator, another problem that often presents itself is that the data set might not be updated on a consistent basis. For example, while there have been several studies of tree canopy coverage in Boston over the years, they are often one-time studies that would not provide the City with a metric that it could regularly publish to monitor change (and measure success) over time.

In the coming years, it seems likely that cities will see a proliferation of data sets, as well as increasingly widely accepted methodologies and technologies for collecting adaptation-related data. Even with this new information, there will likely still be city actions that are better expressed qualitatively. Boston and other cities should remember the importance of supplementing any quantitative metrics with qualitative information.

Quantitative indicators are not prerequisites for action

The search for indicators and monitoring using indicators should not become a substitute for action or an excuse for not taking action. While quantitative indicators are often important to understanding success, in many cases a robust plan for qualitative evaluation can be sufficient for initiating action. Quantitative indicators can be added later on, when appropriate. As mentioned above, there are also certain actions that may only be appropriate to evaluate qualitatively. Actions that are particularly ripe for qualitative analysis (and thus can be initiated right away) include the following:

- Conducting a local vulnerability assessment and crafting a plan that identifies actions to reduce those vulnerabilities and enhance resilience.

- Developing a strategy to train city staff on climate risks and identifying ways to integrate climate adaptation planning into all city departments.
- Exploring changes to zoning and building codes that address risk.

Additionally, many key actions (e.g., expanding health insurance coverage and planting trees) have been important to society long before climate change was seen as a threat, and cities can leverage existing efforts and metrics on these actions to increase resilience, lessening the burden of starting from scratch.

Finding ways to analyze adaptation actions' level of impact (including on socially vulnerable groups) is critical

To promote equity, it is important to ensure that the actions that Boston and other cities take adequately benefit vulnerable groups, or at least do not disproportionately burden them. Any evaluation of adaptation should attempt to reveal how actions affect these groups. For example, while Boston may show significant improvement in the number of people protected by newly installed flood barriers (an indicator I suggest in Part VI), if the people protected are primarily from traditionally privileged groups, the city will be falling short on its goals to advance equity.

As mentioned in the limitations of many of the indicators in Part VI, ideally many of the them would be broken down by different social variables and by geographic distribution. The City should consider integrating some of the indicators into the Climate Ready Boston Map Explorer, a recently published tool that houses all the data from the Climate Ready Boston report. Via this tool, the geographic distribution of indicators could be displayed and could be overlaid with different social vulnerability variables (already included in the tool) (City of Boston, 2017c). For example, if a GIS data set was available for tree plantings and removals, this could be added as an additional layer to the existing tool.

City staff should carefully consider which indicators would benefit from this kind of spatial analysis. Most of the data sets are currently not in a GIS format, so significant data collection alterations and processing would likely be needed. The benefits of mapping each indicator should thus be weighed against these significant costs. Additionally, some indicators like "residents and businesses guarded via coastal flood protection measures" may not be good candidates for spatial mapping because the data could be easily misinterpreted. Just because a particular building is expected to be protected because of a flood protection measure installed by the City does not mean other areas will definitely be flooded. Identifying these specific buildings as protected may also give residents a false sense of security that their homes or businesses will be safeguarded from all kinds of climate-related events (and therefore disincentivize them from taking additional site-specific protective measures), when really this protection cannot be guaranteed.

Another way to understand different levels of impact of City actions (including on socially vulnerable groups) is to disaggregate the indicator data. Thus, the last column in Table 6 lists some potential sub-metrics that could help the City decide if it is taking action in ways that provide the most impact. For example, instead of just analyzing the net number of trees planted, the City could look at the net number of trees planted in tree deficient areas or the net number of trees planted in areas with high percentages of socially vulnerable groups. For many risk management indicators, sub-metrics can help the City understand if different risk reduction actions have been successful (e.g., FEMA dollars spent on repetitive loss properties in areas with high percentages of green space versus areas with low percentages of green space).

Progress should be easy to understand

To make the performance clear to the public, the City should consider ways to convey performance on the various indicators that is easier to understand than a raw number. The ideal way to accomplish this would be to establish a grading scale for each indicator (green for good performance, yellow for average performance, and red for poor performance). Each time the set of indicators is updated, the color of the indicator would be reassessed based on the scale. I suggest what a scale could look like in the description section for each indicator in Part VI. In general, for those with pre-established targets, the scale could be based around those. For many risk reduction indicators, understanding if they improved significantly over the previous year may be the most appropriate way to understand progress, especially in the absence of a specific target. For risk management indicators like heat-related illness, the scale might be based on a comparison to the performance of other cities with similar summer temperatures to control for hazard level fluctuations.

Besides weather fluctuations (for which the related hazard indicators can provide context), there are many other external factors that could cause significant changes in indicator values in a given year (e.g., a change in federal health policy might increase the number of uninsured people by a large amount). Therefore, it is important to include a qualitative explanation of any significant fluctuations in conjunction with published numeric values, so the public understands the circumstances fully.

This is similar to the approach taken in *OneNYC* but with significant improvements. Each *OneNYC* update includes both the new and previous data and shows if performance has improved or not since the last measurement using stoplight colors (see Figure 16 for a visual example of *OneNYC*'s system). This approach is less robust than the one suggested for Boston above because it is only based on a relative scale with no other performance standards. For example, if the baseline metric for an indicator is severely deficient and it remains stable or improves slightly (but is still deficient) in the next year, the indicator is colored green according the *OneNYC* legend. The fact that performance is sub-optimal will be hidden from the public, especially if the target for the indicator is only "increase" or "decrease" instead of a specific number (as it is for many of the *OneNYC* metrics).

Figure 16: Example of *OneNYC* performance scale (City of New York, 2018)

Vision 4: Buildings

4.2.1	Number of flood insurance policies across the city	55,000 (2018)	55,700 (2017)	Increase
4.2.2	Square footage of buildings upgraded against flood risk	21,534,000 (2018)	7,692,000 (2017)	Increase
4.2.3	Number of elevated homes in the Build It Back program (cumulative)	1,315 (2018)	957 (2017)	Increase

- Performance Improving or Stable
- Performance Declining (< or = 10%)
- Performance Declining (> or = 10 or Zero Tolerance*)
- New Indicator or No Data Available This Year

Progress should be easily accessible

Besides being easy to understand, progress should be easily accessible. In addition to publishing indicators in each CAP update, they could be housed on a web dashboard on the City's website and updated annually. Boston's *Imagine Boston 2030* metrics dashboard is a good example on which to base this effort.

Because data sets for these indicators vary in the amount of lag time and consistency of data collection, metrics should be reported along with the year they were last measured. An interactive dashboard could include the Climate Ready Boston Map Explorer where some of these indicators are mapped spatially to understand impact in terms of location and interaction with socially vulnerable groups. Including important sub-metrics and charts to show change over time would also be helpful.

Connecting evaluation to action will be a vital next step

After collecting indicator data, it can be challenging to figure out how to prioritize City efforts to address the information they provide. One way to help in this analysis is to employ the EPA METRO tool discussed in Part V. In that tool, each indicator is weighted by experts based on their judgments about the importance of the indicator to the city's resilience (i.e., its importance score) and its performance based on thresholds established in the literature or through case-specific analysis (i.e., its resilience score). I provide an example for how Boston might use this tool to prioritize action on its suggested indicators in Table 7 and Figure 17 below. It is important to note the assumptions and limitations related to the resilience scores, as I did not have access to many of the data sets and/or made my own assumptions about what ideal performance looks like in the absence of targets. My justification for each score is included in Table 7. Because one of the main reasons I selected each of these indicators was because of its relevance and importance to Boston, all the indicators have high importance scores.[9] For those that I did not assign the maximum score of four, I include the justification in the appropriate cell.

Table 7: Applying the EPA METRO tool concept to suggested Boston indicators

ID number	*Indicator*	*Metric*	*Importance score*	*Resilience score and justification*
1	Prevalence of heat-related illness	Heat-related illness emergency department visits during warm-weather months per 100,000 residents	4	3 In 2015 there were 10 emergency department visits per 100,000 people. This number has remained relatively consistent from 2011-2015 and is similar to other parts of Massachusetts. While it would be preferable for the number to be even lower, resilience in this area seems to be adequate for now.
2	Adequate health insurance coverage	Civilian non-institutionalized population without health insurance	3 While health insurance will be important as climate effects worsen, it is arguably a bit less important than some of the other indicators in the list.	4 The EPA METRO tool details that cities where less than 5% of people lack health insurance should receive a resilience score of 4. In 2016, only 4.5% of people lacked health insurance in Boston.
3	Reliable emergency response	Average annual Emergency Medical Service (EMS) response time- EMS priority 1 responses triggered by 911 calls related to life-threatening illness or injury	4	3 The EPA METRO tool details that cities with an average response time of less than 8 minutes should receive a resilience score of 4. While the Boston's response time appears to be less than 8 minutes, it has also recently been missing the 6 minute target goal that the City set for itself. Thus, I give it a score of 3.

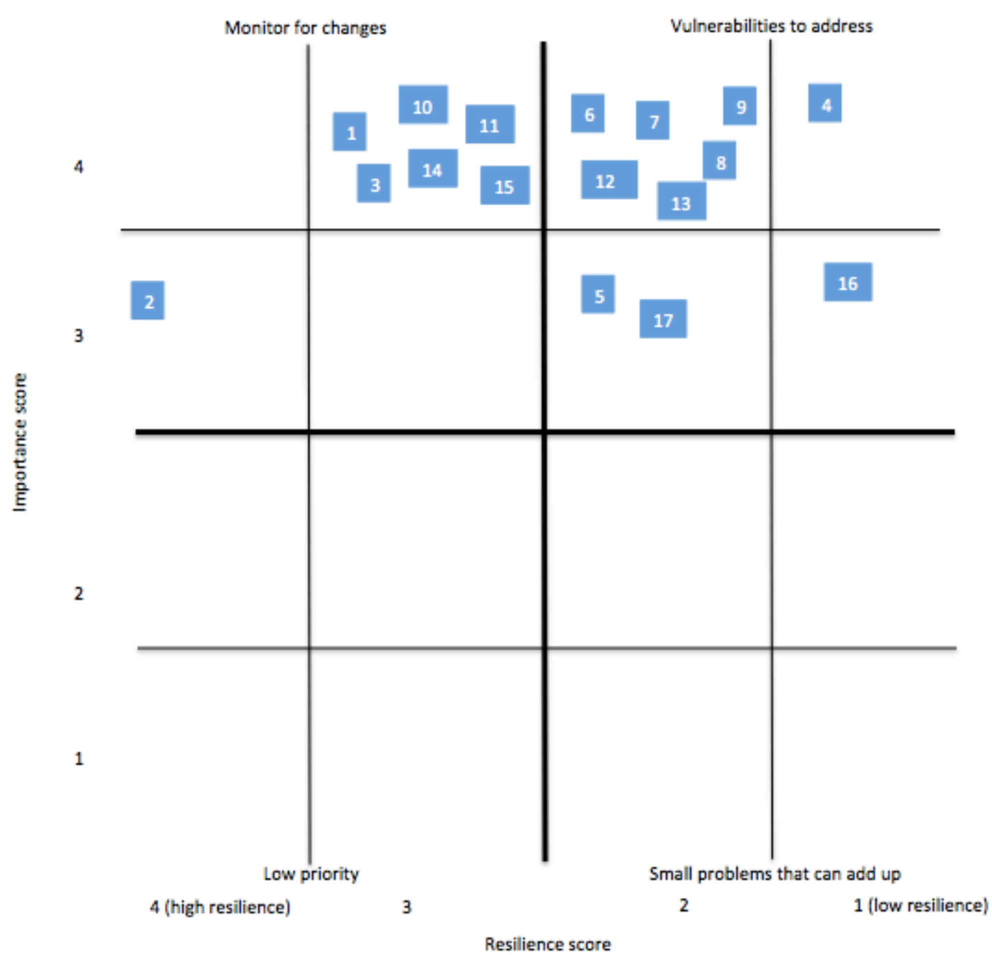
[9] The importance score is perhaps more appropriate in the EPA case because the tool includes hundreds of indicators that are not city-specific.

4	Access to critical services for vulnerable populations	Number of facilities and community organizations serving vulnerable populations with continuity of operations plans	4	1 The BPHC program that will increase the number of continuity of operations plans for facilities and groups serving vulnerable populations has not yet started. Once it starts, this number will likely improve.
5	Community awareness of hazards and need for adaptation	Number of Climate Ready Boston Leaders trained and number of people reached by these Leaders	3 While community awareness of hazards is important, this awareness is not always vital to survival as is the case with many of the other indicators.	2 The Climate Ready Boston Leaders program (launched in 2017) is helping to spread awareness but has so far only reached a small fraction of Boston residents.
6	Residents and businesses guarded via coastal flood protection measures	Number of residents and businesses expected to be protected due to new coastal defense measures from the neighborhood-level planning processes	4	2 The City has only recently started to identify neighborhood-level strategies to mitigate flooding. While commitments made in East Boston and Charlestown are a good start, there is still a lot of room for improvement.
7	Amount of vulnerable coastline secured	Feet of coastal defenses completed	4	2 See above description.
8	Resilient electricity system	1) Average number of months between interruptions 2) System average time in minutes to restore service to customers	4	2 Eversource missed its targets by more than 15% for each of these metrics in 2016 (the most recent year with data).
9	Reliable public transit	Reliability of buses, subway, and commuter rail (yearly average)	4	2 MBTA's measurements of both subway and bus reliability missed their targets on average in a recent month and data from the day of Winter Storm Grayson indicate that a major storm can have a significant effect on service.

10	Increased tree canopy coverage	Net number of new trees per year (plantings minus removals)	4	3 While I did not have access to the metric's data set, a recent study on tree canopy conducted by MIT's Senseable City Lab shows that Boston's tree canopy is about average compared to the 26 other cities studied so far (MIT Senseable Cities Lab, 2018).
11	Amount of green space	Park land as a percentage of city area	4	3 Boston scored 18 out of 20 on this metric according to the Trust for Public Land, suggesting a little room for improvement.
12	Adequate stormwater system	Volume of sanitary sewer overflows	4	2 Further analysis is needed for this metric, but Boston's vulnerability assessment suggests that the current stormwater system is struggling to accommodate "fairly frequent rain events" (City of Boston, 2016b).
13	Increased flood insurance coverage	Number of flood insurance policies across the city	4	2 As of the end of 2014, there were only 1,292 flood insurance policies in the city with more than 2,130 buildings exposed to the nine inches of sea level rise/ the one percent storm (~2030s). Additionally, about 8,970 buildings will be exposed to frequent stormwater flooding around 2030 (City of Boston, 2016b).
14	Resilience components incorporated into new development	Number of buildings incorporating resilience measures from Article 80 Climate Resiliency Checklist	4	3 While data on this metric would need to be obtained, the BPDA's recently updated Climate Resiliency Checklist is likely facilitating a boost in this indicator.
15	Economic losses due to flood events	FEMA dollars spent on repetitive loss properties	4	3 Through 2012, there were only 23 repetitive loss properties in Boston. Due to recent storms, I would expect that the number has gone up, but I would need more recent data from FEMA to verify.

16	Prepared municipal facilities	Budgeted investments in resilience projects through the capital planning process	3 While prepared municipal facilities are important, many of the other indicators are more important to survival in a climate event.	1 Only two projects in the FY2018 Fiscal Budget have resilience as a core component, suggesting that this is an area for improvement.
17	Climate risk considerations included in neighborhood planning processes	Percentage of neighborhood plans released annually that consider climate resilience	3 While including climate risk in neighborhood planning is important, it is not as critical to survival as many of the other indicators.	2 Climate considerations have been included in several recent plans, but there is still a lot of room for growth.

Figure 17: Quadrant plot of Boston indicators inspired by the EPA METRO tool



Based on this rough example for how to apply the EPA concept, the City should prioritize indicator 4 "access to critical services for vulnerable populations" for immediate action, with the others in the "vulnerabilities to address" quadrant close behind. Those in the "monitor for changes" quadrant are indicators that seem to be showing good performance for now and may be lower priorities for municipal resources at the current moment.

Concluding thoughts

Appreciating and attempting to address challenges while embracing opportunities has been the objective for cities related to climate adaptation planning so far and determining the best way to evaluate the implementation of these plans is no different. Cities like Boston on the forefront of preparing for an uncertain future have the opportunity to play a key leadership role in establishing indicators to evaluate their actions and hold themselves accountable to the public. Such indicator sets will no doubt grow and evolve over time with the advent of more information and as climate impacts increase, but the time to start the process is now.

References

100 Resilient Cities. (n.d.) *What is Urban Resilience?* Retrieved from http://www.100resilientcities.org/resources/

Arup. (n.d.) City Resilience Index. London, UK: Author. Retrieved from https://www.arup.com/publications/research/section/city-resilience-index

Arup. (2014). Research Report Volume 3: Urban Measurement Report. *City Resilience Index.* A report for the Rockefeller Foundation. London, UK: Author.

Arup. (2016a). Inside the CRI: Reference Guide. *City Resilience Index.* A report for the Rockefeller Foundation. London, UK: Author.

Arup. (2016b). Research Report Volume 4: Measuring City Resilience. *City Resilience Index.* A report for the Rockefeller Foundation. London, UK: Author.

Baltimore Office of Sustainability. (2018). Urban Heat Island Sensors. Retrieved from http://www.baltimoresustainability.org/urban-heat-island-sensors/

Bossel, H. (1999). *Indicators for Sustainable Development: Theory, Method, Applications*. A Report to the Balaton Group.

Boston Planning & Development Agency. (2017). Climate Resiliency Guidance. Retrieved from http://www.bostonplans.org/getattachment/5d668310-ffd1-4104-98fa-eef30424a9b3

Boston Public Health Commission. (2018). *Health of Boston, 2016-2017.* Boston, MA: Author.

Boston Water and Sewer Commission. (2017). *2016 Stormwater Management Report.* Boston, MA: Author.

Boston Water and Sewer Commission. (2018a). Sanitary Sewer Overflows. Retrieved from http://www.bwsc.org/COMMUNITY/maps/SSO.asp

Boston Water and Sewer Commission. (2018b). Yearly rainfall. Retrieved from http://www.bwsc.org/COMMUNITY/rainfall/telog_rainfall/rf_yearly.asp

Bourne Consulting Engineering. (2007). Massachusetts Coastal Infrastructure Inventory and Assessment Project. Retrieved from http://www.mass.gov/eea/docs/czm/stormsmart/seawalls/boston-harbor/boston.pdf

City of Boston. (2007). An Order Relative to Climate Action in Boston. Retrieved from https://www.cityofboston.gov/images_documents/Clim_Action_Exec_Or_tcm3-3890.pdf

City of Boston. (2011). *A Climate of Progress*. Boston, MA: Author.

City of Boston. (2014a). *2014 Climate Action Plan Update*. Boston, MA: Author.

City of Boston. (2014b). *Natural Hazard Mitigation Plan.* Boston, MA: Author. Retrieved from https://www.cityofboston.gov/images_documents/Boston%20Revised%20Draft%20Hazard%20Mitigation%20Plan%202014%20Update%20%2003-31-15_tcm3-51167.pdf

City of Boston. (2015). *Open Space and Recreation Plan, 2015-2021.* Boston, MA: Author.

City of Boston. (2016a). *Approach and Methodology for Asset Data Collection and Exposure and Consequence Analysis*. Boston, MA: Author.

City of Boston. (2016b). *Climate Ready Boston Final Report*. Boston, MA: Author.

City of Boston. (2017a). Analyze Boston. Retrieved from https://data.boston.gov/

City of Boston. (2017b). City of Boston to Take Immediate Steps to Protect East Boston, Charlestown from Climate Change. Press Release.

City of Boston (2017c). Climate Ready Boston Map Explorer. Retrieved from https://www.boston.gov/departments/environment/climate-ready-boston-map-explorer

City of Boston. (2017d). Fiscal Year 2018 Budget: Energy and Environment. Retrieved from https://budget.boston.gov/capital-projects/energy-and-environment/

City of Boston. (2017e). *Go Boston 2030*. Boston, MA: Author.

City of Boston. (2017f). *Imagine Boston 2030*. Boston, MA: Author.

City of Boston. (2017g). Imagine Boston 2030 Metrics Dashboard. Retrieved from https://imagine.boston.gov/metrics-dashboard/

City of Boston. (2017h). *Resilient Boston*. Boston, MA: Author.

City of Boston. (2018a). CityScore. Retrieved from https://www.boston.gov/cityscore

City of Boston. (2018b). Climate Ready Progress. Retrieved from https://www.boston.gov/departments/environment/climate-ready-boston-progress

City of Boston. (2018c). Climate Ready South Boston presentation. Proceedings from Fort Point Neighborhood Association January 2018 meeting. Boston, MA: Author.

City of New York. (2015). *OneNYC.* New York City, NY: Author.

City of New York. (2017). De Blasio Administration Releases Mayor's Management Report for Fiscal Year 2017. Press Release. 18 September 2017.

City of New York. (2018). *OneNYC 2018 Progress Report*. New York City, NY: Author.

Deas, M. (2014). *Summary of Climate Preparedness Indicators*. Memo to the City of Boston Environment Department.

Doran, G. T. (1981). There's a SMART way to write management's goals and objectives. *Management review*, *70*(11), 35-36.

Downing, T. E. et al. (2005). Assessing vulnerability for climate adaptation. In: Lim, Bo; Spanger-Siegfried, Erica; Burton, Ian; Malone, Elizabeth; Huq, Saleemul (eds.). *Adaptation policy frameworks for climate change: Developing strategies, policies and measures.* Cambridge, UK: Cambridge University Press.

Eversource. (2017). 2017 Sustainability Report. Retrieved from https://www.eversource.com/content/docs/default-source/pdfs/sustainability-report-2017.pdf

Federal Emergency Management Agency. (2018). Policy and Claim Statistics for Flood Insurance. Retrieved from https://www.fema.gov/policy-claim-statistics-flood-insurance#

Ford, J., Berrang-Ford, L., Lesnikowski, A., Barrera, M., & Heymann, S. (2013). How to track adaptation to climate change: a typology of approaches for national-level application. *Ecology and Society*, *18*(3).

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global environmental change*, *16*(3), 293-303.

Green Ribbon Commission. (n.d.). Homepage. Retrieved from http://www.greenribboncommission.org/

Hansen et al. (2013). *The State of Adaptation in the United States: An Overview*. A report for the John D. and Catherine T. MacArthur Foundation: EcoAdapt.

Innovation Network for Communities. (2017). *Essential Capacities for Urban Climate Adaptation*.

Intergovernmental Panel on Climate Change. (2001). *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Working Group II. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the IPCC. [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge, UK: Cambridge University Press.

Lipsky, A. & Starbuck, K. (2015). *Draft Climate Adaptation Indicators Framework for the City of Boston, MA*. Boston, MA: SeaPlan.

Massachusetts Bay Transportation Authority. (2018). MBTA Dashboard: Reliability. Retrieved from http://www.mbtabackontrack.com/performance/index.html#/home

Massachusetts Institute of Technology Senseable City Lab. (2018). Treepedia. Retrieved from http://senseable.mit.edu/treepedia/

Meadows, D. (1998). *Indicators and Information Systems for Sustainable Development*.

Metric. (2018). In Merriam-Webster.com. Retrieved from: https://www.merriam-webster.com/dictionary/metric

Moldan, B., Janoušková, S., & Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological Indicators*, *17*(Supplement C), 4–13.

National Oceanic and Atmospheric Administration. (2018a). Boston Harbor Hydrograph. Advanced Hydrologic Prediction Service. Retrieved from https://water.weather.gov/ahps2/hydrograph.php?wfo=box&gage=bhbm3

National Oceanic and Atmospheric Administration. (2018b). NOAA/NOS/CO-OPS: Observed Water Levels at 8443970 Boston, MA. Retrieved from https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970

National Oceanic and Atmospheric Administration. (2018c). NowDATA. Retrieved from http://w2.weather.gov/climate/xmacis.php?wfo=box

Notre Dame Global Adaptation Initiative. (2018). Urban Adaptation. Retrieved from http://gain.nd.edu/our-work/urban-adaptation/

Parris, T. M. & Kates, R.W. (2003). Characterizing and Measuring Sustainable Development. *Annual Review of Environment and Resources, 28* (1):559-86.

Plovnick, A. (2016). *Measuring Climate Adaptation: Assessing the Use of Indicators in U.S. Coastal Cities* (Master's thesis). Massachusetts Institute of Technology, Cambridge, MA.

Preston, B. L., Westaway, R., Dessai, S., & Smith, T. F. (2009). Are we adapting to climate change? Research and methods for evaluating progress. In *89th American Meteorological Society Annual Meeting: Fourth Symposium on Policy and Socio-Economic Research.*

Pringle, P. (2011). *AdaptME Toolkit: Adaptation Monitoring and Evaluation*. Oxford, UK: UK Climate Impacts Programme.

Rossi, P. H., Lipsey, M. W., & Freeman, H. E. (2003). *Evaluation: A systematic approach*. Sage publications.

Shi, L., Chu, E., & Debats, J. (2015). Explaining progress in climate adaptation planning across 156 US municipalities. *Journal of the American Planning Association*, *81*(3), 191-202.

Solecki, W., et al. (2015). New York City Panel on Climate Change 2015 Report Chapter 6: Indicators and Monitoring. Ann. N.Y. Acad. Sci., 1336: 89–106.

STAR Communities. (2016a). *STAR Community Rating System Version 2.0*. Washington, DC: Author.

STAR Communities. (2016b). *Technical Guide to the STAR Community Rating System.* Washington, DC: Author.

STAR Communities. (2017). *Climate Change Mitigation and Adaptation.* Washington, DC: Author.

Susskind, L., Rumore, D., Hulet, C., & Field, P. (2015). *Managing Climate Risks in Coastal Communities: Strategies for Engagement, Readiness and Adaptation*. London; New York, NY: Anthem Press.

The Trust for Public Land. (2017). ParkScore® 2017 City Profile: Boston, MA. Retrieved from http://parkscore.tpl.org/city.php?city=Boston#sm.00004l1n0hnzmfovu8m23tnzfryw4

Urban Sustainability Directors Network. (2016). *Developing Urban Climate Adaptation Indicators*. A report in partnership with the Institute for Sustainable Communities.

U.S. Agency for International Development. (2009). Glossary of Evaluation Terms. Planning and Performance Management Unit, Office of the Director of U.S. Foreign Assistance.

U.S. Census Bureau (2012-2016). QuickFacts Massachusetts, 2012-2016 American Community Survey 5-year estimates. Retrieved from https://www.census.gov/quickfacts/fact/table/MA/AGE295216

U.S. Environmental Protection Agency. (2016). Climate Change Indicators: Coastal Flooding. Retrieved from https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding

U.S. Environmental Protection Agency. (2017). *Evaluating Urban Resilience to Climate Change: A Multi-Sector Approach*. Washington, DC: Author. Retrieved from https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=322482

Vogel et al. (2016). *Climate Adaptation: The State of Practice in U.S. Communities*. A report for the Kresge Foundation. Abt Associates.

Interviews

Indicator Framework Experts

Anonymous. City of New York. February 1, 2018.

Anonymous. City of New York. February 1, 2018.

Blue, Julie. Principal Climate Scientist, Eastern Research Group. March 8, 2018.

Crowley, Michael. Former Senior Program Officer, Institute for Sustainable Communities. February 7, 2018.

Nadkarny, Siddharth. Senior Consultant, Arup. February 20, 2018.

Regan, Patrick. January 11, 2018. Associate Director for the Environmental Change Initiative, Notre Dame Global Adaptation Initiative. January 11, 2018.

Wamstad-Evans, Kristi. Technical Director, USGBC/STAR Communities. November 29, 2017.

City of Boston Officials

Brizius, Alison. Director of Climate and Environmental Planning, City of Boston. January 12, 2017.

Mansfield, Mia. Climate Ready Boston Program Manager City of Boston. January 12, 2017.

Spector, Carl. Commissioner of the Environment, City of Boston. January 24, 2018.

Climate Change Adaptation/Evaluation Experts

Brahim, Nasser. Senior Planner, Climate Risk & Resiliency, Kleinfelder. January 15, 2018.

Cleveland, John. Executive Director, Boston Green Ribbon Commission. November 30, 2017.

Plovnick, Amy. Community Planner, Volpe. February 8, 2018.

Wormser, Julie. Principle, North Cambridge Consulting. January 10, 2018.

Appendix A: Interview Guide

General outline of interview questions for adaptation/evaluation experts:

- What do you see as Boston's biggest vulnerabilities in terms of climate change? The Climate Ready Boston report identified extreme heat and flooding impacts from sea level rise and increased precipitation as vulnerabilities. What would you add to the list?
- Do you know of ways that these vulnerabilities can be measured? Do you know of existing data streams that could be used?
- Do you know whether/how Boston has measured these vulnerabilities in the past?
- What are the most important improvements the city can make, in your opinion, to address these vulnerabilities?
- How would you suggest measuring progress on those improvements? Do you know of existing data streams that could be used?

General outline of interview questions for indicator framework experts:

- Could you explain the general structure and function of your evaluation framework?
- Why is it set up this way and how is it unique from frameworks developed by other groups?
- How did you come up with the indicators used?
- How do you measure those indicators?
- How do you get consistent data on these indicators? From where did you get it?
- Why do you think these are the best indicators available?
- What challenges did you come across as you were developing your framework and choosing indicators?
- Are there some indicators that you think are more important than others? How do you express that in your framework?
- Do you include both outcome and process indicators? How do the two interact in your framework?
- How do you make sure results are interpretable? Do you aggregate scores, supply targets, etc.?
- What advice do you have for cities that want to develop their own indicators of progress in this field?

Appendix B: Compiled List of Indicators from All Frameworks

This appendix contains the compiled list of indicators and metrics from the frameworks reviewed for this thesis, organized by the structure of Boston's climate change vulnerability assessment.

Extreme Heat

Indicators

Climate hazard indicators

Hazard indicators	**Source**
WSDI: Warm spell duration index- annual count of days with at least six consecutive days when daily maximum temperature is higher than the 90th percentile of the maximum temperature in the base period	ND-GAIN, 2018
Average temperature at assigned community hotspots	USDN, 2016 (ICLEI)
Number of times cooling shelters are triggered annually	USDN, 2016 (City of Vancouver)
Number of times the Emergency Operations Center is triggered for weather-related events	USDN, 2016 (City of Vancouver)
Number of days above 90 degrees	USDN, 2016
Average summer temperature highs	USDN, 2016
Number of hotspots (areas of particularly high temperature)	USDN, 2016
Ground-level ozone levels	USDN, 2016
Number of heat advisories per year	NPCC, 2015
Change in surface and air temperature during peak periods (July-August)	NPCC, 2015
Cooling (and heating) degree days per year	NPCC, 2015
Average seasonal daily maximum temperatures	Susskind, Rumore, & Field, 2015
Number of days above 90 degrees	Susskind, Rumore, & Field, 2015

People (health and safety)

Risk reduction indicators	**Source**
Hospital preparedness	
Percentage of hospital and long-term care beds benefitting from facility retrofits for resiliency to heat events	Adapted from OneNYC, 2018
Percentage of hospitals that have developed business continuity plans and plans for dealing with heat-related events	Adapted from Arup, 2016
Number of acute care hospital beds available per 1,000 residents	ND-GAIN, 2018
Availability of medical facilities (i.e. population/# of hospital beds; hospital workers/total population; public health center employees/total population; number of general hospitals)	USDN, 2016 (ICLEI)
# of medical facilities per 1000 residents and/or # of doctors per 1000 residents	USDN, 2016 (ND-GAIN-draft)
Medical emergency program for vulnerable population	USDN, 2016 (ND-GAIN-draft)
Hospital beds per 100,000 people	Arup, 2016

Average number of kilometers (or travel time) to closest trauma center	Arup, 2016
Emergency physicians or nurses per 1000	Arup, 2016
Percentage of hospitals that have carried out heat-related disaster preparedness drills in the last year	Adapted from Arup, 2016
Number of paramedics per 100,000 population	Arup, 2016
Percentage of paramedics trained to deal with risks related to the city's heat hazard	Adapted from Arup, 2016
Number of existing hospitals certified as heat disaster safe	Adapted from Arup, 2016
Number of physicians per capita	EPA, 2017
Is the availability of public health goods and services at risk if other city goods and services (e.g., power, water, public transportation) are affected by extreme climatic events or gradual climatic changes	EPA, 2017
Percentage of designated fleet availability	USDN, 2016 (City of Tulsa, OK)
Assistance with impacts	
Financial and technical assistance for improving people's ability to cope with heat events (especially vulnerable populations)	Adapted from Lipsky & Starbuck, 2015
Percentage of population which has access to disaster recovery mechanisms from heat events	Adapted from Arup, 2016
Number of mechanisms in place to support affected households following a heat event	Adapted from Arup, 2016
Actions are taken by City to help people (especially vulnerable populations) better cope with heat effects	Adapted from Lipsky & Starbuck, 2015
Financial assistance is provided to vulnerable populations	Lipsky & Starbuck, 2015
Early warning system	
Presence of an extreme weather early warning system	USDN, 2016 (ACT: Planning for Adaptation to Climate Change)
Number of media types used to alert people in an emergency	Arup, 2016
Number of heat hazard alarm tests in the last 5 years	Adapted from Arup, 2016
Coverage by type and objective of community vulnerability EWS (Early Warning System)	Arup, 2016
Are public-address systems (e.g., loudspeakers, text messages, radio broadcasts, emergency television broadcasts) in place to provide instructions to the public in case of an emergency	EPA, 2017
Are early warning systems for meteorological extreme events available?	EPA, 2017
Percentage of the city's top 5 natural hazards which have specific scientific monitoring and alert mechanisms	Arup, 2016
Water supply	
Number of new fountains in known hotspots	USDN, 2016 (City of Vancouver)
Percentage of population which can be supplied water by alternative methods for 72 hours during disruption	Arup, 2016
Percent of population which has set aside emergency bottled water	Arup, 2016
Health insurance	
Percent of population with health insurance	ND-GAIN, 2018
Percentage of population with medical insurance	Deas, 2014
Percentage of population that have health insurance coverage, including both public and private or have access to 'free' (at the point of delivery) healthcare	Arup, 2016
Percentage access to health insurance of non-institutionalized population	EPA, 2017

Heat emergency plan	
Heat emergency plans are in place (e.g., emergency plan, food security plan, post event recovery plan, evacuation plan), including coordination for extreme weather event activities within and outside of city, clarity of roles, responsibilities	Adapted from Lipsky & Starbuck, 2015
City has adequate capacity and supplies for heat emergencies (e.g., personnel, supplies, equipment, emergency shelters, and vehicle fleet)	Adapted from Lipsky & Starbuck, 2015
System/plan in place to ensure critical city workers can reach offices/destinations during heat emergency situations	Adapted from Lipsky & Starbuck, 2015
Number of multi-stakeholder heat emergency scenario drills/year	Adapted from Arup, 2016
Number of reviews of city-wide heat emergency protocols undertaken in the past 5 years	Adapted from Arup, 2016
Percentage of budget allocated for heat emergency relief.	Adapted from Arup, 2016
Heat emergency planning budget as a percentage of total city budget	Adapted from Arup, 2016
Number of times heat risk plans have been updated in the last 5 years	Adapted from Arup, 2016
Coverage by type and objective of risk specific management policies, planning, and programming into sector activities	Arup, 2016
How familiar is the community with evacuation procedures	EPA, 2017
Cooling centers	
Capacity of accessible cooling centers	Adapted from OneNYC, 2018
Percentage of population that could be served by city's access to cooling shelters for 72 hours	Adapted from Arup, 2016
Capacity of cooling centers	USDN, 2016 (City of Vancouver)
Average distance to cooling centers from known hot spots/vulnerable population location	USDN, 2016 (City of Vancouver)
Percentage of population within a 2 mile radius of an appropriately sized, designated cooling center	Adapted from Arup, 2016
What evacuation and shelter-in-place options are available to residents in the event of a heat wave	EPA, 2017
Do plans exist to provide public access to cooling centers or for other heat adaptation strategies (e.g., opening public swimming pools earlier or later than normal, using fire hydrants for cooling), given predicted climatic changes	EPA, 2017
Food supply	
Percent of population which has set aside emergency packaged food	Arup, 2016
Emergency response capacity	
Number by type of internationally certified heat emergency and recovery management specialists	Adapted from Arup, 2016
Percentage of emergency responders with arrangements, which enable them to communicate in an emergency (e.g., MTPAS (UK), satellite phones, airwaves, etc.)	Arup, 2016
Percentage of emergency responders which have undertaken an emergency communications exercise in the last 5 years (that included material on heat emergencies)	Adapted from Arup, 2016
Number of times the city emergency responders have communicated with agencies responsible for scientific monitoring of heat hazard in the last month	Adapted from Arup, 2016
Number of times multi-stakeholder heat emergency responders meet and undertake joint activities (e.g., exercises, risk assessment, plan reviews) per year	Adapted from Arup, 2016
Coverage by type and objective of assessment of human resources capacity,	Arup, 2016

technical and financial assessments for disaster risk reduction	
Number of emergency workers undergoing City coordinated heat hazard training	Adapted from Arup, 2016
Number of sworn police officers per capita	EPA, 2017
How many people are in place to respond to emergencies, and what is the level of communication connectivity of emergency response teams and offices	Adapted from EPA, 2017
Are emergency response staff well trained to respond to large-scale extreme weather events	EPA, 2017
Is the distribution of public health workers and emergency response resources appropriate for the population that would be affected during an extreme event	EPA, 2017
Is there sufficient capacity in public health and emergency response systems for responding to extreme events	EPA, 2017
Is the health care community, including primary care physicians, prepared for changes in patients' treatments necessitated by climate change (e.g., emerging infectious diseases)	EPA, 2017
Percentage of the police force that has undertaken heat event response training in the last 5 years	Adapted from Arup, 2016
Have public health agencies identified infectious diseases and/or disease vectors that may become more prevalent in the urban area under the expected climatic changes	EPA, 2017
Number major heat incident training scenarios undertaken by police in last 5 years	Adapted from Arup, 2016
Have public health agencies developed plans for responding to increased disease and vector exposure in ways that may reduce the associated morbidity/mortality	EPA, 2017
Number of times the emergency response center capability has been tested (and successfully passed) in the last 5 years (for scenario)	Adapted from Arup, 2016
Number of times the city's multi-stakeholder heat emergency management strategy has been tested in the last 5 years	Adapted from Arup, 2016
Percentage score of the city's last major incident exercise	Arup, 2016
The number of times heat hazards have been exercised in the last 5 years. (Add up total and divide by 5)	Adapted from Arup, 2016
Air conditioning	
Percentage of housing units with air conditioning	EPA, 2017
Disparity in households without air conditioning across neighborhoods with respect to a variety of equity conditions	NPCC, 2015
Estimated percent of households with residential air conditioning	NPCC, 2015
Air pollution	
Has an air quality analysis been completed at multiple scales/resolutions	EPA, 2017
Does the urban area have health warnings or alerts for days when air quality may be hazardous	EPA, 2017

People (health and safety)

Risk management indicators	Source
Health impacts of heat	
Number of disease outbreaks and heat-related illnesses, and prevention measures included in ongoing health programs	Adapted from Lipsky & Starbuck, 2015
Death toll per capita and per hazard occurrence	ND-GAIN, 2018

Injured population per capita and per hazard occurrence	ND-GAIN, 2018
Heat-related illness and injury	USGBC/STAR Communities, 2016
Number of patients with vector-borne disease/total population	USDN, 2016 (ICLEI)
Projected change of length of transmission season (LTS) of vector-borne diseases	USDN, 2016 (ND-GAIN, National)
Heat related hospitalizations/mortalities	USDN, 2016 (City of Vancouver)
Percentage of population experiencing heat-related deaths	EPA, 2017
Heat-related morbidity and excess mortality from extreme heat events per year	NPCC, 2015
Other health-related heat impacts (e.g., heat-induced strokes)	NPCC, 2015
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)	NPCC, 2015
Air pollution	
Asthma prevalence (percentage of population affected by asthma)	EPA, 2017
Air pollution	USGBC/STAR Communities, 2016
Number of days per year with observed air quality index > 100	NPCC, 2015
Air quality ranking among major U.S. cities	OneNYC, 2018
Disparity in SO2 across city neighborhoods	OneNYC, 2018
Disparity in PM2.5 levels across city neighborhoods	OneNYC, 2018
Social dynamics	
School closures	USGBC/STAR Communities, 2016
Number of social interactions	Adapted from USGBC/STAR Communities, 2016
Amount of crime	USGBC/STAR Communities, 2016
Number of seasonal disorders	Adapted from USGBC/STAR Communities, 2016
Emergency response	
Number of times hospital has failed to meet surge demands in last 5 years	Arup, 2016
Average emergency call-out response time last year (minutes)	Arup, 2016
The number of times emergency response center capacity/capability has been exceeded in the last 10 years	Arup, 2016
Access to critical services (e.g., hospitals, fire departments), cooling centers, and shelters reliable during heat events, especially for vulnerable populations	Adapted from Lipsky & Starbuck, 2015
Proportion of excess shelter beds during hot weather	Adapted from USDN, 2016 (City of Vancouver)
Neighborhood level emergency preparedness	USDN, 2016 (City of Surrey, BC-draft)
Emergency medical service response times	EPA, 2017
Average police response time	EPA, 2017
Percentage of fire response times less than 6.5 minutes	EPA, 2017
Number of times the emergency response center capability has been tested (and successfully passed) in the last 5 years (for real)	Adapted from Arup, 2016

The number of times emergency response center capacity/capability has been exceeded in the last 10 years	Arup, 2016
Early warning system	
Percentage of people reached by early warning systems for heat emergency events	Adapted from Lipsky & Starbuck, 2015
Percentage of population that received hazard warnings via 2+ systems when given/required	Arup, 2016
Percentage of local severe weather warnings issued by national metrological agency which are received in a timely fashion by city emergency responders	Arup, 2016
Percentage responses to heat alerts	Adapted from Arup, 2016
Vulnerable populations	
Heat Vulnerability Index in census block groups experiencing relatively higher heat stress	NPCC, 2015

Infrastructure

Risk reduction indicators	Source
Transportation and utility infrastructure	
Energy	
Electricity and energy- Existence and maintenance of back-up and stand-by power systems	Lipsky & Starbuck, 2015
Number of days that city fuel supplies could maintain essential household functions (through alternative sources)	Arup, 2016
Proportion of key municipal facilities with back-up power sufficient to remain functional over and above life safety requirements	USDN, 2016 (City of Vancouver)
Percent of gas stations with quick-connects for generators	USDN, 2016 (OneNYC, 2014)
Number of grocery stores with generators or quick connects for generators	USDN, 2016 (OneNYC, 2014)
How many years ahead does the city's electricity plan look (e.g., does it analyze the city's 10 year + needs?) (number of years)	Arup, 2016
Percentage of total annual expenditure spent on upgrades to electricity infrastructure in the last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016
Number of different supply sources providing at least 5 percent of electricity generation capacity	Arup, 2016
Loss of load expectation (the average number of hours per year in which supply is expected to be lower than demand under normal operation of the system)	Arup, 2016
City electricity supply capacity as a percentage of total demand	Arup, 2016
Percentage of gas stations with quick-connects for generators.	Deas, 2014
Average capacity of a decentralized energy source	EPA, 2017
Energy source capacity per unit area	EPA, 2017
Diversity of energy portfolio	Adapted from EPA, 2017
Are there redundant systems in place for coping with extreme events	Adapted from EPA, 2017
Is the availability of energy goods and services at risk if other city goods and services (e.g., water, transportation, telecommunications) are affected by extreme climatic events or gradual climatic changes	Adapted from EPA, 2017
Does capacity exist to handle a higher peak demand or peaks at different times	EPA, 2017
To what extent have efforts been made to reduce energy demand	EPA, 2017

What are the opportunities for distributed generation sources (e.g., different capacity for energy generation from different sources including renewable)	EPA, 2017
Are there smart grid opportunities to manage demand	EPA, 2017
Are there services and emergency responses aimed at quickly reaching vulnerable populations during power outages	EPA, 2017
Has the city consulted with local power companies to develop plans for potential increases in electricity demand for summer cooling	EPA, 2017
Transportation	
Percent of transportation assets adapted for heat-related climate change resiliency	Adapted from USDN, 2016 (OneNYC, 2014)
Number of or percentage of transportation assets adapted for climate change resilience	Deas, 2014
Is the availability of transportation goods and services at risk if other city goods and services (e.g., power, water, telecommunications) are affected by extreme climatic events or gradual climatic changes	EPA, 2017
How much risk is assumed in the design of transportation systems (bridges, culverts), and does it span the anticipated changes in temperature	Adapted from EPA, 2017
How resistant to potential impacts of climate change are critical transportation facilities	EPA, 2017
What degree of redundancy exists for major transportation links? Are there single points of failure? What are the implications of losing a particular link, and how rapidly can you recover?	EPA, 2017
What length of time would be required to restore major high-traffic vehicle transportation facilities in the urban area if they experience a failure	EPA, 2017
Are there funding mechanisms that exist or could be put into place to complete the necessary work on the transportation system to adapt to anticipated climatic changes and increased risks	EPA, 2017
What length of time would be required to restore major passenger rail transportation facilities in the urban area if they experience a failure	EPA, 2017
What length of time would be required to restore major freight rail transportation facilities in the urban area if they experience a failure	EPA, 2017
What length of time would be required to restore major bicycle and pedestrian transportation links in the urban area if they experience a failure	EPA, 2017
Are urban areas set up to provide accessibility (e.g., to jobs) if mobility is interrupted or impeded	EPA, 2017
Are the materials currently in use in transportation systems, such as the common asphalt formulations and rail types, compatible with anticipated changes in temperature	EPA, 2017
Have new or innovative materials been tested that may be more capable of withstanding the anticipated impacts of climate change (e.g., higher temperatures)	EPA, 2017
To what extent is green infrastructure implemented or planned to reduce climate change impacts on transportation systems	EPA, 2017
How resistant to potential impacts of climate change are critical non-road transportation facilities (e.g., high-traffic rail bridges, tunnels)	EPA, 2017
Percentage of transportation assets adapted for climate change resiliency	Adapted from NPCC, 2015
Planning	
Heat vulnerable infrastructure and utilities have been identified and prioritized	Adapted from Lipsky & Starbuck, 2015
Number of years since last citywide critical asset assessment	Arup, 2016
Number of times critical city infrastructure register has been updated in the last 5 years	Arup, 2016

Vulnerability of critical infrastructure been assessed	Adapted from EPA, 2017
Do plans exist to replace aging infrastructure? If so, do these plans account for the anticipated impacts of climate change on this infrastructure?	EPA, 2017
Utilities	
Adaptation measures are being implemented to reduce vulnerability of identified "at risk" utility structures	Adapted from Lipsky & Starbuck, 2015
Percentage of new utility infrastructure designed to withstand heat effects of climate change	Adapted from Lipsky & Starbuck, 2015
Percentage of new utility infrastructure incorporating heat preparedness measures into building design	Adapted from Lipsky & Starbuck, 2015
Water- water utilities have back-up generators to avoid power loss	Lipsky & Starbuck, 2018
Food	
Number of grocery stores or food markets per square mile, with special attention to low-income neighborhoods	Deas, 2014
Telecommunications	
For each telecommunication service, are there key nodes whose failure would severely affect the service	EPA, 2017
How robust is the telecommunication network in terms of resilience to damage to or failure of key nodes?	EPA, 2017
Are there parts of the telecommunication infrastructure that are particularly vulnerable to high temperatures or prolonged high temperatures	EPA, 2017
Does your community have sufficient access to backup telecommunication systems? What is the capacity of the telecommunication infrastructure?	EPA, 2017
Is backup power for telecommunication systems provided	Adapted from EPA, 2017
What is the extent of telecommunication redundancy	EPA, 2017
General	
Improve facilities and infrastructure throughout the community to be better prepared for heat-related climate change threats	Adapted from USGBC/STAR Communities, 2016
Total critical asset service days at risk of loss	Arup, 2016
Green infrastructure/natural systems	
Laws and regulations	
Legislative and regulatory means of enhancing requirements for green infrastructure are strengthened and expanded	Adapted from Lipsky & Starbuck, 2015
Identified conservation measures for climate change resiliency of natural resources and ecosystems are being implemented	Lipsky & Starbuck, 2015
Regulation changes	Adapted from Lipsky & Starbuck, 2015
Does zoning encourage green roofs or other practices that reduce urban heat	EPA, 2017
What percentage of open/green space is required for new development (to encourage increases in such space)	EPA, 2017
Amount of green infrastructure	
Green infrastructure and other measures are used as valuable tools in climate preparedness to help reduce the effects of urban heat island	Adapted from Lipsky & Starbuck, 2015
Ratio of paved to open/unpaved surfaces	USDN, 2016 (ND-GAIN-draft)
Average number of permeable and non-permeable surface area (m2) in permitted developments	USDN, 2016 (ICLEI)
Percentage of permeable ground to total ground coverage	USDN, 2016 (City of Vancouver)

Paved surfaces in urban areas (natural, permeable, impermeable)	USDN (Committee on Climate Change, UK)
Percent change in impervious cover	EPA, 2017
To what extent was green infrastructure selected to provide the maximum ecological benefits	EPA, 2017
Awareness	
Awareness of role of ecosystem components in the city's disaster resilience.	Lipsky & Starbuck, 2015
Number of environmental groups focused on ecosystem protection	USDN, 2016 (ND-GAIN-draft)
Amount of natural assets	
Parks, trees and ecosystem components are used as valuable tools in climate preparedness to help reduce the effects of urban heat island	Adapted from Lipsky & Starbuck, 2015
Amount and type of land cover preserved as open space	Adapted from Lipsky & Starbuck, 2015
Tree planting.	Adapted from Lipsky & Starbuck, 2015
Percent of land covered by tree canopy	Lipsky & Starbuck, 2015
Proximity of residents on average to natural areas	USDN, 2016 (ND-GAIN- National)
Average increase/decrease in green space and trees	USDN, 2016 (City of Vancouver)
Tree canopy coverage / total terrestrial area	Adapted from USDN, 2016 (City of Vancouver)
Tree canopy cover	USDN, 2016 (City of Surrey, BC-draft)
Ratio of paved to open/unpaved surfaces	USDN, 2016 (ND-GAIN-draft)
Protected areas	USDN, 2016 (ND-GAIN-draft)
Percent of green space	USDN, 2016 (ND-GAIN-draft)
Green spaces for reducing urban heat island	USDN, 2016 (ACT: Planning for Adaptation to Climate Change)
Percentage green, open space increase or decrease over the past 5 years.	Arup, 2016
Percentage of natural habitats within the city and up to 10km beyond the city boundary that are officially recognized for the protective services provided to the city/ city area	Arup, 2016
Percentage of city area that has been officially recognized for environmental protection	Arup, 2016
Tree plantings and removals	City of Boston (suggested indicator), 2017
Square miles of green space or vegetative cover	Deas, 2014
Proportion of shade coverage (canopy cover)	USDN, 2016 (City of Vancouver)
Extent and condition of ecosystem components (e.g., tree canopy, parks, open space)	Adapted from Lipsky & Starbuck, 2015
Percentage of natural area that is in small natural patches	EPA, 2017
Ratio of perimeter to area of natural patches	EPA, 2017

Percentage of city land that is urban and suburban	EPA, 2017
Macro invertebrate Index of Biotic Condition	EPA, 2017
Are there mechanisms to support tree shading programs in urban areas (to reduce urban heat and improve air quality)	EPA, 2017
Is the availability of environmental/ecosystem goods and services at risk if other city goods and services (e.g., power, water, telecommunications) are affected by extreme climatic events or gradual climatic changes	EPA, 2017
Change in vegetation cover	NPCC, 2015
Number of trees planted per year	NPCC, 2015
Proportion of shade coverage (canopy cover)	USDN, 2016 (City of Vancouver)
Funding	
Targeted public funding for open space	Adapted from Lipsky & Starbuck, 2015
Funding available for adaptive development projects that could also serve as recreation areas	Adapted from EPA, 2017
Maintenance	
Enhanced monitoring of open space	Adapted from Lipsky & Starbuck, 2015
Ecosystem restoration projects	USDN, 2016 (ND-GAIN-draft)
Number of trees inspected and pruned	USDN, 2016 (OneNYC, 2014)
Has green infrastructure maintenance been built into the budget?	EPA, 2017
Planning	
Percentage of natural areas within the city that have undergone ecological evaluation for their protective services	Arup, 2016
Have land use/land cover types, such as soil and vegetation types and areas of tree canopy cover, been inventoried, and are these inventories used in planning	EPA, 2017
Do plans exist for increasing open and green space	EPA, 2017
Has an analysis of areas with good ventilation (e.g., aligned with prevailing breezes, good tree canopy cover) been completed	EPA, 2017
Do plans exist for preserving areas with good ventilation (e.g., those aligned with prevailing breezes)	EPA, 2017
Does the urban area have a district-scale (i.e., higher resolution than city scale) thermal comfort index	EPA, 2017
Does knowledge of historical land use/land cover changes contribute to planners' understanding of climate stresses	EPA, 2017
Have specific historical land use/land cover changes been recognized as increasing or decreasing vulnerability to climate stresses	EPA, 2017

Infrastructure

Risk management indicators	Source
Transportation and utility infrastructure	
Energy	
Electricity brown-outs/black-outs	USGBC/STAR Communities, 2016
System Average Interruption Frequency Index (SAIFI) per 1,000 customers (power outages)	OneNYC, 2018
Customer Average Interruption Duration Index (CAIDI) in hours	OneNYC, 2018

De-rated capacity margin: the amount of excess electricity supply above peak demand (expressed as a percentage)	Arup, 2016
Average length of electrical interruptions (hours per year per customer)	Arup, 2016
How many minutes per year or hours per year do you have power outages?	EPA, 2017
What is the response time to restore electrical power after an outage	EPA, 2017
Duration of blackouts/brownouts per year associated with weather-related events	NPCC, 2015
Transportation	
Total annual hours of rail line closure due to heat and maintenance problems	EPA, 2017
Average hours of passenger transit delay per capita due to heat related issues	EPA, 2017
Number of weather-related transit and subway outages per year	NPCC, 2015
Telecommunications	
Number of weather-related telecommunications outages and customer hours without telecommunications per year	NPCC, 2015
General	
Economic loss due to infrastructure failure in last 2 years	Arup, 2016
Green infrastructure and natural systems	
Health of natural systems	
Dehydration of the natural environment	USGBC/STAR Communities, 2016
Mortality rate of trees on public property, by species	USDN, 2016 (City of Surrey, BC-draft)

Buildings	
Risk reduction indicators	**Source**
Planning	
Vulnerable buildings have been identified and prioritized	Lipsky & Starbuck, 2015
Coverage by hazard type and objective of incorporation of disaster risk reduction management elements into physical planning and infrastructure development procedures	Arup, 2016
Laws and regulations	
Modifications to building codes are identified in accordance with best practices in building resiliency (work with commonwealth, insurance and finance sectors, and property owners); and application of building codes.	Lipsky & Starbuck, 2015
Adopt building codes or land use ordinances that address specific climate impacts in the community	USGBC/STAR Communities, 2016
Number of years since the oldest current building code was reviewed.	Arup, 2016
Percentage of current planning policies and land/zoning plans that have been developed with reference to a relevant hazard risk assessment	Arup, 2016
Percentage of high-risk areas within the city where development is restricted or prohibited under planning guidelines	Arup, 2016
Does zoning encourage green roofs or other practices that reduce urban heat	EPA, 2017
Insurance	
Percentage of buildings with insurance for heat risk hazards relevant to the city	Adapted from Arup, 2016
Extent of natural hazard insurance for homes, business, agriculture, and public infrastructure	Arup, 2016

Number of mechanisms in place to support affected households following a disaster	Arup, 2016
Cool roofs implementation	
Proportion of buildings with green or cool roofs	USDN, 2016 (City of Vancouver)
Percentage or number of buildings with cool or green roofs.	Deas, 2014
Square footage of white/green roofs	NPCC, 2015
Certification	
Proportion of building permits issued that have LEED certification	USDN, 2016 (City of Vancouver)
Green Certification for New Buildings	USDN, 2016 (City of Surrey, BC-draft)
Percentage of LEAF approved buildings	USDN, 2016 (ND-GAIN-draft)
Implementation- general	
Adaptation measures are being implemented to reduce vulnerability of identified "at risk" buildings	Lipsky & Starbuck, 2015
Small-scale resiliency interventions and pilots are established in particularly vulnerable areas	Lipsky & Starbuck, 2015
Resilient design Implementation	
Percentage of new development designed to withstand heat associated with climate change	Adapted from Lipsky & Starbuck, 2015
Percentage of new buildings incorporating heat-related climate preparedness measures into building design	Adapted from Lipsky & Starbuck, 2015
Number of renovations or new construction that incorporate resilience measures.	Deas, 2014
Where developed land is located in areas vulnerable to extreme events, are resilient retrofits being implemented or planned	EPA, 2017
Urban form	
Are urban forms used that address (lessen) urban heat island effects (e.g., through increasing evapotranspiration or increasing urban ventilation)	EPA, 2017
Has the city made efforts to use urban forms to mitigate climate change impacts and to maximize benefits (e.g., urban tree canopy cover)	EPA, 2017
Number of buildings at risk	
Percent of buildings identified as vulnerable	Lipsky & Starbuck, 2015
Percentage urban development within the city that are situated within high risk areas	Arup, 2016
Percentage of construction or building projects in floodplain and other mapped hazard-prone areas	Arup, 2016
Percentage of residential dwellings within the city that are situated within high risk areas (which could be addressed by zonation and relocation)	Arup, 2016

Buildings

Risk management indicators	Source
Safety	
Structural safety and disaster resilience of buildings are adequate.	Lipsky & Starbuck, 2015
Energy	

Energy use	USGBC/STAR Communities, 2016
Utilities	
Utility expense	USGBC/STAR Communities, 2016
Urban form	
Surface temperature change in areas that have adopted white/green roofs relative to non-white/green roof locations	NPCC, 2015

Economy

Risk reduction indicators	Source
Planning	
Number of years since the city economic asset assessment (public and private)	Arup, 2016
Business continuity plans	
Programs are established to assist businesses with developing business continuity plans (that address heat risks)	Adapted from Lipsky & Starbuck, 2015
Percentage of vulnerable businesses with continuity of business plan [prepared and implemented plans] (that address heat risks)	Lipsky & Starbuck, 2015
Percentage of large businesses (500+ employees) within the city that have developed business continuity plans in accordance with ISO 22301	Arup, 2016
Percentage of registered small and medium-sized businesses the city has engaged with regarding business continuity in the last 5 years	Arup, 2016
Percentage of medium-small businesses (less than 500 employees) within the city that have made business continuity arrangements	Arup, 2016
Number of businesses with disaster continuity plans	Deas, 2014
Support following event	
Number of mechanisms in place to support local, small-, and medium-sized businesses following a heat event	Adapted from Arup, 2016
Access to micro-finance services in high hazard risk areas	Adapted from Arup, 2016
Percentage of city businesses that feel they have support options in the event of a disaster	Arup, 2016
Percentage of population which has access to disaster recovery mechanisms from shocks	Arup, 2016
Mechanisms to help businesses quickly return to normal operations	Adapted from EPA, 2017
Insurance	
Percentage of businesses with insurance cover for high risk hazards relevant to the city	Arup, 2016
Percentage of large businesses which have comprehensive insurance for the high-risk hazards within the city's risk profile	Arup, 2016
Percentage of SMEs which have comprehensive insurance for the high risk hazards within the city's risk profile	Arup, 2016
Women/minority businesses	
Percentage value of loans/credit provided to female/minority owned businesses as a percentage of overall loans	Arup, 2016
Percentage of public procurement contracts awarded to women-owned/minority-owned businesses (% overall total)	Arup, 2016

Economy

Risk management indicators	Source
Support following event	
Evidence of utilization of micro-finance services in high hazard risk area following disasters for recovery	Adapted from Arup, 2016
Economic loss	
Average annual economic losses resulting from heat related events	Adapted from OneNYC, 2018
Total losses (in dollars) due to weather-related events incurred by the municipality	USDN, 2016 (City of Vancouver)
Total economic losses from heat-related events per year	Adapted from NPCC, 2015
Economic disruption	
Number of Bostonians and businesses that are back at work 72 hours after a severe weather event	City of Boston (suggested indicator), 2017
Disruption to business	USGBC/STAR Communities, 2016

Stormwater Flooding (based on 10-year, 24-hour events (chronic))

Indicators

Climate hazard indicators

Stormwater flooding hazard indicators	Source
Number of flood events	USDN, 2016
Magnitude of flood events	USDN, 2016
Monthly maximum consecutive 5-day precipitation	ND-GAIN, 2018
Number of extreme precipitation events (95th percentile values) per year	NPCC, 2015
Percentage change in stream flow divided by percentage change in precipitation	EPA, 2017
Annual mean precipitation (inches)	Susskind, Rumore, & Field, 2015

People (health and safety)

Risk reduction indicators	Source
Assistance with impacts	
Actions are taken by City to help people (especially vulnerable populations) better cope with stormwater flooding	Adapted from Lipsky & Starbuck, 2015
Financial and technical assistance for improving people’s ability to cope with climate change	Lipsky & Starbuck, 2015
Financial assistance is provided to vulnerable populations	Lipsky & Starbuck, 2015
Percentage of population which has access to disaster recovery mechanisms from shocks	Arup, 2016
Number of mechanisms in place to support affected households following a disaster	Arup, 2016
Access to critical facilities	
Dedicated routes for emergency services	Adapted from Arup, 2016

Average number of kilometers (or travel time) to closest trauma center	Arup, 2016
Medical emergency program for vulnerable population	USDN, 2016 (ND-GAIN-draft)
System/plan in place to ensure critical city workers can reach offices/destinations during emergency situations	Lipsky & Starbuck, 2015
Emergency personnel capacity and expertise	
Number of times the city emergency responders have communicated with agencies responsible for scientific monitoring of hazards in the last month	Arup, 2016
Number of emergency workers undergoing City coordinated hazards training	Deas, 2014
The number of times the 5 most significant hazards identified in the city's local risk profile have been exercised in the last 5 years (Add up total and divide by 5)	Arup, 2016
Percentage of paramedics trained to deal with risks related to the city's local hazard profile	Arup, 2016
Hazard alert system	
Percentage of the city's top 5 natural hazards which have specific scientific monitoring and alert mechanisms	Arup, 2016
Stormwater flooding plan	
Number of times the top 5 city risks have had their plans updated in the last 5 years	Arup, 2016
Coverage by type and objective of risk specific management policies, planning, and programming into sector activities	Arup, 2016
Programs that promote information transmission during and after flood	USDN, 2016 (ND-GAIN-draft)
Water supplies	
Percentage of city's hospitals with back-up water supply to meet its needs for three days	Arup, 2016
Percent of population which has set aside emergency bottled water	Arup, 2016
Percentage of population which can be supplied water by alternative methods for 72 hours during disruption	Arup, 2016

People (health and safety)

Risk management indicators	Source
Access to critical facilities	
Access to critical services (e.g., hospitals, fire departments), cooling centers, and shelters reliable during extreme events, especially for vulnerable populations	Lipsky & Starbuck, 2015
Emergency response capabilities (wait times for ambulances, police, fire truck)	USDN, 2016 (ND-GAIN-draft)
Average emergency call-out response time last year (minutes)	Arup, 2016
Emergency medical service response times	EPA, 2017
Emergency response time	Adapted from Arup, 2016
Health impacts of stormwater flooding	
Number of disease outbreaks and climate-related illnesses, and prevention measures included in ongoing health programs	Lipsky & Starbuck, 2015
Insect-borne diseases	USGBC/STAR Communities, 2016
Chronic mold	USGBC/STAR Communities, 2016
Number of patients with respiratory disease/total population	USDN, 2016 (ICLEI)

Number of cases of mold reported in online rental database	USDN, 2016 (City of Vancouver)
Infectious disease as aftermath of flooding	USDN, 2016 (ND-GAIN-draft)
Seasonal affective disorder	USGBC/STAR Communities, 2016
Percentage of population affected by waterborne diseases	EPA, 2017
Water quality	
Drinking water quality	USGBC/STAR Communities, 2016
Quality of drinking water	ND-GAIN, 2018
Emergency response	
Neighborhood level emergency preparedness	USDN, 2016 (City of Surrey, BC-draft)
Percentage responses to alerts	Arup, 2016
Percentage of local severe weather warnings issued by national metrological agency, which are received in a timely fashion by city emergency responders	Arup, 2016

Infrastructure

Risk reduction indicators	Source
Transportation and utility infrastructure	
Water and sewer	
Stormwater and sewer- Water absorption plans for neighborhoods are created and implemented	Lipsky & Starbuck, 2015
Percentage of new utility infrastructure designed to withstand climate change.	Lipsky & Starbuck, 2015
Percentage of new utility infrastructure incorporating climate preparedness measures into building design	Lipsky & Starbuck, 2015
Percent backlog of catch basin repairs in most affected communities	OneNYC, 2018
Percentage of population which can be served by alternative methods of sanitation during disruption	Arup, 2016
Number of years since the city's wastewater contingency plan was updated	Arup, 2016
Draining capacities	USDN, 2016 (ND-GAIN-draft)
Number of sewer miles built in areas with no or partial sewers	USDN, 2016 (OneNYC, 2014)
Number of years the city's stormwater (or other protective) infrastructure has been inspected	Arup, 2016
Percentage of annual budget for stormwater infrastructure spent on upgrades.	Arup, 2016
Percentage of average water demand that can be delivered in the event of one unplanned and one planned outage	Arup, 2016
Average $ per $10,000 of total annual expenditure of city sanitation provider(s) spent on strategic, long-term (10 years +) planning activities	Arup, 2016
Percentage of total annual expenditure spent on upgrades to sanitation infrastructure last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016
Percentage of total annual expenditure spent on upgrades to solid waste disposal infrastructure last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016
Designated critical asset service days at risk from water supply failure	Arup, 2016

Percentage of flood-affected areas with improved storm drainage	NPCC, 2015
Does the water department or utility for the city consider past experience in addressing anticipated increases in the frequency of sewer overflows?	EPA, 2017
Percentage of city culverts that are sized to meet current stormwater capacity requirements	EPA, 2017
Percentage of city culverts that are sized to meet future stormwater capacity requirements	EPA, 2017
Does the water supply draw from a diversity of sources?	EPA, 2017
To what extent do water supplies come from outside the metropolitan area?	EPA, 2017
Does the water system have emergency interconnections with adjacent water systems or other emergency sources of supply?	EPA, 2017
Are there redundant drinking water systems in place for coping with extreme events, including supply, treatment, and distribution systems?	EPA, 2017
Are there redundant wastewater and stormwater systems in place for coping with extreme events, including collection systems and wastewater treatment systems?	EPA, 2017
Does a water/wastewater agency response network provide technical resources/support to the urban area's water system during emergencies?	EPA, 2017
Have storm sewers and drains to storm sewers been inventoried, and are these inventories used in planning?	EPA, 2017
Is the availability of water goods and services at risk if other city goods and services (e.g., power, transportation, public health) are affected by extreme climatic events or gradual climatic changes?	EPA, 2017
Has the water utility conducted a water audit to identify current losses (e.g., leaks, billing errors, inaccurate meters, unauthorized usage)?	EPA, 2017
To what extent have efforts been made to reduce water demand?	EPA, 2017
Have specific historical land use/land cover changes been recognized as increasing or decreasing vulnerability to climate stresses?	EPA, 2017
Planning	
Vulnerable infrastructure and utilities have been identified and prioritized	Lipsky & Starbuck, 2015
Number of years since the last city-wide review of the adequacy of the city's protective infrastructure assets	Arup, 2016
Number of years since last citywide critical asset assessment	Arup, 2016
Number of times critical city infrastructure register has been updated in the last 5 years	Arup, 2016
Has the vulnerability of critical infrastructure been assessed? Are there plans to relocate or protect vulnerable infrastructure in ways that promote resilience and protect other infrastructure and properties?	EPA, 2017
Number of years since the last city-wide review of the adequacy of the city's protective infrastructure assets	EPA, 2017
Transportation	
Percentage of transportation assets adapted for climate change resiliency	Adapted from NPCC, 2015
How much risk is assumed in the design of transportation systems (bridges, culverts), and does it span the anticipated changes in precipitation, temperature, and storm intensities under climate change?	EPA, 2017
How resistant to potential impacts of climate change are critical transportation facilities (e.g., high-traffic vehicle or rail bridges, tunnels)?	EPA, 2017
What degree of redundancy exists for major transportation links? Are there single points of failure? What are the implications of losing a particular link, and how rapidly can you recover?	EPA, 2017
What length of time would be required to restore major high-traffic vehicle transportation facilities in the urban area if they experience a failure?	EPA, 2017

Are any portions of the transportation system less important if the duration of the disturbance is a few days? What if the duration of the disturbance is more on the order of weeks?	EPA, 2017
What proportion of the population has limited access to transportation options due to compromised health or lower income levels? For what proportion of this population might transportation failures be life-threatening (e.g., due to reduced access to specialized medical care or equipment)?	EPA, 2017
Are urban areas set up to provide accessibility (e.g., to jobs) if mobility is interrupted or impeded?	EPA, 2017
What length of time would be required to restore major bicycle and pedestrian transportation links in the urban area if they experience a failure?	EPA, 2017
Are there funding mechanisms that exist or could be put into place to complete the necessary work on the transportation system to adapt to anticipated climatic changes and increased risks?	EPA, 2017
Have municipalities considered new methods of designing roads/bridges to prepare for heavily traveled routes during an extreme climate event (e.g., coastal evacuation routes)?	EPA, 2017
How resistant to potential impacts of climate change are critical non-road transportation facilities (e.g., high-traffic rail bridges, tunnels)?	EPA, 2017
General	
Improve facilities and infrastructure throughout the community to be better prepared for climate change threats	USGBC/STAR Communities, 2016
Total critical asset service days at risk of loss	Arup, 2016
Do plans exist to replace aging infrastructure? If so, do these plans account for the anticipated impacts of climate change on this infrastructure?	EPA, 2017
Green infrastructure/natural systems	
Laws and regulations	
Legislative and regulatory means of enhancing requirements for green/gray infrastructure are strengthened and expanded	Lipsky & Starbuck, 2015
Identified conservation measures for climate change resiliency of natural resources and ecosystems are being implemented	Lipsky & Starbuck, 2015
Regulation changes for preserving open space	Adapted from Lipsky & Starbuck, 2015
Soil erosion control measures	USDN, 2016 (ACT: Planning for Adaptation to Climate Change)
What percentage of open/green space is required for new development (to encourage increases in such space)?	EPA, 2017
Do incentives exist to integrate green stormwater infrastructure into infrastructure planning to mitigate flooding?	EPA, 2017
Are there incentives to reduce the amount of impervious surface, to prevent development in floodplains, to use urban forestry to reduce impacts, to use green infrastructure for stormwater management, etc.?	EPA, 2017
Amount of green infrastructure	
Green/gray infrastructure and other measures are used as valuable tools in climate preparedness to help reduce the effects of urban heat island, sea level rise, and storm frequency	Lipsky & Starbuck, 2015
Average number of permeable and non-permeable surface area (m2) in permitted developments	USDN, 2016 (ICLEI)
Percentage of permeable ground to total ground coverage	USDN, 2016 (City of Vancouver)
Paved surfaces in urban areas (natural, permeable, impermeable)	USDN, 2016

	(Committee on Climate Change, UK)
Green Infrastructure Network (GIN) Protected	USDN, 2016 (City of Surrey, BC-draft)
Ratio of paved to open/unpaved surfaces	USDN, 2016 (ND-GAIN-draft)
Number of right-of-way bioswales constructed	USDN, 2016 (OneNYC, 2014)
To what extent is green infrastructure implemented or planned to reduce climate change impacts on transportation systems?	EPA, 2017
Percent change in impervious cover	EPA, 2017
Amount of natural assets	
Extent and condition of ecosystem components (e.g., coastal habitats, shorelines, adjacent shore areas, tree canopy, parks, open space)	Lipsky & Starbuck, 2015
Percentage green, open space increase or decrease over the past 5 years.	Arup, 2016
Parks, trees and ecosystem components are used as valuable tools in climate preparedness to help reduce the effects of urban heat island, sea level rise, and storm frequency	Lipsky & Starbuck, 2015
Amount and type of land cover preserved as open space	Lipsky & Starbuck, 2015
Proximity of residents on average to natural areas	USDN, 2016 (ND-GAIN-national)
Average increase/decrease in green space and trees	USDN, 2016 (City of Vancouver)
Tree planting	Lipsky & Starbuck, 2015
Ecosystem restoration projects	USDN, 2016 (ND-GAIN-draft)
Protected areas	USDN, 2016 (ND-GAIN-draft)
Percent of green space	USDN, 2016 (ND-GAIN-draft)
Percentage of natural habitats within the city and up to 10km beyond the city boundary that are officially recognized for the protective services provided to the city/ city area	Arup, 2016
Percentage of city area that has been officially recognized for environmental protection (including shorelines down to low-tide mark)	Arup, 2016
Square miles of green space or vegetative cover.	Deas, 2014
Percentage of natural area that is in small natural patches	EPA, 2017
Ratio of perimeter to area of natural patches	EPA, 2017
Percentage of city land that is urban and suburban	EPA, 2017
Relative ecological condition of undeveloped land	EPA, 2017
Funding	
Targeted public funding for open space	Adapted from Lipsky & Starbuck, 2015
Is funding available for adaptive development projects that could also serve as recreation areas (e.g., retention areas along waterways that could also serve as parks)? Are such multipurpose projects required or are there incentives for these projects?	EPA, 2017
Awareness	

Number of environmental groups focused on ecosystem protection	USDN, 2016 (ND-GAIN-draft)
Planning	
Percentage of natural areas within the city that have undergone ecological evaluation for their protective services	Arup, 2016
Have land use/land cover types, such as soil and vegetation types and areas of tree canopy cover, been inventoried, and are these inventories used in planning?	EPA, 2017
Do plans exist for increasing open and green space?	EPA, 2017
Does knowledge of historical land use/land cover changes contribute to planners' understanding of climate stresses?	EPA, 2017
Have specific historical land use/land cover changes been recognized as increasing or decreasing vulnerability to climate stresses?	EPA, 2017
Maintenance	
Enhanced monitoring of open space	Adapted from Lipsky & Starbuck, 2015
Number of trees inspected and pruned	USDN, 2016 (OneNYC, 2014)
Has green infrastructure maintenance been built into the budget?	EPA, 2017
Mortality rate of trees on public property, by species	USDN, 2016 (City of Surrey, BC-draft)

Infrastructure

Risk management indicators	Source
Transportation	
Sinkholes	USGBC/STAR Communities, 2016
Potholes	USGBC/STAR Communities, 2016
General	
Economic loss due to infrastructure failure in last 2 years	Arup, 2016
Infrastructure damage	USGBC/STAR Communities, 2016
Water and sewer	
Combined Sewer Overflow capture rate	OneNYC, 2018
Number of combined sewer overflows	USDN, 2016 (City of Vancouver)
Percent of water quality samples complying with Surface Water Treatment Rule standard for turbidity	USDN, 2016 (OneNYC, 2014)
Average annual hours of water service interruptions per household	Arup, 2016
Annual percentage of wastewater system losses (due to storms) prior to treatment and/or discharge to the environment.	Arup, 2016
Volume of combined sewer overflows	Deas, 2014
Average length of water shortages for critical assets in the last 2 years.	Arup, 2016
Costs of additional water treatment owing to extreme rainfall events per year	NPCC, 2015
Percentage of infiltration and inflow (I/I) in wastewater	EPA, 2017
Wet weather flow bypass volume relative to the 5- year average	EPA, 2017
Total number of Safe Drinking Water Act (SDWA) violations	EPA, 2017

Green infrastructure/natural systems	
Health of natural systems	
Soil destabilization	USGBC/STAR Communities, 2016
Non-point source pollutants	USGBC/STAR Communities, 2016

Buildings

Risk reduction indicators	Source
Planning	
Coverage by hazard type and objective of incorporation of disaster risk reduction management elements into physical planning and infrastructure development procedures.	Arup, 2016
Vulnerable buildings have been identified and prioritized	Lipsky & Starbuck, 2015
Laws and regulations	
Modifications to building codes are identified in accordance with best practices in building resiliency (work with commonwealth, insurance and finance sectors, and property owners); and application of building codes	Lipsky & Starbuck, 2015
Adopt building codes or land use ordinances that address specific climate impacts in the community	USGBC/STAR Communities, 2016
Number of years since the oldest current building code was reviewed	Arup, 2016
Implementation- general	
Small-scale resiliency interventions and pilots are established in particularly vulnerable areas	Lipsky & Starbuck, 2015
Percentage of new development designed to withstand climate change	Lipsky & Starbuck, 2015
Resilient design implementation	
Number of buildings implementing Core Flood Resiliency Measures	USDN, 2016 (OneNYC, 2014)
Number of square feet of residential and non-residential buildings implementing Core Flood resiliency measures	USDN, 2016 (OneNYC, 2014)
Estimated percentage of new buildings completed within the city in the last 5 years that conform to current building codes and standards	Arup, 2016
Number of renovations or new construction that incorporate resilience measures	Deas, 2014
Insurance	
Percentage of buildings with insurance for high risk hazards relevant to the city	Arup, 2016
Extent of natural hazard insurance for homes, business, agriculture, and public infrastructure	Arup, 2016
Number of flood insurance policies across the city	OneNYC, 2018
Number and or cost of insurance claims related to water incurred losses	USDN, 2016 (City of Vancouver)
Average premium paid for National Flood Insurance Program (NFIP) policies	USDN, 2016 (OneNYC, 2014)
Green roofs implementation	
Square footage of green roofs	Adapted from NPCC, 2015
Proportion of buildings with green roofs	Adapted from USDN, 2016 (City of Vancouver)

Percentage or number of buildings green roofs.	Adapted from Deas, 2014

Buildings

Risk management indicators	**Source**
Safety	
Structural safety and disaster resilience of buildings are adequate	Lipsky & Starbuck, 2015
Damage	
Loss of or damage to homes and property to flooding	USGBC/STAR Communities, 2016

Economy

Risk reduction indicators	**Source**
Business continuity plans	
Programs are established to assist businesses with developing business continuity plans	Lipsky & Starbuck, 2015
Percentage of vulnerable businesses with continuity of business plan [prepared and implemented plans]	Lipsky & Starbuck, 2015
Percentage of large businesses (500+ employees) within the city that have developed business continuity plans in accordance with ISO 22301	Arup, 2016
Percentage of registered small and medium-sized businesses the city has engaged with regarding business continuity in the last 5 years	Arup, 2016
Percentage of medium-small businesses (less than 500 employees) within the city that have made business continuity arrangements	Arup, 2016
Number of businesses with disaster continuity plans	Deas, 2014
Insurance	
Percentage of businesses with insurance cover for high risk hazards relevant to the city	Arup, 2016
Percentage of SMEs which have comprehensive insurance for the high risk hazards within the city's risk profile	Arup, 2016
Women/minority businesses	
Percentage of public procurement contracts awarded to women-owned/minority-owned businesses (% overall total)	Arup, 2016
Percentage value of loans/credit provided to female/minority owned businesses as a percentage of overall loans	Arup, 2016
Planning	
Number of years since the city economic asset assessment (public and private)	Arup, 2016
Support following event	
Does the urban area have mechanisms to help businesses quickly return to normal operations?	EPA, 2017

Economy

Risk management indicators	**Source**
Economic loss	
Average annual economic losses resulting from climate related events	OneNYC, 2018

Total losses (in dollars) due to weather-related events incurred by the municipality	USDN, 2016 (City of Vancouver)
Total losses incurred by the City due to significant rainfall events	USDN, 2016 (City of Surrey, BC-draft)
Total economic losses from climate-related events per year	NPCC, 2015
Loss of business	Adapted from USGBC/STAR Communities, 2016
Economic disruption	
Disruption to supply chains	USGBC/STAR Communities, 2016
Disruption to business	Adapted from USGBC/STAR Communities, 2016

Coastal and Riverine Flooding (due to sea level rise plus 1% annual chance storm OR high tide)

Indicators

Climate hazard indicators

Coastal flooding hazard indicators	**Source**
Number of flood events	USDN, 2016
Magnitude of flood events	USDN, 2016
Percent change from a baseline in projected sea level rise in 2080	ND-GAIN, 2018- draft
Number of times extreme weather shelters are triggered annually	USDN, 2016 (City of Vancouver)
Number of times the Emergency Operations Center is triggered for weather-related events	USDN, 2016 (City of Vancouver)
Trend in mean sea level	NPCC, 2015
Number of coastal flooding advisories for major or moderate flooding	NPCC, 2015
Trend in peak storm surge for 100-year and 500-year storms	NPCC, 2015
Annual mean daily tide level	Susskind, Rumore, & Field, 2015

People (health and safety)

Risk reduction indicators	**Source**
Hospital preparedness	
Percentage of hospital and long-term care beds benefitting from facility retrofits for resiliency	OneNYC, 2018
Percentage of hospitals that have developed business continuity plans and plans for dealing with flooding	Adapted from Arup, 2016
Number of acute care hospital beds available per 1,000 residents	ND-GAIN, 2018
Availability of medical facilities (i.e. population/# of hospital beds; hospital workers/total population; public health center employees/total population; number of general hospitals)	USDN, 2016 (ICLEI)
Number of medical facilities per 1000 residents and/or # of doctors per 1000 residents	USDN, 2016 (ND-GAIN-draft)
Medical emergency program for vulnerable population	USDN, 2016 (ND-GAIN-draft)
Hospital beds per 100,000 people	Arup, 2016

Average number of kilometers (or travel time) to closest trauma center	Arup, 2016
Emergency physicians or nurses per 1000	Arup, 2016
Percentage of hospitals that have carried out heat-related disaster preparedness drills in the last year	Adapted from Arup, 2016
Number of paramedics per 100,000 population	Arup, 2016
Percentage of paramedics trained to deal with risks related to flooding	Adapted from Arup, 2016
Number of existing hospitals certified as disaster safe	Arup, 2016
Number of physicians per capita	EPA, 2017
Is the availability of public health goods and services at risk if other city goods and services (e.g., power, water, public transportation) are affected by extreme climatic events or gradual climatic changes	EPA, 2017
Percentage of designated fleet availability	USDN, 2016 (City of Tulsa, OK)
Percent of hospital beds in 500-year floodplain meeting resiliency standards	OneNYC, 2014
Percent of beds in nursing homes and adult care facilities in 100-year floodplain meeting resiliency requirements	OneNYC, 2014
Percentage of city's hospitals with back-up water supply to meet its needs for three days	Arup, 2016
Assistance with impacts	
Financial and technical assistance for improving people’s ability to cope with flooding events (especially vulnerable populations)	Adapted from Lipsky & Starbuck, 2015
Percentage of population which has access to disaster recovery mechanisms from shocks	Arup, 2016
Number of mechanisms in place to support affected households following a disaster	Arup, 2016
Actions are taken by City to help people (especially vulnerable populations) better cope with climate change	Lipsky & Starbuck, 2015
Financial assistance is provided to vulnerable populations	Lipsky & Starbuck, 2015
Emergency shelters	
Capacity of accessible emergency shelters	OneNYC, 2018
Percentage of population that could be served by city's access to stock of emergency shelters for 72 hours	Arup, 2016
Percentage of population within a 2-mile radius of an appropriately sized, designated rest center/emergency shelter.	Arup, 2016
Early warning system	
Presence of an extreme weather early warning system	USDN, 2016 (ACT: Planning for Adaptation to Climate Change)
Number of media types used to alert people in an emergency	Arup, 2016
Number of hazard alarm tests in the last 5 years.	Arup, 2016
Coverage by type and objective of community vulnerability EWS (Early Warning System)	Arup, 2016
Are public-address systems (e.g., loudspeakers, text messages, radio broadcasts, emergency television broadcasts) in place to provide instructions to the public in case of an emergency	EPA, 2017
Are early warning systems for meteorological extreme events available?	EPA, 2017
Percentage of the city's top 5 natural hazards which have specific scientific monitoring and alert mechanisms	Arup, 2016
Percentage of community with access to FEMA emergency radio broadcasts	EPA, 2017

Emergency transportation routes	
Capacity of evacuation routes out of the city (cars per hour)	Arup, 2016
Dedicated routes for emergency services and response time	Arup, 2016
Number of major roads out of the city	Arup, 2016
Does the city have the capacity to provide public transportation for emergency evacuations?	EPA, 2017
How familiar is the community with evacuation procedures?	EPA, 2017
Number of years since the city evacuation plan was updated	Arup, 2016
Water supply	
Percentage of population which can be supplied water by alternative methods for 72 hours during disruption	Arup, 2016
Percent of population which has set aside emergency bottled water	Arup, 2016
Health insurance	
Percent of population with health insurance	ND-GAIN, 2018
Percentage of population with medical insurance	Deas, 2014
Percentage of population that have health insurance coverage, including both public and private or have access to 'free' (at the point of delivery) healthcare	Arup, 2016
Percentage access to health insurance of non-institutionalized population	EPA, 2017
Coastal flooding emergency plan	
Emergency plans are in place (e.g., emergency plan, food security plan, post event recovery plan, evacuation plan), including coordination for extreme weather event activities within and outside of city, clarity of roles, responsibilities	Lipsky & Starbuck, 2015
City has adequate capacity and supplies for heat emergencies (e.g., personnel, supplies, equipment, emergency shelters, and vehicle fleet)	Adapted from Lipsky & Starbuck, 2015
System/plan in place to ensure critical city workers can reach offices/destinations during heat emergency situations	Adapted from Lipsky & Starbuck, 2015
Number of multi-stakeholder emergency scenario drills/year	Arup, 2016
Number of reviews of city-wide emergency protocols undertaken in the past 5 years	Arup, 2016
Percentage of budget allocated for emergency relief.	Arup, 2016
Number of times the top 5 city risks have had their plans updated in the last 5 years	Arup, 2016
Coverage by type and objective of risk specific management policies, planning, and programming into sector activities	Arup, 2016
Programs that promote information transmission during and after flood	USDN, 2016 (ND-GAIN-draft)
Emergency planning budget as a percentage of total city budget	Arup, 2016
Exposure	
Population living under 5m above sea level	USDN, 2016 (ND-GAIN- National)
Population residing in floodplain areas	USDN, 2016 (City of Surrey, BC- draft)
Population growth/decline in 100-year floodplain	NPCC, 2015
Percent of population living in floodplain	ND-GAIN, 2018
Percentage of population living within the 500-year floodplain	EPA, 2017
Percentage of city area in 100-year floodplain	EPA, 2017
Percentage of city area in 500-year floodplain	EPA, 2017
Percentage of city population in 100- year floodplain	EPA, 2017

Percentage of city population in 500- year floodplain	EPA, 2017
Food supply	
Percentage per capita food reserves within city (including supermarket agreements) for 72 hours (percentage population which could be served)	Arup, 2016
Percent of population which has set aside emergency packaged food	Arup, 2016
Emergency personnel capacity and expertise	
Number by type of internationally certified heat emergency and recovery management specialists	Adapted from Arup, 2016
Percentage of emergency responders with arrangements, which enable them to communicate in an emergency (e.g., MTPAS (UK), satellite phones, airwaves, etc.)	Arup, 2016
Percentage of emergency responders which have undertaken an emergency communications exercise in the last 5 years	Arup, 2016
Number of times the city emergency responders have communicated with agencies responsible for scientific monitoring of hazards in the last month	Arup, 2016
Coverage by type and objective of assessment of human resources capacity, technical and financial assessments for disaster risk reduction	Arup, 2016
Number of emergency workers undergoing City coordinated hazards training	Deas, 2014
Number of sworn police officers per capita	EPA, 2017
How many people are in place to respond to emergencies, and what is the level of communication connectivity of emergency response teams and offices	Adapted from EPA, 2017
Are emergency response staff well trained to respond to large-scale extreme weather events	EPA, 2017
Is the distribution of public health workers and emergency response resources appropriate for the population that would be affected during an extreme event	EPA, 2017
Is there sufficient capacity in public health and emergency response systems for responding to extreme events	EPA, 2017
Is the health care community, including primary care physicians, prepared for changes in patients' treatments necessitated by climate change (e.g., emerging infectious diseases)	EPA, 2017
Percentage of the police force that has undertaken disaster response training in the last 5 years	Arup, 2016
Have public health agencies identified infectious diseases and/or disease vectors that may become more prevalent in the urban area under the expected climatic changes	EPA, 2017
Number of search and rescue trained emergency responders with collapsed structures expertise per 100,000 population	Arup, 2016
Search and rescue specialists per 100,000 population	Arup, 2016
Number of times multi-stakeholder emergency responders meet and undertake joint activities (e.g., exercises, risk assessment, plan reviews) per year	Arup, 2016
Number major incident training scenarios undertaken by police in last 5 years.	Arup, 2016
Have public health agencies developed plans for responding to increased disease and vector exposure in ways that may reduce the associated morbidity/mortality	EPA, 2017
Emergency response testing	
Number of times the emergency response center capability has been tested (and successfully passed) in the last 5 years (for scenario)	Adapted from Arup, 2016
Number of times the city's multi-stakeholder emergency management strategy has been tested in the last 5 years	Arup, 2016
Percentage score of the city's last major incident exercise	Arup, 2016
The number of times the 5 most significant hazards identified in the city's local risk profile have been exercised in the last 5 years (Add up total and	Arup, 2016

divide by 5)	
Percentage of citizens intended to be evacuated, which were successfully evacuated in the last disaster drill in the last 5 years	Adapted from Arup, 2016

People (health and safety)

Risk management indicators	Source
Health impacts	
Number of disease outbreaks and climate-related illnesses, and prevention measures included in ongoing health programs	Lipsky & Starbuck, 2015
Death toll per capita and per hazard occurrence	ND-GAIN, 2018
Injured population per capita and per hazard occurrence	ND-GAIN, 2018
Insect-borne diseases	USGBC/STAR Communities, 2016
Infectious disease as aftermath of flooding	USDN, 2016 (ND-GAIN-draft)
Climate hazard-related morbidity and mortality per year (e.g., drowning due to storms)	Adapted from NPCC, 2015
Disparity in climate-related morbidity and mortality across neighborhoods with respect to a variety of equity conditions	NPCC, 2015
Mold	Adapted from USGBC/STAR Communities, 2016
Percentage of population affected by waterborne diseases	EPA, 2017
Deaths from extreme weather events	EPA, 2017
Emergency response	
Access to critical services (e.g., hospitals, fire departments), cooling centers, and shelters reliable during extreme events, especially for vulnerable populations	Lipsky & Starbuck, 2015
Proportion of excess shelter beds during extreme weather	USDN, 2016 (City of Vancouver)
Neighborhood Level Emergency Preparedness	USDN, 2016 (City of Surrey, BC-draft)
Emergency response capabilities (wait times for ambulances, police, fire truck)	USDN, 2016 (ND-GAIN-draft)
Number of times hospital has failed to meet surge demands in last 5 years	Arup, 2016
Average emergency call-out response time last year (minutes)	Arup, 2016
Number of times the emergency response center capability has been tested (and successfully passed) in the last 5 years (for real)	Adapted from Arup, 2016
The number of times emergency response center capacity/capability has been exceeded in the last 10 years	Arup, 2016
Percentage of citizens intended to be evacuated, which were successfully evacuated in the last disaster event in the last 5 years	Adapted from Arup, 2016
Emergency medical service response times	EPA, 2017
Average police response time	EPA, 2017
Early warning system	
Percentage of people reached by early warning systems for hazards and other climate-influenced emergency events	Lipsky & Starbuck, 2015
Percentage of local severe weather warnings issued by national metrological agency which are received in a timely fashion by city emergency responders.	Arup, 2016
Percentage responses to alerts	Arup, 2016

Percentage of population that received hazard warnings via 2+ systems when given/required	Arup, 2016
Displacement	
Disaster-related long-term displacement of New Yorkers from homes by 2050	OneNYC, 2018
Migration	USGBC/STAR Communities, 2016
Water quality	
Floodwater runoff	USGBC/STAR Communities, 2016
Drinking water quality	USGBC/STAR Communities, 2016
Salinization of drinking water	USGBC/STAR Communities, 2016
Total number of Safe Drinking Water Act (SDWA) violations	EPA, 2017
Percentage of population affected by food poisoning (i.e., unsafe drinking water)	Adapted from EPA, 2017

Infrastructure

Risk reduction indicators	Source
Coastal protection infrastructure	
Linear feet of coastal defenses completed	OneNYC (2017 update)
Investment in flood defenses, by investor	USDN, 2016 (Committee on Climate Change, UK)
Length of coastline realigned	USDN, 2016 (Committee on Climate Change, UK)
Federal dollars secured for coastal protection projects	USDN, 2016 (OneNYC, 2014)
Funding secured for flood protection projects	Deas, 2014
Miles of coastal defenses erected (dune replenishment/hard defenses)	NPCC, 2015
Number of buildings with reduced coastal risk due to coastal protection projects	USDN, 2016 (OneNYC, 2014)
Number of years since the last city-wide review of the adequacy of the city's protective infrastructure assets	Arup, 2016
Percentage of the population in unprotected coastal flood prone areas	USDN, 2016 (City of Vancouver)
Number of residents benefiting from coastal defenses and restored ecosystems	OneNYC, 2018
Transportation and utility infrastructure	
Energy	
Electricity and energy- Existence and maintenance of back-up and stand-by power systems	Lipsky & Starbuck, 2015
Number of days that city fuel supplies could maintain essential household functions (through alternative sources)	Arup, 2016
Tax incentives for renewable energy	ND-GAIN, 2018
Proportion of key municipal facilities with back-up power sufficient to remain functional over and above life safety requirements	USDN, 2016 (City of Vancouver)
Percent of gas stations with quick-connects for generators	USDN, 2016 (OneNYC, 2014)
Percent of regional fuel terminal capacity in the 100—year floodplain	USDN, 2016

hardened against a 100-year flood	(OneNYC, 2014)
Percent of regional refining capacity in the 100-year floodplain hardened against a 100-year flood	USDN, 2016 (OneNYC, 2014)
Number of grocery stores with generators or quick connects for generators	USDN, 2016 (OneNYC, 2014)
How many years ahead does the city's electricity plan look (e.g., does it analyze the city's 10 year + needs?) (number of years)	Arup, 2016
Percentage of total annual expenditure spent on upgrades to electricity infrastructure in the last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016
Number of different supply sources providing at least 5 percent of electricity generation capacity	Arup, 2016
Number of different supply sources providing at least 5 percent of water supply capacity	Arup, 2016
De-rated capacity margin: the amount of excess electricity supply above peak demand (expressed as a percentage)	Arup, 2016
Loss of load expectation (the average number of hours per year in which supply is expected to be lower than demand under normal operation of the system)	Arup, 2016
City electricity supply capacity as a percentage of total demand	Arup, 2016
Percentage of gas stations with quick-connects for generators	Deas, 2014
Do you have a diverse energy portfolio?	EPA, 2017
Are there redundant systems in place for coping with extreme events?	EPA, 2017
To what extent do energy supplies come from outside the metropolitan area?	EPA, 2017
Is the availability of energy goods and services at risk if other city goods and services (e.g., water, transportation, telecommunications) are affected by extreme climatic events or gradual climatic changes?	EPA, 2017
Does capacity exist to handle a higher peak demand or peaks at different times?	EPA, 2017
To what extent have efforts been made to reduce energy demand?	EPA, 2017
What are the opportunities for distributed generation sources (e.g., different capacity for energy generation from different sources including renewable)?	EPA, 2017
Are there smart grid opportunities to manage demand?	EPA, 2017
Do municipal managers in coastal areas consider the impacts of sea level rise on power generation facilities?	EPA, 2017
Average capacity of a decentralized energy source	EPA, 2017
Total energy source capacity per capita	EPA, 2017
Energy source capacity per unit area	EPA, 2017
Transportation	
Transportation- Elevation of high-risk flood zone public transportation stops	Lipsky & Starbuck, 2015
Elevation of high-risk flood zone public transportation stops	USDN, 2016 (ICLEI)
Number of lane-miles reconstructed or resurfaced	USDN, 2016 (OneNYC, 2014)
Percent of city transportation assets adapted for climate change resiliency	Adapted from USDN, 2016 (OneNYC, 2014)
Number of or percentage of transportation assets adapted for climate change resilience	Deas, 2014
Percentage of transportation assets adapted for climate change resiliency	Adapted from NPCC, 2015
Is the availability of transportation goods and services at risk if other city goods and services (e.g., power, water, telecommunications) are affected by	EPA, 2017

extreme climatic events or gradual climatic changes?	
How much risk is assumed in the design of transportation systems (bridges, culverts), and does it span the anticipated changes in precipitation, temperature, and storm intensities under climate change?	EPA, 2017
How resistant to potential impacts of climate change are critical transportation facilities (e.g., high-traffic vehicle or rail bridges, tunnels)?	EPA, 2017
What degree of redundancy exists for major transportation links? Are there single points of failure? What are the implications of losing a particular link, and how rapidly can you recover?	EPA, 2017
What length of time would be required to restore major high-traffic vehicle transportation facilities in the urban area if they experience a failure?	EPA, 2017
Are any portions of the transportation system less important if the duration of the disturbance is a few days? What if the duration of the disturbance is more on the order of weeks?	EPA, 2017
To what extent is the area dependent on long-range transportation of goods and services versus locally available goods and services (food, energy, etc.)?	EPA, 2017
What proportion of the population has limited access to transportation options due to compromised health or lower income levels? For what proportion of this population might transportation failures be life-threatening (e.g., due to reduced access to specialized medical care or equipment)?	EPA, 2017
What length of time would be required to restore major passenger rail transportation facilities in the urban area if they experience a failure?	EPA, 2017
What length of time would be required to restore major freight rail transportation facilities in the urban area if they experience a failure?	EPA, 2017
What length of time would be required to restore major bicycle and pedestrian transportation links in the urban area if they experience a failure?	EPA, 2017
Are urban areas set up to provide accessibility (e.g., to jobs) if mobility is interrupted or impeded?	EPA, 2017
Are there funding mechanisms that exist or could be put into place to complete the necessary work on the transportation system to adapt to anticipated climatic changes and increased risks?	EPA, 2017
Have municipalities considered new methods of designing roads/bridges to prepare for heavily traveled routes during an extreme climate event (e.g., coastal evacuation routes)?	EPA, 2017
How resistant to potential impacts of climate change are critical non-road transportation facilities (e.g., high-traffic rail bridges, tunnels)?	EPA, 2017
Percentage of roads and railroads within the city that are located within 10 feet of water	EPA, 2017
Percentage of roads and railroads within the city in the 500- year floodplain	EPA, 2017
Percentage of roads and railroads within the city in the 100- year floodplain	EPA, 2017
Planning	
Vulnerable infrastructure and utilities have been identified and prioritized	Lipsky & Starbuck, 2015
Number of years since last citywide critical asset assessment	Arup, 2016
Number of times critical city infrastructure register has been updated in the last 5 years	Arup, 2016
Has the vulnerability of critical infrastructure been assessed? Are there plans to relocate or protect vulnerable infrastructure in ways that promote resilience and protect other infrastructure and properties?	EPA, 2017
Utilities-general	
Adaptation measures are being implemented to reduce vulnerability of identified "at risk" utility structures (e.g., elevation of Deer Island)	Lipsky & Starbuck, 2015
Percentage of new utility infrastructure designed to withstand climate change.	Lipsky & Starbuck, 2015

Percentage of new utility infrastructure incorporating climate preparedness measures into building design	Lipsky & Starbuck, 2015
Percentage of new utility infrastructure constructed in high-risk flood zones	Lipsky & Starbuck, 2015
Food	
Percent of DCAS food procurement backstopped with more resilient distributors	USDN, 2016 (OneNYC, 2014)
Number of grocery stores or food markets per square mile, with special attention to low-income neighborhoods	Deas, 2014
Telecommunications	
Telecommunications- Existence and maintenance of back-up and stand-by communications systems	Lipsky & Starbuck, 2015
Number of critical telecommunications facilities implementing Core Flood Resiliency Measures	USDN, 2016 (OneNYC, 2014)
Percentage of Boston's telecommunication system transitioned to fiber optics or coaxial cables	Deas, 2014
How would a temporary loss of telecommunication infrastructure affect the local and regional economies?	EPA, 2017
How robust is the telecommunication network in terms of resilience to damage to or failure of key nodes?	EPA, 2017
Are telecommunication data centers located within or outside of the urban area?	Adapted from EPA, 2017
For each telecommunication service, are there key nodes whose failure would severely affect the service?	EPA, 2017
Are there satellite-based communications on frequency bands (e.g., the Ka band) that are vulnerable to wet-weather disruption?	EPA, 2017
Are your telecommunication infrastructure components located wisely with respect to your anticipated climate stressors (i.e., aboveground, underground, or serviced by satellite)?	EPA, 2017
Are belowground infrastructure components vulnerable to rising water or salt water intrusion?	EPA, 2017
If the area has satellite-based communications that are vulnerable to wet-weather disruption, does the area have a backup tower network?	EPA, 2017
Does your community have sufficient access to back up telecommunication systems? What is the capacity of the telecommunication infrastructure?	EPA, 2017
Is backup power for the telecommunication systems provided?	EPA, 2017
What is the extent of telecommunication redundancy? Do first responders and the public have multiple communication options, served by different infrastructures?	EPA, 2017
What percentage of telecommunications system capacity is required for the baseline level of use?	EPA, 2017
Does telecommunication infrastructure have the capacity for increased public demand in an emergency?	EPA, 2017
Do local authorities have established relations with telecommunication infrastructure service providers? Are emergency protocols and plans in place?	EPA, 2017
Do local private-sector telecommunication infrastructure service providers have the authority and resources to make quick decisions and implement them in and after an emergency?	EPA, 2017
Can local authorities and telecommunication providers give first-responder and decision-maker communications priority during an expected surge in traffic in emergency situations?	EPA, 2017
What modes to authorities in the urban area use to communicate emergency information and alerts? Are these modes low or high bandwidth?	EPA, 2017
What is the likelihood that the capacity of local first responder communication systems would be exceeded during a disaster?	EPA, 2017

Does the area have access to backup emergency call/response networks if the primary networks fail or are overloaded?	EPA, 2017
Is the availability of telecommunication goods and services at risk if other city goods and services are affected by extreme climatic events or gradual climatic changes?	EPA, 2017
Do telecommunication systems have enough energy and water supply to handle an extra load in the case of sudden natural disasters?	EPA, 2017
Have city planners consulted with other city governments with similar telecommunication systems to learn from their experience with natural disasters and prepare for similar events?	EPA, 2017
General	
Value of city infrastructure in floodplain areas	USDN, 2016 (City of Surrey, BC- draft)
Improve facilities and infrastructure throughout the community to be better prepared for climate change threats	USGBC/STAR Communities, 2016
Value of city assets in unprotected coastal flood prone areas	USDN, 2016 (City of Vancouver)
Total critical asset service days at risk of loss	Arup, 2016
Do plans exist to replace aging infrastructure? If so, do these plans account for the anticipated impacts of climate change on this infrastructure?	EPA, 2017
In general, what is the monetary value of infrastructure located within the 500-year floodplain in the city?	EPA, 2017
Water and Sewer	
Water- water utilities have back-up generators to avoid power loss	Lipsky & Starbuck, 2015
Percentage of population which can be served by alternative methods of sanitation during disruption	Arup, 2016
Number of years since the city's wastewater contingency plan was updated	Arup, 2016
Draining capacities	USDN, 2016 (ND-GAIN-draft)
Number of wastewater facilities or assets protected or raised above the 100-year floodplain	USDN, 2016 (OneNYC, 2014)
Number of DSNY facilities protected or raised above the 100-year floodplain	USDN, 2016 (OneNYC, 2014)
Number of years the city's stormwater (or other protective) infrastructure has been inspected	Arup, 2016
Percentage of average water demand that can be delivered in the event of one unplanned and one planned outage	Arup, 2016
Average $ per $10,000 of total annual expenditure of city sanitation provider(s) spent on strategic, long-term (10 years +) planning activities	Arup, 2016
Stormwater and sewer- Water absorption plans for neighborhoods are created and implemented	Lipsky & Starbuck, 2015
Percent backlog of catch basin repairs in most affected communities	OneNYC, 2018
Percentage of population which can be served by alternative methods of sanitation during disruption	Arup, 2016
Number of years since the city's wastewater contingency plan was updated	Arup, 2016
Number of sewer miles built in areas with no or partial sewers	USDN, 2016 (OneNYC, 2014)
Number of years the city's stormwater (or other protective) infrastructure has been inspected	Arup, 2016
Percentage of annual budget for stormwater infrastructure spent on upgrades.	Arup, 2016
Percentage of total annual expenditure spent on upgrades to sanitation infrastructure last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016

Percentage of total annual expenditure spent on upgrades to solid waste disposal infrastructure last year that was spent on programs aligned with long-term (>15 years) plans	Arup, 2016
Designated critical asset service days at risk from water supply failure	Arup, 2016
Percentage of flood-affected areas with improved storm drainage	NPCC, 2015
Does the water supply draw from a diversity of sources?	EPA, 2017
To what extent do water supplies come from outside the metropolitan area?	EPA, 2017
Does the water system have emergency interconnections with adjacent water systems or other emergency sources of supply?	EPA, 2017
Are there redundant drinking water systems in place for coping with extreme events, including supply, treatment, and distribution systems?	EPA, 2017
Is backup power for water supply, treatment, and distribution systems provided?	EPA, 2017
Are there redundant wastewater and stormwater systems in place for coping with extreme events, including collection systems and wastewater treatment systems?	EPA, 2017
Does a water/wastewater agency response network provide technical resources/support to the urban area's water system during emergencies?	EPA, 2017
Have storm sewers and drains to storm sewers been inventoried, and are these inventories used in planning?	EPA, 2017
Is the availability of water goods and services at risk if other city goods and services (e.g., power, transportation, public health) are affected by extreme climatic events or gradual climatic changes?	EPA, 2017
Has the water utility conducted a water audit to identify current losses (e.g., leaks, billing errors, inaccurate meters, unauthorized usage)?	EPA, 2017
Does the water department or utility for the city consider past experience in addressing anticipated increases in the frequency of sewer overflows?	EPA, 2017
Is backup power for wastewater collection and treatment provided?	EPA, 2017
Percentage of city culverts that are sized to meet current stormwater capacity requirements	EPA, 2017
Percentage of city culverts that are sized to meet future stormwater capacity requirements	EPA, 2017
Green infrastructure/natural systems	
Laws and regulations	
Legislative and regulatory means of enhancing requirements for green/gray infrastructure are strengthened and expanded	Lipsky & Starbuck, 2015
Identified conservation measures for climate change resiliency of natural resources and ecosystems are being implemented	Lipsky & Starbuck, 2015
Regulation changes for preserving open space	Adapted from Lipsky & Starbuck, 2015
Soil erosion control measures	USDN, 2016 (ACT: Planning for Adaptation to Climate Change)
What percentage of open/green space is required for new development (to encourage increases in such space)?	EPA, 2017
Do incentives exist to integrate green stormwater infrastructure into infrastructure planning to mitigate flooding?	EPA, 2017
Are there incentives to reduce the amount of impervious surface, to prevent development in floodplains, to use urban forestry to reduce impacts, to use green infrastructure for stormwater management, etc.?	EPA, 2017
Amount of green infrastructure	
Green infrastructure and other measures are used as valuable tools in climate preparedness to help reduce the effects of urban heat island, sea level rise, and	Adapted from Lipsky & Starbuck, 2015

storm frequency	
Average number of permeable and non-permeable surface area (m2) in permitted developments	USDN, 2016 (ICLEI)
Percentage of permeable ground to total ground coverage	USDN, 2016 (City of Vancouver)
Paved surfaces in urban areas (natural, permeable, impermeable)	USDN, 2016 (Committee on Climate Change, UK)
Green Infrastructure Network (GIN) Protected	USDN, 2016 (City of Surrey, BC- draft)
Ratio of paved to open/unpaved surfaces	USDN, 2016 (ND-GAIN-draft)
Number of right-of-way bioswales constructed	USDN, 2016 (OneNYC, 2014)
To what extent is green infrastructure implemented or planned to reduce climate change impacts on transportation systems?	EPA, 2017
Percent change in impervious cover	EPA, 2017
Amount of natural assets	
Extent and condition of ecosystem components (e.g., coastal habitats, shorelines, adjacent shore areas, tree canopy, parks, open space)	Lipsky & Starbuck, 2015
Parks, trees and ecosystem components are used as valuable tools in climate preparedness to help reduce the effects of urban heat island, sea level rise, and storm frequency	Lipsky & Starbuck, 2015
Percentage green, open space increase or decrease over the past 5 years	Arup, 2016
Amount and type of land cover preserved as open space.	Lipsky & Starbuck, 2015
Proximity of residents on average to natural areas	USDN, 2016 (ND-GAIN-national)
Average increase/decrease in green space and trees	USDN, 2016 (City of Vancouver)
Tree planting	Lipsky & Starbuck, 2015
Ecosystem restoration projects	USDN, 2016 (ND-GAIN-draft)
Protected areas	USDN, 2016 (ND-GAIN-draft)
Percent of green space	USDN, 2016 (ND-GAIN-draft)
Percentage of natural habitats within the city and up to 10km beyond the city boundary that are officially recognized for the protective services provided to the city/ city area	Arup, 2016
Percentage of city area that has been officially recognized for environmental protection (including shorelines down to low-tide mark)	Arup, 2016
Square miles of green space or vegetative cover	Deas, 2014
Percentage of natural area that is in small natural patches	EPA, 2017
Ratio of perimeter to area of natural patches	EPA, 2017
Percentage of city land that is urban and suburban	EPA, 2017
Relative ecological condition of undeveloped land	EPA, 2017
Acres of coastal ecosystems restored	OneNYC, 2018
Area of coastal habitats (saltmarsh, shingle, sand dunes)	USDN, 2016 (Committee on Climate Change, UK)
Acres of restored coastal wetlands	NPCC, 2015

Altered wetlands (percentage of wetlands lost)	EPA, 2017
Funding	
Targeted public funding for open space	Adapted from Lipsky & Starbuck, 2015
Is funding available for adaptive development projects that could also serve as recreation areas (e.g., retention areas along waterways that could also serve as parks)? Are such multipurpose projects required or are there incentives for these projects?	EPA, 2017
Awareness	
Number of environmental groups focused on ecosystem protection	USDN, 2016 (ND-GAIN-draft)
Planning	
Percentage of natural areas within the city that have undergone ecological evaluation for their protective services.	Arup, 2016
Have land use/land cover types, such as soil and vegetation types and areas of tree canopy cover, been inventoried, and are these inventories used in planning?	EPA, 2017
Do plans exist for increasing open and green space?	EPA, 2017
Does knowledge of historical land use/land cover changes contribute to planners' understanding of climate stresses?	EPA, 2017
Have specific historical land use/land cover changes been recognized as increasing or decreasing vulnerability to climate stresses	EPA, 2017
Maintenance	
Enhanced monitoring of open space	Adapted from Lipsky & Starbuck, 2015
Number of trees inspected and pruned	USDN, 2016 (OneNYC, 2014)
Has green infrastructure maintenance been built into the budget?	EPA, 2017
Mortality rate of trees on public property, by species	USDN, 2016 (City of Surrey, BC-draft)
Resiliency upgrades in open space	
Percent of DPR facilities in Sandy inundation zone upgraded for greater resiliency	USDN, 2016 (OneNYC, 2014)

Infrastructure

Risk management indicators	Source
Coastal protection infrastructure	
Adequacy of both man-made and natural coastal infrastructure in protecting against climate change and related events (e.g., dikes, ecosystem components providing protection, levees, flood barriers, sea walls)	Lipsky & Starbuck, 2015
Area of land inundated by coastal flooding per year	NPCC, 2015
Transportation and utility infrastructure	
General	
Infrastructure damage	USGBC/STAR Communities, 2016
Economic loss due to infrastructure failure in last 2 years	Arup, 2016
Transportation and utility infrastructure	
Energy	
Percentage of electricity generated within the 500-year floodplain able to remain	Deas, 2014

online after a 500-year flood event	
System Average Interruption Frequency Index (SAIFI) per 1,000 customers (power outages)	OneNYC, 2018
Customer Average Interruption Duration Index (CAIDI) in hours	OneNYC, 2018
Electricity brown-outs/black-outs	USGBC/STAR Communities, 2016
Power plant failure	USGBC/STAR Communities, 2016
Average length of electrical interruptions (hours per year per customer)	Arup, 2016
Duration of blackouts/brownouts per year associated with weather-related events	NPCC, 2015
How many minutes per year or hours per year do you have power outages?	EPA, 2017
What is the response time to restore electrical power after an outage?	EPA, 2017
Average customer energy outage (hours) in recent major storm	EPA, 2017
Transportation	
Sinkholes	USGBC/STAR Communities, 2016
Potholes	USGBC/STAR Communities, 2016
Port closures	USGBC/STAR Communities, 2016
Number of weather-related transit and subway outages per year	NPCC, 2015
Water and sewer	
Changes to salinity of groundwater	USDN, 2016 (City of Vancouver)
Percent of water quality samples complying with Surface Water Treatment Rule standard for turbidity	USDN, 2016 (OneNYC, 2014)
Combined Sewer Overflow capture rate	OneNYC, 2018
Number of combined sewer overflows	USDN, 2016 (City of Vancouver)
Average annual hours of water service interruptions per household	Arup, 2016
Annual percentage of wastewater system losses (due to storms) prior to treatment and/or discharge to the environment	Arup, 2016
Volume of combined sewer overflows	Deas, 2014
Average length of water shortages for critical assets in the last 2 years.	Arup, 2016
Costs of additional water treatment owing to extreme rainfall events per year	NPCC, 2015
Percentage of infiltration and inflow (I/I) in wastewater	EPA, 2017
Wet weather flow bypass volume relative to the 5- year average	EPA, 2017
Total number of Safe Drinking Water Act (SDWA) violations	EPA, 2017
Telecommunications	
Number of weather-related telecommunications outages and customer hours without telecommunications per year	NPCC, 2015
Green infrastructure/natural systems	
Health of natural systems	
Increased acidity in ecosystems	USGBC/STAR Communities, 2016
Habitat loss or loss of species	USGBC/STAR Communities, 2016
Soil destabilization	USGBC/STAR Communities, 2016

Non-point source pollutants	USGBC/STAR Communities, 2016

Buildings	
Risk reduction indicators	**Source**
Planning	
Vulnerable buildings have been identified and prioritized	Lipsky & Starbuck, 2015
Coverage by hazard type and objective of incorporation of disaster risk reduction management elements into physical planning and infrastructure development procedures	Arup, 2016
Laws and regulations	
Modifications to building codes are identified in accordance with best practices in building resiliency (work with commonwealth, insurance and finance sectors, and property owners); and application of building codes	Lipsky & Starbuck, 2015
Integrate climate preparedness into zoning, all project and permit review and licensing and into the regulations and guidelines that govern these processes. Review and improve waterfront development zoning	Lipsky & Starbuck, 2015
Adopt building codes or land use ordinances that address specific climate impacts in the community	USGBC/STAR Communities, 2016
Estimated percentage of new buildings completed within the city in the last 5 years that conform to current building codes and standards	Arup, 2016
Number of years since the oldest current building code was reviewed	Arup, 2016
Percentage of current planning policies and land/zoning plans that have been developed with reference to a relevant hazard risk assessment	Arup, 2016
Percentage of high-risk areas within the city where development is restricted or prohibited under planning guidelines	Arup, 2016
Are there codes to prevent development in flood-prone areas?	EPA, 2017
Are regulations in place regarding whether communities that are affected by floods will be rebuilt in the same location?	EPA, 2017
Are there mechanisms for the local government to purchase land that is unfavorable for redevelopment due to the results of extreme events (e.g., flooding from a hurricane)? If so, what are those mechanisms?	EPA, 2017
Have the regulations regarding rebuilding of communities affected by floods been enforced to date?	EPA, 2017
Insurance	
Flood insurance penetration levels and limits of coverage	USDN, 2016 (ND-GAIN-draft)
Percentage of buildings with insurance for high risk hazards relevant to the city	Arup, 2016
Extent of natural hazard insurance for homes, business, agriculture, and public infrastructure	Arup, 2016
Number of flood insurance policies across the city	OneNYC, 2018
Percent of residences in 100-year floodplain purchasing flood insurance	USDN, 2016 (OneNYC, 2014)
Average premium paid for National Flood Insurance Program (NFIP) policies	USDN, 2016 (OneNYC, 2014)
Green roofs implementation	
Proportion of buildings with green roofs	Adapted from USDN, 2016 (City of Vancouver)
Square footage of green roofs	Adapted from

	NPCC, 2015
Implementation-general	
Adaptation measures are being implemented to reduce vulnerability of identified "at risk" buildings	Lipsky & Starbuck, 2015
Small-scale resiliency interventions and pilots are established in particularly vulnerable areas	Lipsky & Starbuck, 2015
Resilient design implementation	
Percentage of new development designed to withstand climate change	Lipsky & Starbuck, 2015
Square footage of buildings upgraded against flood risk	OneNYC, 2018
Number of elevated homes in the Build-it-Back program	OneNYC, 2018
Number of buildings implementing Core Flood Resiliency Measures	USDN, 2016 (OneNYC, 2014)
Number of square feet of residential and non-residential buildings implementing Core Flood resiliency measures	USDN, 2016 (OneNYC, 2014)
Number of square feet of residential and non-residential buildings implementing Core Flood resiliency measures	USDN, 2016 (OneNYC, 2014)
Number of renovations or new construction that incorporate resilience measures.	Deas, 2014
Number of residential units in the 100-year floodplain implementing Core Flood Resiliency measures	NPCC, 2015
Where developed land is located in areas vulnerable to extreme events, are resilient retrofits being implemented or planned?	EPA, 2017
Number of buildings at risk	
Annual growth rate (%) in river floodplain, coastal floodplain, coastal erosion areas, and outside the floodplain	USDN, 2016 (Committee on Climate Change, UK)
Annual stock of properties (million) in river floodplain, coastal floodplain, coastal erosion areas, and outside the floodplain	USDN, 2016 (Committee on Climate Change, UK)
Development in areas of flood risk (low, moderate, significant)	USDN, 2016 (Committee on Climate Change, UK)
Percent of housing in the flood zones or at risk to floods	USDN, 2016 (ND-GAIN-draft)
Number of buildings in the floodplain	ND-GAIN, 2018
Percent of buildings identified as vulnerable	Lipsky & Starbuck, 2015
Percentage of new buildings constructed in high risk flood zones	Lipsky & Starbuck, 2015
Number of development applications approved by local authorities despite flood risk warning (agency does not object, concerns resolved and objection not sustained or application withdrawn, application approved against agency advice, application refused or approved with conditions in line with agency advice, agency not informed of outcome	USDN, 2016 (Committee on Climate Change, UK)
Percentage of residential dwellings within the city that are situated within high risk areas (which could be addressed by zonation and relocation)	Arup, 2016
Percentage urban development within the city that are situated within high risk areas.	Arup, 2016
Percentage of construction or building projects in floodplain and other mapped hazard-prone areas	Arup, 2016
Square footage of residential, commercial, industrial space not flood-proofed or	NPCC, 2015

elevated in areas within the 100-year floodplain	
Certification	
Proportion of building permits issued that have LEED certification	USDN, 2016 (City of Vancouver)
Green certification for new buildings	USDN, 2016 (City of Surrey, BC-draft)
Percent of LEAF approved buildings	USDN, 2016 (ND-GAIN-draft)

Buildings

Risk management indicators	Source
Safety	
Structural safety and disaster resilience of buildings are adequate	Lipsky & Starbuck, 2015
Damage	
Loss of or damage to homes and property to flooding	USGBC/STAR Communities, 2016
Repetitive loss properties tracked every 5 years by FEMA (in hazard mitigation plan)	City of Boston (suggested indicator), 2017
Number and or cost of insurance claims related to water incurred losses	USDN, 2016 (City of Vancouver)
Property damage per capita and per hazard occurrence	ND-GAIN, 2018

Economy

Risk reduction indicators	Source
Business continuity plans	
Programs are established to assist businesses with developing business continuity plans	Lipsky & Starbuck, 2015
Percentage of vulnerable businesses with continuity of business plan [prepared and implemented plans]	Lipsky & Starbuck, 2015
Percentage of large businesses (500+ employees) within the city that have developed business continuity plans in accordance with ISO 22301	Arup, 2016
Percentage of registered small and medium-sized businesses the city has engaged with regarding business continuity in the last 5 years	Arup, 2016
Percentage of medium-small businesses (less than 500 employees) within the city that have made business continuity arrangements	Arup, 2016
Number of businesses with disaster continuity plans	Deas, 2014
Planning	
Number of years since the city economic asset assessment (public and private)	Arup, 2016
Is the economy of the urban area largely independent, or is it largely dependent on economic activity in other urban areas?	EPA, 2017
If jobs are lost in one sector of the urban area, does the capacity exist to expand the economy and job opportunities in another sector?	EPA, 2017
Support following event	
Number of mechanisms in place to support local, small-, and medium-sized businesses following a disaster	Arup, 2016
Access to micro-finance services in high hazard risk areas, evidence of utilization following disasters for recovery and reconstruction	Arup, 2016
Percentage of population which has access to disaster recovery mechanisms from shocks	Arup, 2016

Number of mechanisms in place to support affected households following a disaster	Arup, 2016
Number of mechanisms in place to support local, small-, and medium-sized businesses following a disaster	Arup, 2016
Does the urban area have mechanisms to help businesses quickly return to normal operations?	EPA, 2017
Insurance	
Percentage of businesses with insurance cover for high risk hazards relevant to the city	Arup, 2016
Percentage of large businesses which have comprehensive insurance for the high-risk hazards within the city's risk profile	Arup, 2016
Percentage of SMEs which have comprehensive insurance for the high risk hazards within the city's risk profile	Arup, 2016
Women/minority businesses	
Percentage of public procurement contracts awarded to women-owned/minority-owned businesses (% overall total)	Arup, 2016
Percentage value of loans/credit provided to female/minority owned businesses as a percentage of overall loans	Arup, 2016

Economy

Risk management indicators	Source
Economic loss	
Average annual economic losses resulting from climate related events	OneNYC, 2018
Total losses (in dollars) due to weather-related events incurred by the municipality	USDN, 2016 (City of Vancouver)
Total losses incurred by the City due to significant rainfall events	USDN, 2016 (City of Surrey, BC-draft)
Total economic losses from climate-related events per year	NPCC, 2015
Loss of business	Adapted from USGBC/STAR Communities, 2016
Economic disruption	
Disruption to supply chains	USGBC/STAR Communities, 2016
Disruption to business	Adapted from USGBC/STAR Communities, 2016
Increase the number of Bostonians and businesses that are back at work 72 hours after a severe weather event	City of Boston (suggested indicator), 2017
Disaster cleanup	
Post-disaster cleanup	USGBC/STAR Communities, 2016

General Adaptation Capacity (related to all hazards)

Indicators

Education and engagement

Risk reduction indicators	Source
Outreach campaign	
Presence of website	Adapted from Lipsky & Starbuck, 2015

Education and awareness materials/messaging available to public	Lipsky & Starbuck, 2015
Number of meetings/trainings held	Lipsky & Starbuck, 2015
Create neighborhood-based programs that increase climate preparedness while supporting job training and job creation	Lipsky & Starbuck, 2015
Create and education and outreach campaign to engage residents, businesses, and local government staff in climate change vulnerability reduction efforts.	USGBC/STAR Communities, 2016
Existence and regular use of ongoing forums for sharing information on climate change impacts	USDN, 2016 (ICLEI)
Funding for community DRR as a proportion of overall city budget	Arup, 2016
Can resilience planning/adaptation be incorporated into existing programs that communities engage in regularly (e.g., zoning, hazard mitigation plans)?	EPA, 2017
Are government-led, community-based, or other organizations actively promoting adaptive behaviors at the neighborhood or city level?	EPA, 2017
Do policies and outreach/education programs promote behavioral changes that facilitate climate change adaptation	EPA, 2017
Schools	
School curriculum incorporates climate change adaptation	Adapted from Lipsky & Starbuck, 2015
Percentage of school children educated in DRR	Arup, 2016
Measures of awareness/impact of outreach activities	
Awareness of public, property owners and tenants to their individual vulnerabilities related to climate change	Lipsky & Starbuck, 2015
Percent of at risk households holding flood insurance policies	Lipsky & Starbuck, 2015
Number of people at meetings	Lipsky & Starbuck, 2015
Participation of stakeholders/public in pre-event and event response activities	Lipsky & Starbuck, 2015
Communities exhibit social connectedness and neighborhood cohesion.	Lipsky & Starbuck, 2015
Estimated percent of adults who think global warming is already harming people in the US now or within 10 years	ND-GAIN, 2018
Number of people attending public meetings on adaptation	USDN, 2016 (ICLEI)
Proportion of households with an emergency plan	Arup, 2016
Percentage of households that have incorporated safeguard measures into their home	Arup, 2016
Percentage of population that have made a household or a community resilience plan	Arup, 2016
Red Cross/Red Crescent volunteers within the city per capita	Arup, 2016
Coverage by type and objective of hazard-specific vulnerability and capacity assessments at the community level	Arup, 2016
Percentage of population with (last 5 years) first aid or similar certification.	Arup, 2016
Number of individuals pledging to make key preparedness measures in their homes and businesses	Arup, 2016
Number of citizen groups engaged in climate resiliency programs per year	NPCC, 2015
Input to decision-making	
Quality of stakeholder engagement in decision-making to address climate change	Lipsky & Starbuck, 2015
Amount of public/stakeholder input to decision-makers	Adapted from Lipsky & Starbuck, 2015
Uptake by decision-makers	Lipsky & Starbuck,

	2015
Do municipal managers consider local stakeholder knowledge and local resources (e.g., libraries, archives) in climate change resilience planning?	EPA, 2017

Information and governance

Risk reduction indicators	Source
Knowledge creation	
Knowledge of hazards that the city faces and their likelihoods (e.g., hazards for sectors identified in #5 and #6 to floods, storms, and other hazards)	Lipsky & Starbuck, 2015
Knowledge of vulnerability and exposure (e.g., vulnerability of sectors to climate change and related events, scenarios to assess sea level rise/flooding are completed)	Lipsky & Starbuck, 2015
Data gaps related to needed climate change adaptation information are identified	Lipsky & Starbuck, 2015
Conduct a local climate risk and vulnerability assessment	USGBC/STAR Communities, 2016
Develop metrics for measuring the success of adaptation actions to prepare for a changing climate	USGBC/STAR Communities, 2016
Percentage of city area for which a comprehensive exposure and vulnerability assessment has been undertaken within the past 5 years	Arup, 2016
Percentage of hazard risk assessments for the city that have also considered the exacerbating effects of long-term stresses (e.g., climate change, population growth, demographic change, etc.)	Arup, 2016
Number of years since city hazard maps have been updated	Arup, 2016
Frequency to which scientific updates on local hazard profile are provided.	Arup, 2016
Historical record available of hazards and their impacts, climate change and climate vulnerability (catalogues, inventories)	Arup, 2016
Quantity of accurate documentation and databases on disasters	Arup, 2016
Use of knowledge/planning	
Governing structure has established policy definitions for 1) required planning horizons (e.g., end of the century), 2) expected future conditions, and 3) "acceptable risk" from coastal flooding, extreme precipitation and heat.	Lipsky & Starbuck, 2015
Plans are adaptive and flexible; preparedness plans and associated regulations and incentives are indexed to monitored environmental conditions (e.g., sea level, storm intensity), with updates linked to actual monitored/observed conditions	Lipsky & Starbuck, 2015
Climate preparedness is considered a priority in City planning.	Lipsky & Starbuck, 2015
Extent to which climate information is used to inform responses to climate change (e.g., data readily accessible, available, and data are used to inform adaptation interventions)	Lipsky & Starbuck, 2015
Adopt a local plan that incorporates potential climate change impact scenarios and identifies specific actions to reduce risk and exposure from identified hazards	USGBC/STAR Communities, 2016
Demonstrate that internal decisions by local government departments use the most current climate science and that staff monitor climate change impacts.	USGBC/STAR Communities, 2016
Create or enhance programs and services that specifically address the community's greatest climate threats	USGBC/STAR Communities, 2016
Existence of robust adaptation/resilience plan with schedule for updating at regular intervals	USDN, 2016 (ICLEI)
Years since city's climate change strategic plan was updated	Arup, 2016
Number of city plans referencing climate change preparedness	Deas, 2014
How flexible are planning processes for short-term and long-term responses?	EPA, 2017

Does adaptation planning for the urban area include retrospective analyses of past events (including analyses of past climate events in other cities if helpful) to help determine whether decisions on adaptation measures would be effective?	EPA, 2017
Does adaptation planning for the urban area consider the costs and benefits of possible decisions, and does it encourage both pre- and post-event evaluations of the effectiveness of adaptation measures?	EPA, 2017
Do adaptation plans account for tradeoffs between the less resilient but lower cost strategy of increasing protection from climatic changes and the more resilient but higher cost strategy of moving residents from the most vulnerable portions of the urban area?	EPA, 2017
Do current planning regimes include proactive resilience building, or is only reactive disaster response being addressed?	EPA, 2017
Does knowledge of historical land use/land cover changes contribute to planners' understanding of climate stresses?	EPA, 2017
Have specific historical land use/land cover changes been recognized as increasing or decreasing vulnerability to climate stresses?	EPA, 2017
Implementation	
Enforce regulations or offer incentives to encourage residents and businesses to shift behaviors to prepare for future climate change impacts.	USGBC/STAR Communities, 2016
Number of adaptation projects or actions implemented per year	USDN, 2016 (City of Vancouver)
Availability of policies and regulations that promote new investment or rebuilding after disaster	USDN, 2016 (ND-GAIN-draft)
Are policies and programs to promote adaptive behavior designed with frames/messaging that reach the critical audiences in the urban area?	EPA, 2017
Are policies and programs to promote adaptive behavior designed and implemented in ways that promote the health and well-being of vulnerable populations?	EPA, 2017
Are policies and programs to promote adaptive behavior evaluated in ways that take into account vulnerable populations?	EPA, 2017
Government capacity	
Availability of skills and experience for personnel in climate change and disaster resilience (e.g., risk identification, mitigation, planning, response and post-event response)	Lipsky & Starbuck, 2015
Number of staff aware of climate projections	USDN, 2016 (City of Vancouver)
Percentage of government departments that have tested their own continuity arrangements in the last 2 years	Arup, 2016
Percentage of government employees familiar with emergency procedures.	Arup, 2016
Percentage of departments which have passed business continuity assessments in the last 2 years	Arup, 2016
Is planning for climate change adaptation in the urban area incorporated into one office within the local government, or is planning spread out across several offices within the government?	EPA, 2017
Do planners in the urban area know the demographic characteristics of populations vulnerable to climate change?	EPA, 2017
Do planners in the urban area know the locations of populations most vulnerable to climate change effects?	EPA, 2017
Have institutional land practices (i.e., zoning, land use planning) potentially been hindered by other government agencies seeking to shift financial resources when it comes to climate change planning?	EPA, 2017
Collaboration	
Government structure is in place to coordinate inter- and intra-governmental climate preparedness activities across Metro Boston area and outside of Boston	Lipsky & Starbuck, 2015

Convene a regional summit to accelerate regional preparedness planning.	Lipsky & Starbuck, 2015
Partnerships established with research universities to analyze, test and implement new climate-preparedness strategies	Lipsky & Starbuck, 2015
Develop an interdisciplinary committee for the purpose of understanding and addressing vulnerabilities	USGBC/STAR Communities, 2016
Number of climate-related public-private partnerships	USDN, 2016 (City of Vancouver)
Number of universities/ NGOs/ institutions (e.g., weather agency) involved in undertaking DRR or resilience research related to the city	Arup, 2016
The number of times the 5 most significant hazards identified in the city's local risk profile have been assessed by multi-stakeholders in the last 5 years	Arup, 2016
Coverage by type and objective of trans-boundary hazard assessments	Arup, 2016
Number of (multi-stakeholder) hazard risk assessments in the last 2 years	Arup, 2016
Does the city consider the knowledge of local academic research and other stakeholders (e.g., farmers, forest managers, land use managers) in land use planning related to climate resilience?	EPA, 2017
Finance	
Financial support for climate change mainstreaming and related initiatives is in place	Lipsky & Starbuck, 2015
Readiness to accept adaptation investment	ND-GAIN, 2018
Financial expenditure on resiliency activities per year; as a percent of total expenditure	NPCC, 2015
Is comprehensive adaptation planning possible with the urban area's current resources?	EPA, 2017
Number of years since the city economic asset assessment (public and private)	Arup, 2016
What financial capacity is indicated by the city's bond ratings?	EPA, 2017
How available and how comprehensive are your planning resources for responding to extreme events?	EPA, 2017

Information and governance

Risk management indicators	Source
Government capacity	
Government departmental hours lost due to disruption in last 5 years	Arup, 2016
Continuity of all critical government administration functions (e.g., computer systems, data - utilize backup generators) during climate change related events	Lipsky & Starbuck, 2015