Indicators for Flood Adaptation Assessment: The Case of New York City

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Abstract:
Due to both the effects of climate change and the high concentrations of infrastructure and socio-economic activity in low-lying areas in NYC, floods have the potential to destroy homes and businesses, impair infrastructure, and threaten human safety. Measurement, reporting, and verification are vital steps in evaluating the efficiency and effectiveness of a climate change adaptation efforts. However, to date, there is no report that evaluates flood adaptation capacity in NYC nor a universal framework for flood adaptation assessment. The aim of this research is twofold. First it aims at developing a general framework for flood adaptation at the municipal level to guide decision-making in public investment and policy and to identify changes that can increase its flood adaptation capacity. Secondly, through a validation process with key experts, it suggests potential indicators that NYC could use to assess its flood adaptation, which are yet to be selected by the city. The resulting general framework is an adaptation of the framework developed in the NYPCC 2019 Report for assessing flood adaptation capacity, together with the categories for indicators used by ICLEI European Secretariat (2011) and contributions from other frameworks and field experts interviewed. Despite not being able to determine a concrete level with the current framework, the results have some implications for both NYC and future research.

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Summary

One way to reduce climate change risks is through adaptation. Demonstrating that adaptation efforts have minimized vulnerability, reduced risk, and increased adaptive capacity helps to inform future decisions, as well as attract more investment. Despite its importance, to date, there is no available report that evaluates flood adaptation capacity in NYC nor a universal framework for flood adaptation assessment. This situation suggests that, nowadays, there is no clear way to track and assess the city's adaptation and, hence, its current flood and climate change adaptation pathway is unknown. Flooding being one of the most frequent hazards impacting NYC and an absence of a universal framework to assess flood adaptation at the municipal level, the aim of this thesis is two-fold. First, it aims at developing a general framework for flood adaptation at the municipal level to guide decision-making in public investment and policy and to identify changes that can increase its flood adaptation capacity. Secondly, through a validation process with field experts, it suggests potential indicators that NYC could use to assess its flood adaptation, which are yet to be selected by the city.

The resulting general framework is an adaptation of the framework developed in the NYPCC 2019 Report for assessing adaptation, together with the 4 categories for indicators used by ICLEI European Secretariat (2011) (economy, society, ecosystem services and governance) and contributions from other frameworks and field experts. The framework recognizes two integrated processes with a total of 8 steps for the assessment of flood adaptation and the selection of indicators. Furthermore, it has 4 levels of flood adaptation, which depends on the contributions of each indicator to the two variables from the definition of climate change adaptation: vulnerability and anticipation of negative consequences. The level of vulnerability is determined by looking at the current characteristics of the city, whereas anticipation of negative consequences looks at the effectiveness of current policies and programs the city is implementing to reduce flood impacts.

Once developed, the indicators are further validated, corrected, and added to through interviews with selected key experts and adapted to the city's context. Only for illustrative purposes, the thesis applies the framework to the case study, without determining the final level of flood adaptation of the city due to a lack of an existing method to do so. Relative weighing of indicators falls outside the scope of this research and thesis and could be subject to future work. The illustrative application of the indicators and framework is only to show how the framework can be applied and the kind of analysis that is expected from each of the indicators.

These assessment of such indicators have some implications for the city that should be considered to further reduce vulnerabilities. Some examples include the increase of the protection of the poor and homeless to flood risks, the coverage of homes with flood insurance, the protection of ecosystems and an earlier integration of civilians' feedback in urban planning processes. Considering that reductions in risk in the face of increased hazards requires a more significant adaptation effort, a failure to address these vulnerabilities, may reduce the flood adaptation level of NYC in the future.

Given the scope and limitations of this research, further work is required to assess the real contribution of each indicator to flood adaptation and to develop a methodology to translate qualitative and quantitative assessments into a concrete level, as suggested in this research, or into something that allows the decision-maker to easily read and interpret the results achieved. Acknowledging the limitations of this research, given more time and resources, this framework could be further developed, and its application further investigated.

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Abbreviations

BPC: Battery Park City

CC: Climate change

CCA: Climate change adaptation

CCOHS: Canada's National Centre for Occupational Health and Safety

CDP: Carbon Disclosure Project

CNYCN: Center for New York City Neighborhoods

CRDG: Climate Resiliency Design Guidelines

CRED: Center for Research on Environmental Decisions

CSO: Combined sewer overflow

DEP: Department of Environmental Protection from New York City

DPSIR: Drivers, pressures, state, impact and response model of intervention

EPA: United States Environmental Protection Agency

EU: European Union

EWS: Early warning system

FEMA: Federal Emergency Management Agency

GDP: Gross domestic product

GI: Green infrastructure

GIS: Geographic Information System

ICLEI: Local Governments for Sustainability

IFPM: Interim Flood Protection Measure

MCA: Multi-criteria analysis

MHHW: Mean Higher High Water

MTA: Metropolitan Transportation Authority of New York

N.A.: Not applicable

ND-GAIN: Notre Dame Global Adaptation Initiative

NOAA: National Oceanic and Atmospheric Administration

NYC: New York City

NYCEDC: New York City Economic Development Corporation

NYPCC: New York Panel on Climate Change

NYW: New York City Municipal Water Finance Authority

RISE: Resiliency Innovators for a Stronger Economy

UNDESA: United Nations Department of Economic and Social Affairs

UNDP: United Nations Development Program

UNISDR: United Nations Office for Disaster Risk Reduction

US: United States

USAID: United States Agency for International Development

USGCRP: United States Global Change Research Program

WHO: World Health Organization

WMO: World Meteorological Organization

1. Introduction

This section describes the research problem, the current state of knowledge and the gaps that will be covered, as well as the purpose and research questions. Furthermore, it introduces the conceptual framework and research limitations.

1.1. Background

Climate change (CC)[1] is one of the greatest threats facing humanity, which disproportionately affects developing countries more than any other parts of the world (UNDP, 2019). However, this does not imply that only developing countries need to adapt since all regions are affected and no one is spared from climate impact in one form or another (Germanwatch, 2019).

New York City (NYC) is selected as the case study since it constitutes a compelling case to analyze for its geographical location and flood risk, urban density, and diversity and financial importance worldwide. More concretely, NYC is the largest city by population in the US (World Population Review, 2020a), ranked as the first city with more GDP and the third with the highest GDP growth worldwide. Despite being one of the most influential cities (Ross, 2019), it is vulnerable to the effects of CC (New York Academy of Sciences, 2019a). Hurricane Sandy (2012) is one of the many examples that reveals this vulnerability, which resulted in 44 deaths, $19 billion in damages, lost economic activity across NYC (NYC Mayor's Office of Recovery & Resiliency, 2019) and the temporary displacement of thousands of residents (City of New York, 2018). The amount of data that NYC offers, enhances the data collection process for the analysis and constitutes another reason for its selection.

More frequent and intense extreme weather and climate-related events and changes in the average climate conditions are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities (NYC, 2016; USGCRP, 2018). In the absence of significant regional adaptation efforts, rising temperatures, sea-level rise, and changes in extreme events are expected to disrupt societies and generate losses of life and damage to critical infrastructure (Garner et al., 2018; USGCRP, 2018).

1.2. Problem definition

Due to CC effects and the high concentrations of infrastructure and socio-economic activity on low-lying areas in NYC (Kemp et al., 2017)**,** floods have the potential to destroy homes and businesses, impair its infrastructure, and threaten human safety (City of New York, 2016)**.** With CC and sea-level rise, these risks are expected to increase (Garner et al., 2018), affecting mostly the low-lying neighborhoods (City of New York, 2016)**.** One way to reduce these risks is through adaptation (Georgeson et al., 2016; Birkmann et al., 2014; Brooks, 2003).

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[1] Climate change is defined as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (UNFCCC, 2011).

Measurement, reporting, and verification are vital steps in evaluating the efficiency and effectiveness of CC adaptation (CCA) efforts (The World Bank Group, 2011). Despite its importance, to date, there is no report that evaluates flood adaptation capacity in NYC (New York Academy of Sciences, 2019b) nor a universal framework[2] for flood adaptation assessment, as observed in the variety of frameworks and methodologies explored later in this thesis. Chapter 8 from the NYPCC Report 2019, the New York City Climate Change Resilience Indicators and Monitoring System, is merely a set of proposed indicators for the city. This situation suggests that, nowadays, there is no clear way to track and assess the city's adaptation (New York Academy of Sciences, 2019b); hence, its current flood and CCA pathway is unknown.

1.3. Research questions

Floods being one of the most frequent hazard impacting NYC (Depietri & McPhearson, 2018) and the absence of a universal framework to assess flood adaptation at the municipal level, the aim of this thesis is two-fold. First, it aims at developing a general framework for flood adaptation assessment at the municipal level to guide decision making in public investment and policy and to identify changes that can increase its flood adaptation. Secondly, through a validation process with key experts, it suggests potential indicators that NYC could use to assess its flood adaptation, which are yet to be selected by the city. Hence, the two main research questions of this thesis are the following:

How can efforts in flood mitigation and adaptation be evaluated at the municipal level?

What indicators NYC could use to assess flood adaptation?

The second research question is complemented and unpacked into the following sub-research questions:

(1) What are the current plans, programs, or schemes for flood adaptation in NYC?

(2) What indicators and criteria can be used to assess such plans in the long-term?

1.4. Conceptual background

This thesis is based on the **conceptual framework by Brooks (2003)** on vulnerability, risk and adaptation. This framework contributes to the conceptual background and relationships between **vulnerability, adaptation and risk**, which enables the reader to understand the assumptions behind the framework for assessing flood adaptation and for the selection of its indicators.

According to Brooks (2003), two types of vulnerabilities are distinguished in the literature: physical or biophysical, and social or inherent. Physical vulnerability is concerned, with the impacts that a hazard event produces, often viewed in terms of the amount of damage experienced by a system affected by a hazard (pp.4-5). This type of vulnerability is measured through indicators

[2] Framework is defined as *a basic structure underlying a system, concept, or text* (Lexico.com).

of outcome, such as human mortality and monetary costs (p.5). On the other hand, inherent vulnerability is defined as an inherent property of a system arising from its internal characteristics, and as one of the determinants of physical vulnerability (p.4). Later research talks about the dimensions of vulnerability, which need to be addressed when assessing vulnerability, as suggested by the MOVE framework (Birkmann et al., 2014), in Table 1. These dimensions are social, economic, physical, cultural, environmental, and institutional (Birkmann et al., 2014).

Table 1. Dimensions of vulnerability in the MOVE framework (Birkmann et al., 2014, pp. 9-10).

Dimension	Definition
Social	Propensity for human well-being to be damaged by disruption to individual (mental and physical health) and collective (health, education services, among others) social systems and their characteristics (e.g., gender, marginalization of social groups).
Economic	Propensity for loss of economic value from damage to physical assets and/or disruption of productive capacity.
Physical	Potential for damage to physical assets, including built-up areas, infrastructure, and open spaces.
Cultural	Potential for damage to intangible values, including meanings placed on artefacts, customs, habitual practices, and natural or urban landscapes.
Environmental	Potential for damage to all ecological and biophysical systems and their different functions, such as ecosystem functions and environmental services.
Institutional	Potential for damage to governance systems, organizational form and function, as well as guiding formal/legal and informal/customary rules.

These dimensions of vulnerability are seen, in this research, as subcategories of the inherent vulnerability. When choosing proxy indicators of adaptation, these dimensions of vulnerability are considered.

Additionally, Brooks (2003) states that it only makes sense to talk about the vulnerability of a specified system to a particular hazard or a range of hazards, where hazard or climate event is defined as “physical manifestations of climate variability or change”, such as floods (p.3). The interaction of hazards with the properties of the human system that is exposed and affected by the hazards leads to a disaster. The extent to which a society is vulnerable, not only depends on its level of exposure and type of hazard, as stated by Brooks (2003), but also on the fragility or predisposition of the elements at risk to suffer harm, and on the lack of resilience or societal response capacity (Birkmann et al., 2014).

One concept related to vulnerability is **risk**, which can be defined in different compatible ways: (1) as a function of hazard and social vulnerability, (2) as probability times consequence; and (3) in terms of outcome (Brooks, 2003). The probability of an outcome depends on the probability of occurrence of a hazard and on the inherent vulnerability of the exposed system, which determines the consequence of the hazard (Brooks, 2003). Hence, the outcome of the risk may be viewed as a function of event risk and inherent vulnerability. In this sense, the determinants of risk and biophysical vulnerability are the same: hazard and social vulnerability.

Despite its many definitions, **adaptive capacity** is defined as the ability of the system to modify or change its characteristics or behavior to cope better with existing or anticipated external stressors (Brooks, 2003). Reductions of social vulnerability arise from the realization of adaptive capacity, which includes **adaptation**, defined as "any actions that anticipate the negative consequences of CC – to human health, the economy or ecosystems – and attempt to minimize the damage to societies" (Georgeson & Maslin, 2016).

When defining adaptation, Brooks adds changes in the characteristics that enhance the ability of a system to cope with external stresses (Brooks, 2003, p. 8). In this sense, assuming a constant level of hazards over time, **adaptation allows a system to reduce the risk** associated with these hazards **by reducing its inherent vulnerability**. Given this relation, reductions in risk in the face of increased hazard require a more significant adaptation effort. The direct effect of **adaptation** is, therefore, to **reduce inherent vulnerability** (Birkmann et al., 2014). Given these definitions and relationships, adaptation is defined here as the characteristics and actions (programs/projects) of a system that anticipates the negative consequences of CC and minimizes the damage or disruptions to society.

The damage to a system resulting from a discrete hazard event, such as a flood or storm occurring tomorrow, is not a function of the system's ability to pursue future adaptation strategies (adaptive capacity) but to its existing adaptation (Brooks, 2003). This existing adaptation results from the past realization of adaptive capacity, which, at the same time, determines current levels of vulnerability.

1.5. Limitations

There are many challenges encountered when measuring adaptation at the city level. First and foremost, there is a lack of consensus on how to measure and assess adaptation. Whereas some researchers and institutions use indicators or metrics to determine the level of adaptation of a concrete system, others use a process approach. Under this approach, the assessment does not look at indicators that capture a snapshot in time but the evolution of the system towards a higher adaptation (Pilgrim, 2020). The use of indicators poses an oversimplification problem of reality, in which it assumes that by just tracking a set of indicators, an adaptation level can be determined (Leiter et al., 2019). On the other hand, the process approach may be against the simplification criteria that research suggests for a successful application of frameworks developed.

In this research, with the aim to minimize this oversimplification, the indicators are both quantitative and qualitative. Furthermore, those quantitative are not represented by just numbers, but they are complemented with a contextual description of the situation of the city to capture part of the process behind the numbers. Moreover, the results are not represented in a final score, but under different categories, which enhances the interpretation of the results. However, this research does not develop the method to transform the assessment of the indicators to the final level of flood adaptation, since it is beyond the scope of this paper.

When applying this framework, it is assumed that cities have the resources, capability (Johannessen, 2017) and enough and relevant data to perform the assessment. However, as observed in the case study, this is not always the case. Relevant data, such as number of undocumented people or the number of people not speaking the official language may not be available and, hence, other indicators must be assessed instead. This can result in the ignorance of social aspects that may contribute more to adaptation than those where data is available and overestimate the level of adaptation (Coalition for the homeless, 2020). Being aware of this problem, can help cities to enlarge their datasets and better address these problems.

Finally, it was thought to contact local stakeholders for feedback on the indicators. Those stakeholders from other departments from NYC, or energy or water supply companies, could not be reached. However, from the interviewed, two had direct experience with NYC and could identify indicators that are relevant to the city. Additionally, this framework aims at being generalized for those cities with similar context and, hence, more general indicators are needed in the analysis.

2. Methodology

This thesis started with a problem identification and formulation, checking newspaper articles and blogs about NYC and its floods problems. This step was followed with the selection of a theoretical framework that described and defined the interlinkages between risk, vulnerability and adaptation. This framework enabled an understanding of the outcomes of adaptation and, hence, set the guidelines when choosing indicators to assess adaptation. From the definitions and interlinkages presented, the indicators that were selected had an influence on the inherent vulnerabilities of the city and its flood risks.

After the theoretical framework, the process proceeded with a literature review, in which five frameworks for urban adaptation assessment were described, compared, and evaluated. The selection of these frameworks was done considering that they were using indicators for the assessment and ones that are relevant to the case study as well as offering detailed explanation of the process. They were complemented with other key aspects for the implementation of such framework, which included the process of indicator selection and the different ways to represent the levels of adaptation. The theoretical framework was used for the development of the general framework for flood adaptation assessment in urban areas, which constitutes the next step of this research.

The framework suggested specifies the different steps that municipalities should follow to improve their current adaptation, which were adapted from the NYPCC 2019 Report (referred to as the Report). This framework recognizes two different processes that are integrated: flood adaptation assessment and selection of indicators. To simplify and adapt it to a flood adaptation assessment, the flood adaptation assessment has five instead of eight steps and indicators' selection four instead of seven. From the original framework for adaptation assessment, only steps 1, 2, 3 and 8 were adapted and for indicators selection 3, 4, 5 and 7. Once the steps were chosen, they were described, together with their aim.

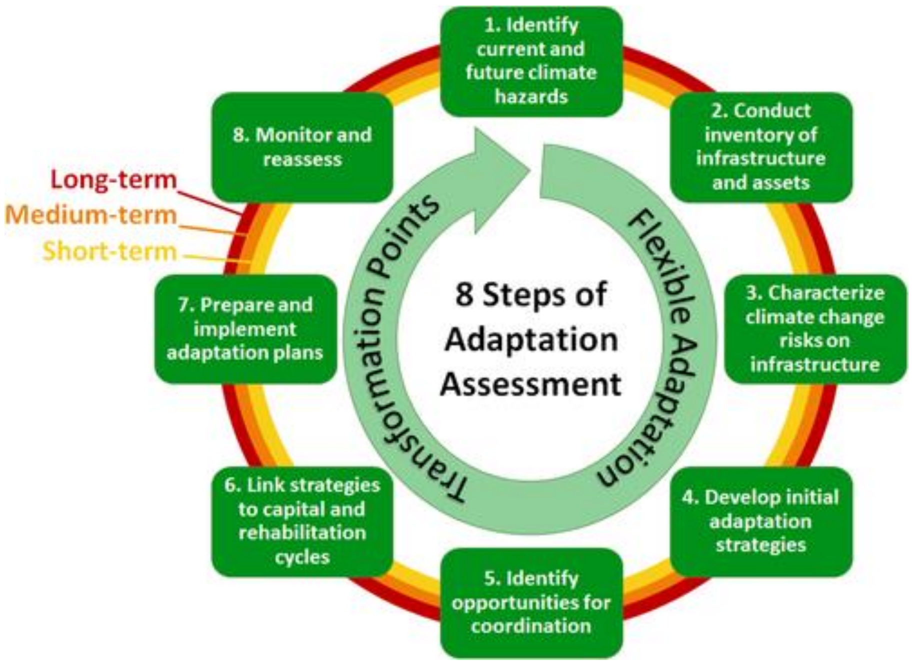

Figure 1. Steps of adaptation assessment (New York Academy of Sciences, 2019c)

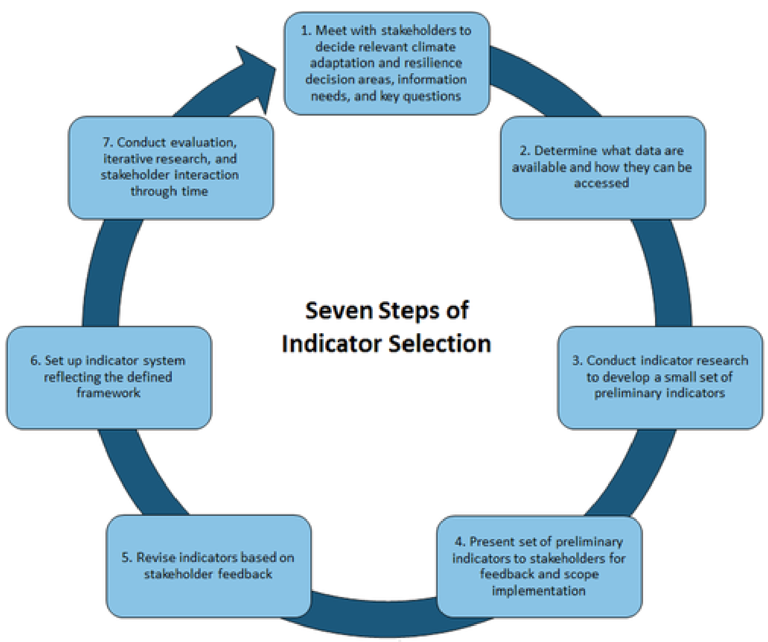

Figure 2. Steps of indicator selection (New York Academy of Sciences, 2019c)

After the description of the steps for the assessment, additional information needed in the framework was brainstormed. From this process, the following was identified: type of indicators and level of detail of the analysis, different levels of flood adaptation, stakeholder engagement in the framework and timeframes and frequency of analysis. Since not all these categories were present in the frameworks analyzed or in other literature, an interview[3] was designed to fill the research gaps. In this questionnaire, details about criteria of indicators to be comparable across time and cities and timeframes and frequency of such analysis were discussed. However, the interviews were not done until a later stage, since it included a question about the feedback of a preliminary set of indicators to analyze the flood adaptation of NYC.

Once the framework was complemented, it was applied to the case study. Before starting with the analysis, the boundaries of the system under assessment were specified (system description). This was followed by a description of the sources of floods of NYC (flood characterization) and the characterization of the risks. After the flood context was studied, the identification of a set of preliminary indicators took place. Once chosen, 44 researchers and organizations were contacted, which resulted in 9 in-depth interviews[4]. With the collaboration of the field experts interviewed, further details could be incorporated in the framework, and other relevant indicators could be added.

Once the initial indicators were modified, the analysis of the flood adaptation from NYC was performed. Quantitative and qualitative data were collected from local official websites, from organizations that work together with the city and from local newspapers. Furthermore, comparison criteria across time and cities were specified for each indicator, so that the framework can be comparable across cities – for either exchange of experiences or prioritization of investment of cities in the same State, and across time – to observe the progress what the city is doing in flood adaptation. To offer a simple illustration of the application of the framework, all the indicators were given the same weight when determining the adaptation level.

3. Literature review

This section explores some of the existing frameworks and guidelines for CC and flood adaptation assessment using an indicator approach.

3.1. Frameworks and guidelines to assess climate change adaptation

The first framework introduced is the **Strategic Planning Framework for Adaptation** in the Handbook for Decision Makers at the Local Level (2011) by ICLEI European Secretariat. This framework provides guidelines for local decision makers **for a successful adaptation** in the field of water management, following **three steps**: (1) review of the adaptive capacity, (2) sensitivity assessment; and (3) vulnerability assessment (ICLEI European Secretariat, 2011). To assess adaptation, it suggests the analysis of **four determinants** (economy, society, governance and

[3] See Appendix 4.
[4] See the field experts interviewed in Appendix 4.

ecosystems), which are evaluated with proxy and context-specific indicators (ICLEI European Secretariat, 2011). Economy covers activities from all sectors that are generated by a city (energy, technology development, health services, etc.); society encompasses a range of factors related to information, social capital and human capital; governance is related to the process of decision making and ecosystems refer to the existence and conditions of the living and non-living environment (ICLEI European Secretariat, 2011).

While this framework provides a flexible implementation, and highlights the importance of being carried out locally, it presents some pitfalls. First, it does not provide a clear process of stakeholder involvement. When it comes to internal coordination, it suggests that it should be done through local governments with or without coordination units (ICLEI European Secretariat, 2011). These coordination units constitute different urban sectors that promote stakeholder involvement in the assessment. Without these coordination units, the assessment can lack perspectives from these urban sectors and, hence, may result in maladaptation (Coaffee & Lee, 2016).

Although it also talks about stakeholder involvement, it is not clear who these stakeholders are and how they are engaged. Furthermore, it is not obvious when the researchers should contribute. Concretely, it states that they should be involved in the scenario building due to CC and in the development of innovative solutions (ICLEI European Secretariat, 2011). However, it does not refer to which type of solutions and, hence, it is ambiguous at which other stage they should be in or if in all.

Similarly, there is the **Urban Adaptation Assessment Technical Document** by the Notre Dame Global Adaptation Initiative (ND-GAIN) (2018), in which urban adaptation to CC is measured through an index that considers indicators of risk and readiness and six life-supporting sectors – food, water, health, ecosystem service, human habitat and infrastructure. Risk is defined as the city´s vulnerability to CC and incorporates indicators of exposure, sensitivity and adaptive capacity, such as the percentage of the population with health insurance, the population living in flood zones and the population spending over 50% of income on rent (ND-GAIN, 2018a, p. 11).

On the other hand, readiness, which is defined as the capacity of a city to mobilize and target more effectively adaptation investments from private sectors, is measured by looking at indicators of economic, governance and social readiness (ND-GAIN, 2018a). Economic readiness measures the economic conditions to support and attract adaptation investment; governance readiness looks at if the governance support enables effective use of adaptation investment and, finally, social readiness assesses the capacity of society to facilitate the uptake of the benefits from the adaptation investment (ND-GAIN, 2018a, p. 3).

Despite its transparency in the conceptualization, methodology and sources used for the development of the index, the assessments are carried out by ND-GAIN. All the literature reviewed in this thesis suggests collaboration with local stakeholders and analysis are to be carried out locally for more relevant analysis and findings. Furthermore, composite indices may fail to capture the interconnectedness of indicators, ignore important dimensions that are difficult to measure, and disguise weaknesses in some components (USAID, 2014). Even if the index was conducted locally, it has 45 indicators, which would constitute a burden for the administrations or result in a too broad assessment (Osman et al., 2013). Finally, some of the indicators should be changed, discarded or adapted to the local context so that the results are useful for decision makers (Jones et al., 2014).

The next framework is the one suggested by **the NYPCC 2019 Report,** which co-generates new tools and methods for the next generation of climate risk assessments and implementation of region-wide resilience (New York Academy of Sciences, 2019c). The report suggests an interactive and circular process for **indicator selection** that ensures that the selection of indicators is relevant to the context. It comprises **seven steps**: (1) stakeholder meeting to decide relevant climate adaptation and resilience decision areas, information needs and key questions; (2) identification of data available and accessibility; (3) preliminary indicators selection through indicator research; (4) presentation of preliminary indicators to stakeholders for feedback and scope implementation; (5) revision of indicators based on the feedback received; (6) indicator set-up; and (7) evaluation, iterative research and stakeholder interaction through time.

Additionally, it sets **eight steps for adaptation assessment**: (1) identification of current and future climate hazards; (2) inventory of infrastructure and assets; (3) characterization of CC risks on infrastructure; (4) development of initial adaptation strategies; (5) identification of opportunities for cooperation; (6) linkage of strategies to capital and rehabilitation cycles; (7) preparation and implementation of adaptation plans; and (8) monitoring and reassessment (New York Academy of Sciences, 2019c). As in the previous framework, it suggests vulnerability indicators to assess the effectiveness of CCA policies and measures in managing the risks to which the city is exposed. However, it differs in the determinants for assessing adaptation (New York Academy of Sciences, 2019c). These five determinants are called sectors and are related to critical infrastructure – energy, telecommunication, transportation, social infrastructure and, finally, water, sewage and waste (New York Academy of Sciences, 2019c).

Unlike the previous report, this report clearly defines how the interactions between stakeholders should take place (through workshops, meetings and teleconferences) and when (New York Academy of Sciences, 2019c). However, its indicators are mainly focused on critical infrastructure, assuming that governance institutions are coordinated and have the willingness to follow the recommendations from scientists when it comes to CC forecasts. Furthermore, economic readiness is also ignored, which is one of the causes of lack of accomplishment of suggestion in rebuilding infrastructure adapted to CC (Caffrey, 2020). Finally, the indicator selection criteria followed by the framework is measurability, policy relevance and analytic soundness (New York Academy of Sciences, 2019c). While these criteria are not defined, this suggests that those variables that cannot be measured (e.g. due to lack of data) are not selected for the assessment. The fact that there is no data about an indicator does not mean that it is not relevant and does not influence the level of what is being measured.

Other frameworks assess flood adaptation measures of a certain area based on several interventions from a previous vulnerability, sensitivity and exposure analysis, such as the **assessment of flood**

adaptation measures in the city of Dhaka (Bangladesh) by Hake et al. (2010). Like the two previous frameworks, the capital assets identified (or determinants in the previous framework) were natural, physical, economic and social (Hake et al., 2010). Furthermore, this assessment was performed with constant feedback and interaction with main stakeholders and experts under a Multi Criteria Analysis (MCA) (Hake et al., 2010). Following focused group discussion, stakeholders decide on the selection criteria for the adaptation options to include in the assessment. Field experts with experience in the case study, used the MCA to score the different adaptation options. The criteria used for the assessment were: vulnerability reduction, minimization of costs, enhancement of ecological conditions, public and political acceptance, employment generation, achievement of millennium development goals and institutional and technical capacity required (Hake et al., 2010, p. 32). This framework allows for a quantification of the adaptation options, which helps to identify which areas need to be prioritized for a greater adaptation (Hake et al., 2010).

Some of the limitations of this framework are the uncomplete analysis provided by the frameworks used for vulnerability and adaptation assessment, which do not account for the impacts of each adaptation option (Hake et al., 2010). Not considering the impacts of adaptation projects, can lead to an increase of risk to other areas and, hence, constitute poor risk management (FLOODsite, 2009). Important factors for the implementation of adaptation options were also ignored, such as financial, institutional and technical capacities (Hake et al., 2010).

Another example is the report **Responding to Climate Change in New York State by ClimAID (2011)**. For the assessment of adaptation of the State, it investigates the adaptation strategies and evaluates different criteria, such as cost and feasibility. This report also identifies eight key sectors when assessing adaptation: water resources, coastal zones, ecosystems, agriculture, energy, transportation, telecommunications and public health (ClimAID, 2011). Moreover, it suggests different steps for vulnerability and adaptation assessments for each sector, which are the same as in the Report. This process was designed in collaboration with stakeholders and it required their involvement to be able to perform the assessment (ClimAID, 2011).

Like in the Report, this report ignores key indicators of adaptation, like those that analyze governance and economic readiness. Furthermore, global climate models are used for this report, which does not capture the changes in the local climate (Rosenzweig et al., 2011). Hence, this report represents only a general guidance for adaptation and rough estimates. Despite being recognized, the limitations of this report are in another extensive document[5], which may not be seen or considered by decision makers.

3.2. Approaches for indicator selection

The frameworks reviewed show two different ways to assess adaptation: assessing adaptation programs or assessing proxy indicators for CCA. In fact, there are different metrics that can be used to assess adaptation. According to Leiter et al. (2019), these metrics can be indicators of

[5] NYSERDA, Responding to Climate Change in New York State – Technical Report (2011)

climate exposure, vulnerability, risk or resilience (which represent factors that determine climate exposure, vulnerability, resilience, adaptive capacity or risk); context-specific indicators of adaptation interventions (used for monitoring and evaluation processes); standard adaptation indicators of portfolios (to measure performance across adaptation interventions for aggregation purposes) and comparative global indices (to rank countries according to an index value).

Additional literature talks about the determinants or drivers of adaptation, which can also be used to assess not only adaptive capacity, but also adaptation, since adaptation is an incremental, non-static process (WHO, 2002; Brooks, 2003). For instance, WHO (2002) states that the determinants of adaptation reduce exposure or sensitivity, and special attention should be placed on socioeconomic factors (p.21). Reckien et al. (2015) classify the different drivers and barriers for adaptation into four factors: institutional, socio-economic, environmental and composite vulnerability factors. Some of the drivers presented are social vulnerability, flood risk and damage (Reckien et al., 2015), which is consistent with most of the research presented previously.

Finally, the criteria that indicators should follow to allow the comparison between cities or regions, are: **aggregable** (aggregation of quantitative/qualitative data), **transparent** (transparency and consistency of definitions, methods and assumptions), **longitudinal** (the indicator can be tracked over time to monitor and evaluate progress), **feasible** (data availability, collectable and it does not represent a burden), **coherent** with the definition of adaptation and **sensitive** to national context (Leiter et al., 2019).

3.3. Levels of adaptation

There are different ways to classify levels of adaptation. Following the **General Framework for Risk Assessment** by Tehler (2015), the classification can be: verbal description, qualitative description using an ordinal scale, semi-quantitative description using an ordinal scale and quantitative estimates on a cardinal scale (Tehler, 2015, p. 14)**.** In a verbal description approach, there would be a description of the flood adaptation of the case study without the use of any scale for ranking or cardinal comparison. The qualitative description using an ordinal scale usually includes a five-step scale with qualitative descriptions of the various steps. The semi-quantitative complements the previous with quantitative values and, finally, the cardinal scale uses quantitative estimates based on different units of measurement.

In their paper, Hu & He (2018) measure the urban adaptive capacity of the city of Changsha (Southern China) to CC through different quantitative indicators classified in five dimensions (driver, pressure, state, impact and response), which corresponds to the driver-pressure-state-impact-response (DPSIR) framework. Through this framework, they identify the effect of each indicator towards urban adaptive capacity and explore the interactions between human society and the ecological environment (Hu & He, 2018). Through a process of transformation of data into scores, they elaborate four types of urban adaptation capacity: **high maladaptation** (with a score between 0 and 0.6), **slight adaptation** (between 0.6 and 0.7), **favorable adaptation** (between 0.7 and 0.85) and **high adaptation** (between 0.85 and 1).

The methodology applied in their paper includes five first-grade indicators and 33 second-grade indicators to evaluate the urban adaptive capacity to CC (Hu & He, 2018). Representing almost 40 indicators in a single score, it makes it hard for decision makers to interpret the study and to take decision to improve the situation. Moreover, there is no disaggregation of data to see the main contributors of an increase in the score calculated and, hence, some information is lost in the results.

The ND-GAIN (2015) also identifies four levels of urban adaptation: **upper, upper-middle, lower-middle** and **low**, which depend on the level of vulnerability and readiness of each country analyzed. Those that have an **upper level** of adaptation have a low level of vulnerability and high level of readiness. However, "these countries still need to adapt, since none of them have a perfect vulnerability score" (ND-GAIN, 2018a). Those in the **upper-middle level** have both a high level of vulnerability and a high level of readiness. Although the need for adaptation is large, these countries are ready to respond and the private sector may be more likely to participate in adaptation than in those countries with less readiness (ND-GAIN, 2018a). The countries with **lower-middle adaptation level** have low levels of both vulnerability and readiness. Despite having a relatively low level of vulnerability, their adaptation may lag behind due to lower readiness (ND-GAIN, 2018). Finally, those countries in a **low adaptation level** have a high level of vulnerability and a low level of readiness. Those have both a great need for investment to improve readiness and a great urgency for adaptation action (ND-GAIN, 2018a).

This framework, as opposed to the previous ones, represents an easier way to interpret the results of adaptation, since each level depends only on two variables, described by the assessment of indicators. However, the level of readiness is more used to measure adaptive capacity and not the current level of adaptation (Brooks & Adger, 2004), since readiness is an indicator that shows an enabling environment for the implementation of future projects or policies (ND-GAIN, 2018b). Hence, the level of readiness describes how adaptation can be in the future based on the conditions that it analyses, which can enable a better future adaptation (ND-GAIN, 2018b). An improvement in this research would be to change the level of readiness to another indicator that describes the current level of adaptation.

To simplify the categorization of adaptation, this thesis adapts a semi-quantitative description using an ordinal scale of four different levels, inspired by the ND-GAIN (2018) and by the validation interviews done. More details are found in the next section.

From this literature review, it appears that there is no universal framework for flood adaptation assessment (Leiter et al., 2019). Instead, each organization or researcher applies a different method for the analysis and takes different approaches. However, all of them agree that the indicators must be context specific and that the analysis should be done over time, with the constant interaction of stakeholders. Furthermore, although the frameworks analyzed describe the process or the different steps of such assessments, they ignore or do not cover relevant and important details when they are used. Those gaps identified were the frequency of assessments, the levels of adaptation from the assessment, the number of indicators selected, the change of indicators and the process behind this change and if the results from the framework can be compared and how.

4. General framework for flood adaptation assessment in urban areas

In this section, a general framework to assess the flood adaptation of a specific urban area is suggested. Analyzing the current characteristics of a city, this framework aims at assessing how the current characteristics of a city reduce the damages and losses of future floods. With this aim, it intends to guide decision-making in public investment and policy and to identify changes that can improve the situation of a city to increase its flood adaptation.

This framework is adapted from the recommendations and procedures pursued in the Report, since it provides a clear and simple procedure to follow. Compared to the one suggested in the Report, for the development of the steps for the assessment only 1, 2, 3 and 8 were selected and for indicators selection 3, 4, 5 and 7. The rest of the steps in both processes, were not considered relevant in this framework, either because they talk about the implementation of adaptation plans (in the case of the assessment) or they are already included in steps such as stakeholder engagement. Furthermore, instead of being presented as separate processes, both were joined, since all the steps take part as one process – the assessment of flood adaptation. Additionally, this process does not always follow the same path, because the change of indicators does not need to be done in every assessment if they are still relevant to the case – as agreed by the field experts.

The original framework considers five key infrastructure sectors (New York Academy of Sciences, 2019c), which ignore other aspects that need to be considered in the assessment. Hence, the categories from ICLEI European Secretariat (2011) were used instead. Moreover, instead of offering a verbal description of the assessment, it includes a semi-quantitative ordinal categorization of the different levels of adaptation that can be achieved. This categorization is based on the definition of adaptation and it was included because it allows for a better interpretation of the results than a verbal description. Scores were not used to simplify the implementation of the framework.

As in the two frameworks mentioned, stakeholder engagement is emphasized. However, instead of being part of concrete steps (as in the Report), the engagement is embedded in all the process. Finally, the framework includes the timeframes and frequency of analysis, which includes additional considerations that are not covered by most of the frameworks reviewed.

4.1. Guidelines for the application of the framework

This section starts with the description of the different steps of the framework. It follows with complementary information about the criteria of the indicators, the level of detail of analysis and the different actors that should be involved in the process.

4.1.1. Steps

The flood adaptation assessment entails two integrated and circular processes with a total of eight steps, as depicted in Figure 3. It starts with a **characterization of floods**, which aims at answering the following questions: What are the causes of floods? Which type of floods are more frequent? What are the forecasts of these floods: are they going to increase in intensity and frequency in the future (in the short (up to three months (WMO, 2008)), medium (one year (WMO, 2008)) and long term (from one year onwards)?[6]

In the second step, the **flood risk analysis** is performed. Based on the definition of risk, it analyses which kind of impacts these floods can generate and where, to determine both the consequences of the hazard and the causes of vulnerability (Doroszkiewicz & Romanowicz, 2017). This helps in the identification of the characteristics of the system that makes it more vulnerable to the risks identified (CCOHS, 2017). If it is the first time performing this type of assessment, the step that follows is the **preliminary selection of indicators**, which need to follow the criteria explained in the next section. These indicators are based on the flood risk analysis performed, since they capture those key areas that need to be addressed to reduce risks (CCOHS, 2017) and, hence, damages and losses or societal disruptions (New York Academy of Sciences, 2019c).

To guarantee that key areas are addressed in the assessment, it is needed to **contact local stakeholders**, so that they can provide feedback on what is intended to be analyzed and what has been ignored (Jetoo, 2019). This step brings to the last stage of this second process, which consists in the **modification of the indicators** based on the feedback received. However, if it is not the first time this framework is used, the change of indicators is done if others more relevant are identified and approved by the stakeholders. According to most of the interviewees, this process of change or update of indicators should not be done too frequently since it is important to be able to compare across time. However, the interviewees recognized that there might be some mistakes when choosing certain indicators or changes in the city that make some indicators not that relevant anymore. For this reason, it is suggested that the change or update of indicators is done every five to six years, as also recommended by the EU Floods Directive.

Once this is finalized, the city would have a set of indicators to start with the assessment. The process follows with **data collection** relevant to each of the indicators and in collaboration with the relevant stakeholders. In this stage, each city should inform about the data collection method used. Finally, it follows an **evaluation of the current characteristics of the system**. This final step involves the analysis of how the area of study, with the current characteristics, programs, policies (etc.) it presents, will be disrupted in the present and future.

[6] The short term forecasts help to see what needs to be prioritized (Buizer et al., 2016; National Academy of Sciences, 2016), whereas those that are in the medium and long term help to keep in mind the conditions of the future so that the measures taken can last over a longer period of time (Singh et al., 2018; Wilson, 2016).

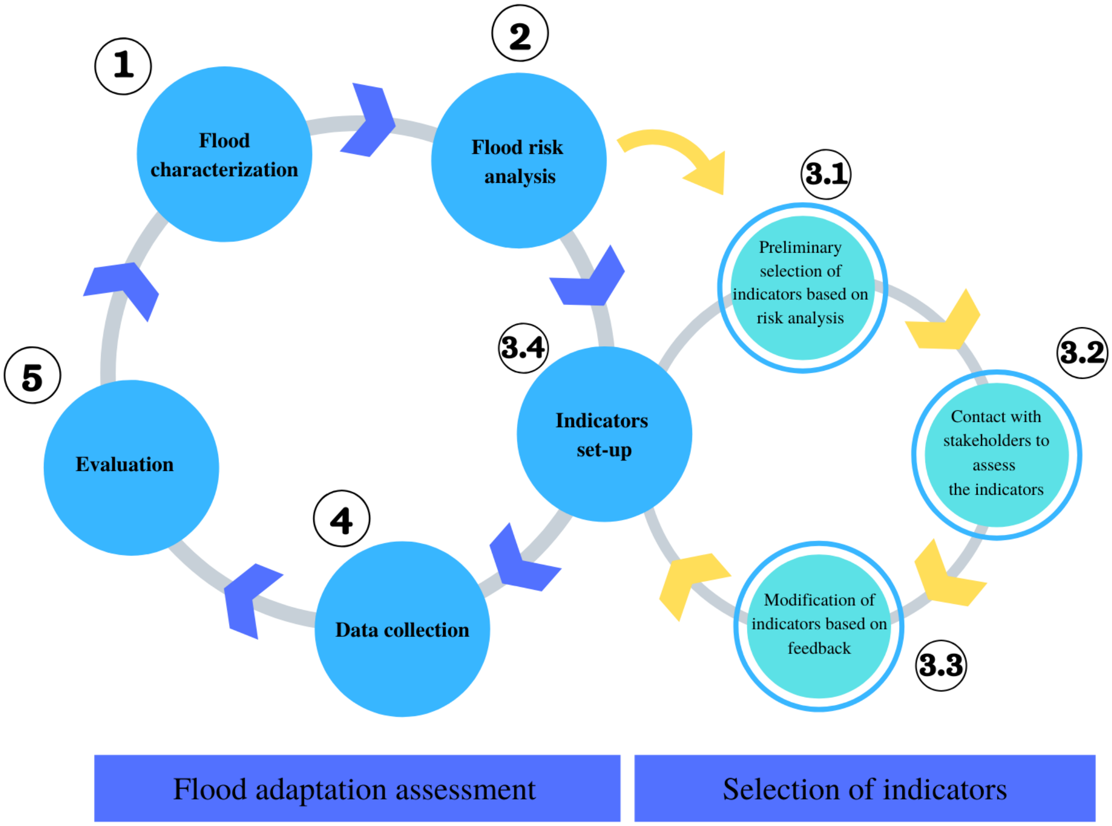

Figure 3. Framework for flood adaptation analysis. Adapted from the NYPCC 2019 Report.

4.1.2. Indicators and level of detail of the analysis

In this framework, the categories of indicators chosen are the ones suggested in the strategic planning framework for adaptation by ICLEI European Secretariat (2011). The reason why they were selected, apart from integrating the determinants of vulnerability by Brickman (2014), is because they offer a more general categorization of indicators than the rest of frameworks reviewed (see Appendix 1). Hence, as a result of this cross comparison, the categories of the indicators are economy, society, ecosystem services[7] and governance. The table below provides a description of what each of the categories entail.

Table 2. Categories of indicators (ICLEI European Secretariat, 2011)

Category	**Definition**
Economy	This section includes proxy indicators that are related with all economic sectors that feed or are generated by the city (agriculture, industry, services, etc.) and its systems (infrastructure, technology

[7] This category is changed to ecosystem services as recommended by the interviewees, since it provides a better description of what is being analyzed under this category.

	development, health services, etc.).
Society	Indicators in this category include the following factors: information (availability and access to information), social capital (connections within and between social groups) and human capital (knowledge, education and skills of the society).
Ecosystem services	These indicators are used to describe the existence and state of the living and non-living environment, as well as their interactions.
Governance	This category includes indicators that describe the process by which a society makes decisions and who is involved in that decision-making process.

Based on assessments previously performed[8] and according to the interviewed, the number of indicators in each category should be between five and six. However, some mentioned that it depends on the focus and the temporal aspect of the assessment, but it is better to keep a small number to assure quality in the assessment (Rosemarin, 2020). Including less indicators can exclude important areas to analyze and distort the assessment, whereas more indicators can represent a burden for municipalities or can incur the risk of not providing enough details (Osman et al., 2013).

From the conceptual background, a decrease in the vulnerability of the system from an indicator, shows an increase in adaptation. Moreover, it needs to be contrasted with the risks the system is exposed to due to this hazard, not only in the short-term, but also medium and long terms, since they are important to inform decision making (New York Academy of Sciences, 2019c). From the definition of adaptation, an increase in anticipation of negative consequences signals how adaptable a system is.

Finally, to compare across time, the city should have the same temporal and spatial scale (New York Academy of Sciences, 2019c). The reason why this framework needs to be comparable is to allow a learning process at the city level and prioritize action for a better flood adaptation. It would be relevant to compare across cities of a similar context to share good practices. However, since the indicators need to be context-specific, the ones selected for the case study, according to the interviewed, would be only comparable for those cities with similar context. Furthermore, the field experts stated that it is important that the assessment is done during the same years or within one- or two-years difference. Otherwise, the cities change, and the comparison may no longer be relevant.

[8] Such as the NYPCC 2019 Report, the Guidance for Municipalities to Adapt to Climate Change by ACT and the Urban Adaptation Assessment indicator list by Notre Dame Global Adaptation Initiative.

4.1.3. Level of adaptation

The different levels of flood adaptation are described in Figure 4. The qualitative description of each of the levels is adapted to the conceptual framework of this thesis, which looks into the level of vulnerability (V) and anticipation of negative consequences (A) in decision making. This last is determined by the effectiveness of current policies and programs the city is implementing to reduce flood impacts, as suggested by some of the interviewed. These two dimensions were selected considering the definition of CCA (see Section 1.4).

The resulting levels of flood adaptation can be represented in the matrix below, where an **upper level of adaptation** is characterized by a low level of V and A to floods, whereas a **lower level of flood adaptation** has a high level of V to floods with a low level of A of floods. Those cities with a high level of V but high A have an **upper-middle level** and those with both low levels of V and low A, have a **lower-middle level**.

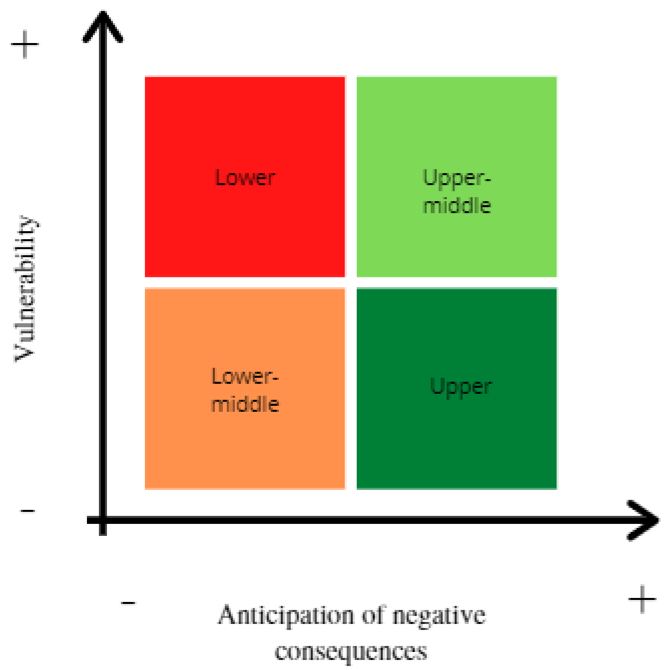

Figure 4. Matrix of flood adaptation levels.

To know the final level of adaptation achieved by the city, the influence of V and A for each of the indicators needs to be accounted for. Those indicators that increases current vulnerability contribute with a "+" to V. On the other hand, if there are programs or efforts in place to reduce this vulnerability and they reduce V, then this indicator contributes with a "+" to A. In this sense, a low (-) level of V (or A) is determined when more than half of the indicators decrease V (or A) and a high (+) level of V (or A) is determined if more than half of the indicators increase V (or A). If exactly half of the indicators increase V (or A) and the other half decrease it, due to equal weighing of all indicators, the city would receive a level between two of the established.

Despite the simplification behind this method, it is not a valid one since the use of "+" and "-" cancel out the contributions of indicators and it assumes that all indicators contribute the same way to the flood adaptation level. However, this method is presented to be able to go through all the steps of the framework later.

4.1.4. Stakeholders engagement

To achieve a centralization and coordination of indicators and monitoring system, as well as a course correction towards the targets and goals of CCA and resilience (New York Academy of Sciences, 2019d), the **municipality** is the one that should be **in charge of the assessment** (UNISDR, 2010; New York Academy of Sciences, 2019c; Madu & Kuei, 2017, pp. 8-21). However, as mentioned before, this process must be in **collaboration with stakeholders**, since they are involved in adaptation (The World Bank Group, 2011). These are: academic and scientific organizations, community-based organizations and small businesses, governments, international nongovernmental organizations, United Nations and international financial institutions and large-scale industries and businesses (The World Bank Group, 2011, pp. 24-25; UNDP, 2008).

The collaboration of these stakeholders will depend on the steps of the framework and on the type and detail of information required, as well as on the context (Jetoo, 2019). Concretely, they are selected in the step if any or more of the following conditions take place: if they are affected by the issue, if their activities affect the issue, if they possess/control information, resources and expertise for strategy formulation and implementation and if their participation is needed for successful implementation (European Commission, 2018).

4.1.5. Timeframes and frequency of analysis

Although there is no consensus on the frequency of such assessments among the interviewed, to ensure the availability of enough data and a good quality of the assessment, this assessment should be done at least once every 4 years (European Commission, 2018). During these years between assessment, data collection should take place and the flood characterization and flood risk analysis should be updated. It is important to consider years where there were elections, an important natural hazard or economic crash, since they can distort the assessment (Caffrey, 2020; Depietri, 2020).

5. Case Study: New York City

This section provides an analysis of the current level of flood adaptation in NYC to guide both decision making in public investment and policy and to identify changes that can improve its situation to increase flood adaptation.

5.1. Analysis

In this section, the framework for flood adaptation assessment is applied to the case study of NYC. It starts with the description of the system analyzed and ends with the conclusions of the assessment.

5.1.1. System Description

Before starting the analysis, it is key to state the system aimed at being evaluated to know the boundaries of the assessment (Smit et al., 1999). The system analyzed is the NYC, a city located in the coastal area of New York State, in the north-east of the U.S. It is the most populated and densely populated city in the U.S., with an estimated population of around 8.5 million people in 2020 and a density of 10,000 people per square kilometer (World Population Review, 2019). The city is divided into five boroughs – Brooklyn, Bronx, Queens, Manhattan and Staten Island.

Figure 5. Borough boundaries (NYC Department of City Planning, 2020)

Department of City Planning, NYC by boroughs [map]. [1:400]. Borough boundaries. March 2020. https://data.cityofnewyork.us/City-Government/Borough-Boundaries/tqmj-j8zm. Using: ArcGIS [GIS software]. New York, NY: Department of City Planning, March 2020.

The map that best represents the areas that are exposed to sea level rise, high tides, extreme rainfall, hurricanes and nor'easters is the Preliminary Flood Insurance Rate Map from FEMA from 2015 (Figure 6), which shows high-risk flood areas. This map is complemented with potential progression of the 100-year flood from present through 2100 for the 90th percentile model-based scenarios of sea-level rise. Since it is important to consider the long-term risks, the areas included are the ones that take until the 2100 75 inches sea-level rise.

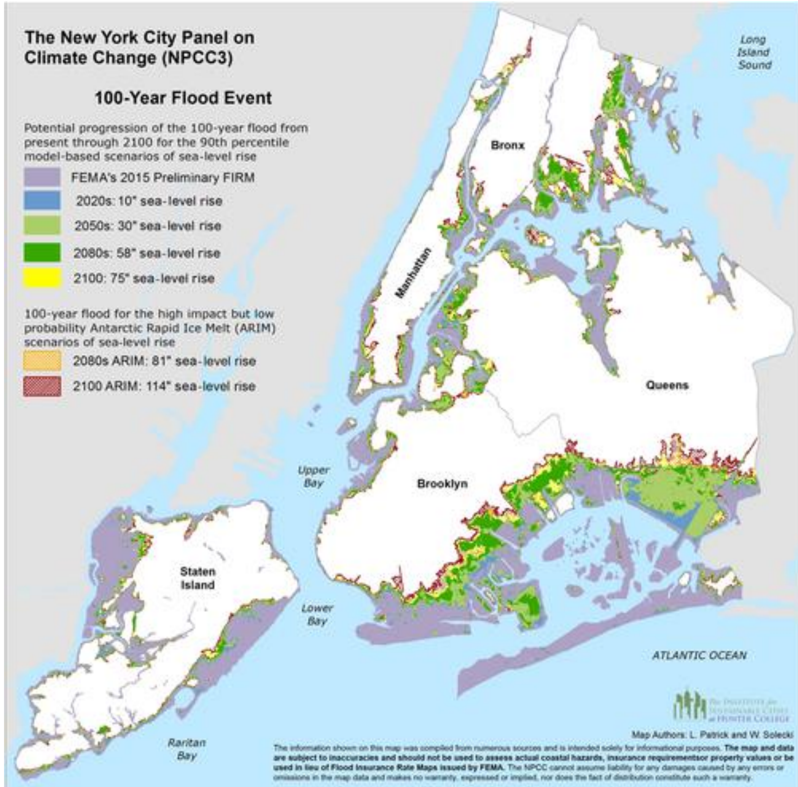

Figure 6. Map of NYC's 100-year floodplain.

Retrieved from the New York Panel on Climate Change 2019 Report (2019)

5.1.2. Flood characterization

Due to its intensively used waterfront and extensive coastal geography, NYC is highly exposed and vulnerable to flooding (City of New York, 2016). The type of flooding that affects NYC is **urban or inland flooding**, defined as the inundation of property in a built environment caused by an overwhelmed drainage systems (Weber, 2019). Urban flooding is **caused by** a complex combination of causes, which are **natural and human** induced (Jha et al., 2012). Those natural refers to groundwater and pluvial, fluvial, coastal and flash floods, whereas human causes are related to the saturation of the drainage and sewage capacity, lack of permeability and faulty drainage system and lack of management (Jha et al., 2012, p. 56).

NYC is exposed to all the floods mentioned due to **hurricanes, nor'easters**[9]**, extreme rainfall, and extreme high tides** (NYC Department of City Planning, 2017; FEMA, 2015; NYC Emergency Management, 2014)**.** Human causes, related to **rainfall patterns, proximity to the**

[9] A nor'easter is a storm along the East Coast of North America, whose winds over the coastal area are typically from the northeast and are most frequent and violent between September and April (U.S. Government, 2020)

coast, impervious coverage[10]**, differing sewer coverage**[11]**, irregular topography, soil infiltration rate, and soil storage capacity,** cause differences in flooding across the city (New York Academy of Sciences, 2019e)[12].

5.1.3. Flood risk analysis

The first step of a risk analysis is to determine **what is at risk** that society wants to protect (Tehler, 2015). Based on the Report and other flood risk analysis, what is aimed at being protected are the **economy**, **society,** and **ecosystems** of NYC. The parameters used to represent these values are: people's life and life quality (Chen, 2018; Maantay & Maroko, 2009)**,** critical infrastructure systems, such as transportation and energy (Santora, 2017), telecommunications, wastewater treatment plants and the state of natural resources (NYC Emergency Management, 2014).

It is difficult to determine **urban flood risk** in NYC and to validate urban flood models due to lack of data (New York Academy of Sciences, 2019e). However, the number of compound flooding events in NYC are expected to increase and to cause larger precipitation amounts and more storm surge as weather patterns shift and sea levels rise (New York Academy of Sciences, 2019e). The **risk scenario** considered in this assessment is the inundation of those areas that are in the 100-year floodplain due to storm surge, since it constitutes a major risk for the city (City of New York, 2013).

5.1.4. Indicators set-up and data collection

The final indicators used for the analysis are in Table 3. Those with an asterisk could not be analyzed due to lack of data. This final selection was done considering the feedback given by the interviewed field experts, which mentioned that all the indicators presented can be used for cities that have the same context as NYC. Only borough discrimination indicators need to be adapted to the name of the areas of each city. It would not make sense to apply these indicators to cities with less resources and infrastructure, since they may not have any sewer in place or available data for the indicator (Gonzalez, 2020). The rationale behind the final indicators and more details about the changes are in Appendix 3.

For economy, the interviewed highlighted the lack of infrastructure indicators, which was addressed replacing some indicators by the current infrastructure ones. For society, they identified that some of the indicators were more generic or harder to measure, such as location of low-income people at risk. Hence, they were substituted for more quantitative ones: evolution of low-economy people at risk and the homeless. CC education was considered important; however, it was not clear what to measure in this indicator. It was then substituted by social networks, also considered relevant by the experts. In ecosystem services all the indicators were changed. The initial ones

[10] Impervious cover is any surface in the landscape that cannot effectively absorb or infiltrate rainfall (Hillsborough Township, 2014).
[11] There are combined sewers (collect both sewage and stormwater into one system), separate sewers (have separate systems for sewage and stormwater) and other, which includes any other means of stormwater conveyance, including direct drainage into local waterways (New York Academy of Sciences, 2019d).
[12] See Appendix 2 for more details.

assessed the location and capacity of those ecosystems in the city, such as parks and buffer zones. They were substituted by more dynamic and measurable indicators. Finally, governance had the same changes as in society, where those general and hard to measure indicators, like well-informed decision-making were exchanged for more concrete ones.

After some changes, the indicators were still generic, and it was not clear what was needed to be measured. To fulfill this requirement, Liz (2020) recommended to add for each of the indicators a comparison criterion across time, which resulted in the variables under assessment. The last column of the table shows the theoretical influence of each indicator on vulnerability (V) and anticipation of negative consequences (A). There are three possible influences: N.A., which means that it is not applicable and, hence, this indicator cannot be evaluated against the variable; positive (+), which shows a positive correlation between the indicator and the variable; and negative (-) shows a negative correlation. There are some V and A that are introduced by a number and others that are alone. Those that are alone means that what is being measured has the same influence in V and A and their influence can be measured for both. Those that have a number means that the influence is specific to what is being measured and not for the indicator in general.

In Evaluation, there is the contribution of each indicator to V and A textually described, which results in Table 9, where the influence that each indicator has in V and A considering the context of the NYC is presented by symbols (+, - or N.A).

Table 3. Final selection of indicators

Category	Indicator	Assessment	Type of indicator (Quantitative/Qualitative; Spatial/Non-spatial)[13]	Influence of indicators on current vulnerability (V) and anticipation (A)
1. Economy	1. Investment efforts in flood adaptation.	1. Number of public projects that aim at reducing the exposure against flood adaptation (during the last five years). 2. Type of project (structural flood protection measure -barriers, EWS, nature-based solution, social protection and risk financing instruments).	(1) Quantitative (2) Qualitative Non-spatial	V: N.A.[14] A: +[15]
	2. Public and private insurance mechanisms against floods.	If the insurance exists: 1. Percentage of people covered. 2. Who and what is covered.	(1) Quantitative (2) Qualitative Non-spatial	V: -[16] A: +[17]
	3. Flood adaptation investment in public transportation (bus, train, subway)	1. Investments done. 2. Stage of the projects.	(1) Quantitative (2) Qualitative Non-spatial	(1) A: +[18] (2) V: -[19]
	4. State of the sewer system	1. Evolution of sewage flooding due to blocked or broken sewer. 2. Projects/Initiatives to improve the sewer.	(1) Quantitative (2) Qualitative Non-spatial	(1) V: +[20] (2) A: +[21]

[13] Suggested by Gonzalez (2020)
[14] (European Commission, 2012, p. 15)
[15] (Banhalmi-Zakar & Rissik, 2017)
[16] (Lamond & Penning-Rowsell, 2014)
[17] (Robinson & Botzen, 2018)
[18] (Banhalmi-Zakar & Rissik, 2017)
[19] (European Commission, 2012, p. 15)
[20] (Caradot et al., 2011)
[21] (Caradot et al., 2011)

	5. Condition of buildings and protection	1. Percentage of retrofitted buildings and new constructions in the 100-year floodplain. 2. Property protection projects against floods: amount and % completed.	Quantitative Spatial	V: -[22] A: +[23]
Category	**Indicator**	**Assessment**	**Type of indicator (Quantitative/Qualitative; Spatial/Non-spatial)**	**Influence of indicators on current vulnerability (V) and anticipation (A)**
2. Society	1. Poverty	1. Evolution of people at poor risk and homeless. 2. Evolution of flood risk in their location.	Quantitative Spatial	V: +[24] A: -[25]
	2. Early Warning Systems (EWS)	1. Percentage of people that receive the alerts.	Quantitative Non-spatial	V: -[26] A: +[27]
	3. Borough discrimination in flood adaptation projects	1. Number of flood adaptation projects implemented by borough. 2. Number of flood adaptation projects completed by borough.	Quantitative Spatial	V: -[28] A: +[29]

[22] (FEMA, 2013)
[23] (FEMA, 2013)
[24] (Winsemius et al., 2018)
[25] (Winsemius et al., 2018)
[26] (Tarchiani et al., 2020, p. 2)
[27] (Tarchiani et al., 2020, p. 2)
[28] (European Commission, 2012, p. 15)
[29] (European Commission, 2012, p. 15)

	4. Social networks*	1. Percentage of people not included in social networks when floods take place (new immigrants, people living for less than two years in the city, homeless, minorities, people with two jobs or more…).	Quantitative Non-spatial	V: +[30] A: -[31]
	5. Waterproofed homes*	1. Percentage and evolution of population that live in a waterproofed home.	Quantitative Spatial	V: -[32] A: +[33]
Category	**Indicator**	**Assessment**	**Type of indicator (Quantitative/Qualitative; Spatial/Non-spatial)**	**Influence of indicators on current vulnerability (V) and anticipation (A)**
3. Ecosystem services	1. Street trees	1. Location and amount. 2. Water absorption capacity.	Quantitative Spatial	V: -[34] A: +[35]
	2. Protection of ecosystems	1. Level of protection of ecosystems. 2. Percentage of ecosystems with healthy conditions.	(1) Qualitative (2) Quantitative Spatial	V: -[36] A: +[37]
	3. Percentage of sealed soil	1. Evolution of soil infiltration capacity.	Quantitative Spatial	V: -[38] A: +[39]

30 (Thomas et al., 2018)
31 (ICLEI European Secretariat, 2011, p. 52)
32 (FEMA, 2013)
33 (FEMA, 2013)
34 (Salmond et al., 2016)
35 (Salmond et al., 2016)
36 (Kamble et al., 2013)
37 (Kamble et al., 2013)
38 (Itsukushima et al., 2018)
39 (Itsukushima et al., 2018)

	4. Green infrastructure (GI) projects	1. Percentage of GI projects completed. 2. Evolution in number and volume of CSOs.	Quantitative Non-spatial	(1) V: -[40] (1) A: +[41] (2) V: +[42]
Category	**Indicator**	**Assessment**	**Type of indicator (Quantitative/Qualitative; Spatial/Non-spatial)**	**Influence of indicators on current vulnerability (V) and anticipation (A)**
4. Governance	1. Political support in flood adaptation efforts	1. Assessment of the government's efforts to provide protection to the population (comparison of the percentage of flood-related programs completed by the current and the first previous mayors). 2. Politicization of actions (comparison of the money invested by mayor in flood adaptation programs).	Quantitative Non-spatial	(1) V: -[43] (1) A: +[44] (2) V: +[45] (2) A: -[46]
	2. Engagement of population in decision making	1. Importance of civilians' voice that live in flood risk areas (number of projects that include community engagement).	Quantitative/Qualitative Non-spatial	V: N.A.[47] A: +[48]
	3. Flood risk in areas of big economic activity	1. Current protection mechanisms 2. Stage of completeness of projects	Qualitative Spatial	V: -[49] A: + [50]

[40] (European Environmental Agency, 2017)
[41] (European Environmental Agency, 2017)
[42] (EPA, 1999)
[43] (Banhalmi-Zakar & Rissik, 2017)
[44] (Banhalmi-Zakar & Rissik, 2017)
[45] (Heltberg et al., 2008)
[46] (Heltberg et al., 2008)
[47] (ICLEI European Secretariat, 2011, p. 52)
[48] (ICLEI European Secretariat, 2011, p. 52)
[49] (Arent et al., 2014)
[50] (Arent et al., 2014)

	4. Strength of departments working for flood adaptation	1. Budget departments/total budget (from the city). 2. Budgetary issues	Quantitative Non-spatial	V: N.A. A: +[51]
	5. Integrated water resource management*	1. Communication channel and frequency across departments and organizations. 2. Time to fix flood-related issues.	Quantitative/Qualitative Non-spatial	V: -[52] A: +[53]

[51] (Johannessen, 2020)
[52] (European Environmental Agency, 2017)
[53] (European Environmental Agency, 2017)

5.2. Evaluation

This section assesses each of the indicators to determine the current level of flood adaptation of the city.

5.2.1. Economy

In the first indicator of **economy**, **investment efforts in flood adaptation, s**ome of the measures taken to prepare the city to meet the challenges of CC are: Climate Resiliency Design Guidelines (CRDG), Rebuild by Design, Redesigned flood maps and zones, NYC Build it Back, RISE: NYC, protection of critical systems through Recovery and Resiliency Division to repair damage done to the subway system by Sandy and harden it against future climate impacts, the Waterfront Revitalization Program and the NYC Retrofit Accelerator (Cho, 2019)[54].

Most of the programs target buildings and set either conditions, guidelines, or policies to build or retrofit new or existing buildings. Furthermore, they are mostly competitions, which only grant a certain amount of money from New York State to those that have won. In the case of the CRDG, it states some guidelines for engineers, architects, landscape architects, and planners for the design of facilities, for new constructions or improvement of buildings (NYC Mayor's Office of Recovery and Resiliency, 2019). However, these guidelines are not mandatory since they are not integrated in the building codes, which are no longer a good guide to the robust design standards that will be required in the future (Acclimatise news, 2019).

The Rebuild by Design initiative consists of a collaborative competition with community and local government for resilient building projects (Rebuild by Design, 2020). Concretely, in NYC, the projects that won were: The Big U (under implementation), the Hunts Point Resiliency (pilot project), Living Breakwaters (in progress) and Living with the Bay (in progress). The redesigned flood maps and zones address specific types of development or the design and quality of public spaces (NYC Planning, 2020).

The NYC Build it Back is a program about to be completed that was created after Hurricane Sandy to return families to their homes, and assist Sandy-impacted residents with their recovery needs (NYC Sandy Funding Tracker , 2018). Through the program, the city worked directly with applicants and contractors to coordinate repairs, rebuilding, and improvements of almost 32,000 homes (NYC Sandy Funding Tracker , 2018). However, more than half of Build It Back applicants dropped out before getting any benefits (Donnelly, 2019).

[54] To know more about all the initiatives mentioned, see Appendix 5.

Finally, the Mayor's Office of Resiliency guides NYC to withstand and emerge stronger from the multiple impacts of CC in the near- and long-term (NYC Mayor's Office of Resiliency, 2020). This is done through its three core functions done in a collaborative approach, involving all stakeholders in society: science-based analysis, policy and program development and capacity building (NYC Mayor's Office of Resiliency, 2020). From this assessment, NYC is being active in especially protecting its infrastructure, which contributes with a "+" to A (Banhalmi-Zakar & Rissik, 2017).

Looking at the **flood insurance mechanisms** in the city, New Yorkers have standard homeowners' insurance that does not cover protection against flood damages. However, many property owners are required by federal law to purchase and maintain flood insurance if their properties are in the highest risk or high risk areas and have a federally backed mortgage or have received federal disaster assistance for flood damage (FloodHelpNYC, 2020). In NYC there is the National Flood Insurance Program (NFIP), a private federal insurance targeted to property owners, renters and businesses (NYC Housing Recovery, 2020a). However, the city does not control this requirement and if there is another flooding event damaging a structure that is not covered by insurance, then it can result in a denial of future federal disaster assistance (NYC Housing Recovery, 2020b).

The State offers subsidies to those buildings built before 1983, however the rest pay an insurance whose rate depends on the property's flood zone, its height above sea level, and the building's characteristics (FloodHelpNYC, 2020). The rates for the two insurances that the NFIP offers, expected to increase in the future (NYC Neighborhoods, 2014), reach a maximum of $250,000 a year for the one covering the structure of the house and a maximum of $100,000 for the one that covers belongings (FloodHelpNYC, 2020). Homeowners in New York's flood-prone areas are largely working and middle class and with a larger proportion of old people than in any other part of the city. As a result, only the 55% of 1-4 family homeowners in New York's 100-year floodplain have flood insurance (NYC Neighborhoods, 2014).

To make sure that more people can afford the insurance, there are some programs that aim at reducing the insurance rates. However, this does not imply that these people will buy the insurance, since these programs are not enforced (CNYCN, 2020). Hence, the current lack of coverage contributes with a "+" to V (Lamond & Penning-Rowsell, 2014), since the city does not control who has insurance, but it anticipates the negative consequences (Robinson & Botzen, 2018), contributing with a "+" to A.

Regarding **flood adaptation investment in subways**, the subway was chosen for being the most used and vulnerable transportation mean in NYC. To prevent the billions of dollars in damages caused by Hurricane Sandy (Quinn, 2019), the Metropolitan Transportation

Authority (MTA) tested flex-gates in their subway systems (Woodward, 2019). These provide a barrier against 4 meters of water and withstand waves 0.3 meters high moving at 1.5 meters per second (ILC Dover, 2017). Furthermore, it is deployable in winds up to 0.44 meters per second, it can be deployed by one or two workers in minutes, and it is compact so it does not impede commuters when stored at the point of use (ILC Dover, 2017). The flex gate seals off the entrance to the station and during major storms, the gate is unrolled and secured against a metal lip, which runs along the edge of a subway stairwell opening, to keep water from rushing into the underground (Meyer & O'Neill, 2019).

The storm surge originated from Hurricane Sandy reached 2.8 meters, the storm tide 3.44 meters (Choi, 2016) and the wind speed in the city was of 130 km/h (City of New York, 2013). It is not clear how hybrid storms like Sandy will change in the future, since some studies contradict each other (New York Academy of Sciences, 2019e). Considering this uncertainty in future forecasts and comparing the impacts of Sandy and the protection offered by the flex gates, one can conclude that this measure contributes to a higher adaptation, since it decreases the vulnerability of the subway system (European Commission, 2012, p. 15) and the people that use it and it anticipates for the negative consequences in the future (Banhalmi-Zakar & Rissik, 2017). Furthermore, MTA is also starting to work on projects to protect the energy supply in the subway during floods (Meyer & O'Neill, 2019).

For the **state of the sewer system**, the main cause of sewer flooding is due to blockage due to the improper disposal of grease, wipes and other trash down toilets and sinks (NYC Environmental Protection, 2020). To change civilians' behavior, in 2019 NYC launched a public awareness campaign called "Trash it. Don´t Flush it". This campaign consisted of ads (both in English and Spanish) featured around the city at select subway stations, bus shelters, and on trains, buses, television, and on social media to remind civilians to properly dispose their trash (NYC Environmental Protection, 2019). The campaign ran for 4 weeks (between February and March 2020) and aimed at reducing sewer backups and costly damage to private plumbing and the City's wastewater system (NYC Environmental Protection, 2019).

Apart from this campaign, the DEP tracks segments with recurring sewer backups and proactively cleans kilometers of sewers (NYC Environmental Protection, 2019). DEP also enforces the city regulation that requires food service establishments to use a grease trap to help keep grease out of the sewer system (NYC Environmental Protection, 2019). Furthermore, it has conducted door-to-door outreach, hosted regular meetings with community boards, churches, civic associations and NYC Housing Authority residents that has resulted in contact with more than 90,000 households (NYC Environmental Protection, 2019). Additionally, the Grow NYC's Zero Waste Schools Program has helped in this issue through education since 2010 (Grow NYC, 2016).

According to the Department of Environmental Protection from NYC, from January to mid-March 2020, there have been 187 floods due to sewer blockage, an 18% less than in the previous year. Comparing yearly between 2015 and 2019, the evolution of reported street flooding due to sewer disruptions has been mostly increasing, achieving a total increase of 115% (NYC Open Data, 2020). Concretely, the number of street flooding reported cases went from 653 to 1,008 between 2015 and 2016, from 1,008 to 899 from 2016 to 2017, from 899 to 1,573 from 2017 to 2018 and from 1,573 to 1,405 from 2018 to 2019 (NYC Open Data, 2020). Those cases that have been reported twice or were not found in the site by the Environmental Agency have not been considered.

From the data in 2019, it does not seem that the efforts done by the city are enough to prevent sewage flooding since the monthly trend from March to December was mostly increasing (NYC Open Data, 2020). Considering this fact and the yearly evolution of sewer flooding, the current state and practices in the sewer system are not reducing vulnerability (Caradot et al., 2011). However, their recognized effort to maintain the sewer, shows how the city is anticipating negative consequences from floods (Allouche & Freure, 2002). Hence this indicator would have a "+" in V and a "+" in A.

Assessing the **condition of buildings,** from 2014 to 2019, NYC has preserved 2,706 houses and constructed 1,678 through different programs from the city to help households have more prepared housing to CC (NYC OpenData, 2020) and the Build it Back homes assisted almost 32,000 homes. Considering that there are more than 67,700 buildings lie in the 100-year floodplain created by FEMA in 2015 (City of New York, 2013), around half of the homes were retrofitted or better built to withstand future floods. Apart from these constructions, there are currently 99 property protection projects against floods, 25% of them completed, located in the flood risk areas of the city (City of New York, 2020a).

From this data, one can see the efforts that the city is doing. Hence, the current condition of buildings, considering those currently improved and the projects in place, results in a "-" to V and shows that the city is anticipating the negative consequences (ND-GAIN, 2018c).

Considering that half of the indicators under economy increase V (public and private insurance mechanisms against floods and state of the sewer system) and only one indicator negatively affects A (state of the sewer system), NYC would reach a level of flood adaptation between upper-middle and upper under economy.

5.2.2. Society

Considering a **poverty** threshold of $32,402 in 2016 and $33,562 in 2017, the poverty rate in NYC between these years was mostly constant, ranging from 19.2% in 2016 to 19% in 2017 (NYC - Mayor's Office for Economic Opportunity, 2019). The near poverty rate[55] experienced the same, reaching a value of 43.3% in 2016 and a 43.1% in 2017 (NYC - Mayor's Office for Economic Opportunity, 2019). Looking at homelessness, in December 2019, there were 62,590 homeless people, including 14,792 homeless families with 22,013 homeless children, sleeping each night in the NYC municipal shelter system (Coalition for the homeless, 2019). Families make up more than two-thirds of the homeless shelter population (Coalition for the homeless, 2019). The number of homeless New Yorkers sleeping each night in municipal shelters is now 63 percent higher than it was ten years ago.

Each night thousands of unsheltered homeless people sleep on NYC streets, in the subway system, and in other public spaces (Coalition for the homeless, 2019). From the 10 poorest neighborhoods, three of them (Hunts Point, Mott Haven and Soundview) are within the 100-year floodplain (Sparkes, 2020). In this assessment, it is assumed that the flood risk is the same, since the projects to reduce flood risk (Hunts Point Lifelines and Mott Haven-Port Morris Waterfront Plan) are not implemented or finished. There are a total of five shelters in the city, where only two are open 24 hours the whole year and the others are only open during the day, except for winters, where they are open 24hrs (NYC Open Data, 2017). One of the shelters that opens 24 hours (The Living Room, in the Bronx) and one of the second group (Project Hospitality, in Staten Island) are in the 100-year floodplain.

The analysis from this indicator results in an increase in the vulnerability of NYC and a decrease in the anticipation of negative consequences, since homelessness and poverty are not being protected enough, showed by the increased number of poor and their lack of protection against floods (Winsemius et al., 2018).

Regarding **EWS**, NYC has the NYC Advance Warning System, which alerts organizations that work with disabled people and others with access and functional needs to various types of hazards and emergencies in NYC (NYC Advance Warning System, 2020). These organizations receive public preparedness and emergency information via e-mail or text messages and, then, they act upon this information (NYC Advance Warning System, 2020). Despite their subscription not being compulsory (NYC Advance Warning System, 2020), almost 70% of the organizations are subscribed[56].

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[55] Near poverty rate = the percentage of people living at 150 percent of the poverty level or below (NYC - Mayor's Office for Economic Opportunity, 2019).

[56] There are 840 subscribed organizations (NYC Advance Warning System, 2020), out of a total of 1,240 non-profit organizations in the city related with adult education and job skills, health and mental health, children and youth, education

For individuals, the city has Notify NYC, the emergency public communications program, where there is a constant monitoring of emergency activity in NYC and the metropolitan area. Related to floods, they have Emergency Alerts and Weather Emergencies. To be able to receive such notifications, one needs either a Twitter account or an account from their platform and an electronic device with access to the Internet. Considering that NYC has a total current population of 8.4 million (World Population Review, 2020b), looking at the followers in Twitter (492,000) and the few retweets from it receives (Twitter, 2020), together with the amount of number of installation of the app (a bit more than 10,000) and the few google searches in NYC of both Notify NYC and hurricane sandy during and before the hurricane (with 0 value[57]) (Google, 2020), the coverage of individuals may be around 6%.

From this analysis, EWS in the city need to improve to increase its coverage, otherwise it makes population more vulnerable and the anticipation of negative consequences for the population are ignored (Tarchiani et al., 2020).

For **borough discrimination in flood adaptation projects,** NYC has around 319 completed and existing projects addressing floods (City of New York, 2020a). Concretely, these projects include emergency services, coastal/natural resources protection, infrastructure project prevention and policy and property protection. The most frequent in most of the boroughs is the emergency services (installation of electric power generators, back-up power for evacuation shelters, installation of generators for trauma centers and deployment of semi-permanent flood protection measures), except in Queens, where the most frequent programs are related with property protection. The table below shows an approximate amount of these projects by borough and the percentage of completeness in 2020.

Table 4. Distribution of flood projects by boroughs in 2020 (City of New York, 2020a)

Borough	Total projects addressing floods	Projects completed / total projects
Staten Island	47	6%
Manhattan	84	7%
Bronx	50	4%
Brooklyn	95	16%
Queens	89	10%

and schools, community development, homeless and housing, hospitals, human rights, hunger and soup kitchens, immigrants and refugees, legal and justice, people with disabilities and seniors (NYC Service, 2020).

[57] A value of 0 means that there is not enough data for the search and a value of 100 means peak popularity for the term (Google, 2020).

Considering that Queens and Brooklyn are the most populated boroughs (City Population, 2018) and the ones with more flood risk (New York Academy of Sciences, 2019e), it makes sense that they have more projects planned and completed. Given the economic importance of Manhattan, with a $600.2 billion GDP in 2018 (Campanile, 2019), the number of projects allocated compared to the rest are also rational. Hence, this distribution does not seem to discriminate between boroughs and, consequently, this indicator contributes with a "-" to V and anticipates the negative consequences of future floods (Thomas et al., 2018), hence it adds a "+" to A.

Under society, both poverty and EWS indicators have a positive influence on V and a negative one on A. Only one indicator, borough discrimination, reduces V and increases A. From this analysis and under society, NYC reaches the lowest level of flood adaptation: lower.

5.2.3. Ecosystem Services

According to the 2015 **Street Tree** Census Report, in 2015 there were 666,134 street trees citywide, which represents a 12.5% increase from 2005. Queens has the most trees (242,414), followed by Brooklyn (173,063) and Staten Island (103,313) (City of New York, 2017). The borough with the greatest increase in trees since 2005, is the Bronx (39%), followed by Manhattan (29%), and Brooklyn (21%). In 2015, there were 109,217 street trees planted and in 2016 113,283 street trees planted (City of New York, 2017), which represents a 4% increase.

Considering that the average street tree in NYC intercepts 5,209 liters of stormwater each year (City of New York, 2017), the annual water infiltration capacity of these trees was 3.5 billion liters citywide in 2015, which is currently higher due to the increase in the number of total trees (Berland et al., 2017). From these facts, it can be concluded that the vulnerability to floods is lowered and, by the increase in their number, the city also anticipates negative consequences (Salmond et al., 2016).

In the case of **protection of ecosystems,** there are 107 recognized ecological complexes in NYC, which include parks, forests, woods, wetlands, islands, marshes, coves, bays, camps, shorelands and sea views (The NYC Waterfront Revitalization Program, 2016). These are part of the NYC Waterfront Revitalization Program, the city's policies for management, use, and development of waterfront properties and coastal resources to increase resilience and minimize risks of flooding (Adaptation Clearninghouse, 2016). Its fourth policy promotes protection, remediation and restoration of these ecological resources (NYC Planning, 2016).

Table 5. Coastal/Natural resources protection projects in NYC *(City of New York, 2020a)*

Borough	Project name	Ecosystem protected	Completion year
Staten Island	Complete Short-term Beach Nourishment, Dune Construction, and Shoreline Protection	Dune and shoreline in 4 different locations.	2014
	Bluebelts	Strems, ponds and other wetlands (in 20 locations)	2025
	Wetlands Restoration	Wetlands	-
Brooklyn	T-groins at Coney Island	Coastline	2016
	Emergency restoration of Coney Island shoreline	Coastline	1995
	Coney Island Creek Raised Shoreline	Coastline	2022
Queens	Hunter's Point South Park	Coastline	2018
	Protection of Rikers shorelines	Coastline	2022
	Flushing Airport wetlands restoration	Wetlands	2019
Manhattan	Lower Manhattan Coastal Resiliency – Battery	Coastline	2022

The healthy conditions of the ecosystems (those that are not in decline or threatened) in NYC are the following: 10% of the area of the forests is healthy (1,122 acres out of 10,542 acres), 0.8% of freshwater wetlands (39.9 out of 4.988 acres), 17% of salt marshes (579.4 out of 3,478 acres) and 8% of streams (9.5 out of 112 miles) (Natural Areas Conservancy & NYC Parks, 2020).

Looking at the protection programs of the city, one can see the efforts the city is doing to prepare for the impacts of CC, which shows their anticipation of negative consequences (Kamble et al., 2013). However, the percentage of ecosystems in healthy conditions does not even reach 50%, while the rest are either threatened, in transition or degraded[58]. Hence the current state of ecosystems increases the vulnerability of NYC, since their capacity to lower the impacts of floods are lower than if they were healthier (European Commission, 2009).

In the **sealed soil and soil infiltration capacity**, 72% of NYC's surface is impervious, which does not absorb water, resulting in stormwater runoff (NYW, 2018). The rest of areas are formed by parks, rain gardens, porous pavement, green roofs, storms chambers and tanks, among others that aim at reducing stormwater runoff (NYC Environmental Protection, 2018). According to the NYC Green Infrastructure 2018 Annual Report, the GI projects managed a total of 2,798 million liters of stormwater between 2010 and 2018. The total capacity in liters of runoff water managed by GI for a 1-inch storm by watershed is found in the table below, as well as the increase of GI assets between 2016 and 2018. Each watershed corresponds to an area in NYC, which can be seen in Figure 7.

Table 6. Water management capacity for each watershed

Watershed	Annual liters of stormwater managed (in millions)	Liters of runoff water managed by GI for 1-inch[59] storm per hour (capacity)
Bronx River Watershed	80	1,203
Coney Island Creek	644	70.75
Flushing Bay Watershed	366	5,589
Flushing Creek Watershed	179	2,689
Gowanus Canal Watershed	63	920
Hutchinson River Watershed	199	2,972
Jamaica Bay and Tributaries	640	9,551
Newtown Creek Watershed	578	8,632
Westchester Creek Watershed	9	142
East River/ Open Waters	684	10,188

[58] According to the source, threatened ecosystems are those that are threatened but they are not yet in decline (Natural Areas Conservancy & NYC Parks, 2020). In transition means that they are not as threatened as before but their condition has not rebounded and degraded are those ecosystems that are so impacted by threats that they have declined in health significantly and significant and costly restoration is required to improve their condition (Natural Areas Conservancy & NYC Parks, 2020).

[59] 2.54 cm

Figure 7. Watershed map key *(NYC Environmental Protection, 2018)*

The number of GI assets in construction for 2018 is 4,585 and for 2019 it was expected to be around 5,500 (NYC Environmental Protection, 2018). Comparing it with the NYC Green Infrastructure 2016 Annual Report, which had 2,477 new constructions (NYC Environmental Protection, 2017), one can see a positive trend, which shows an increase in infiltration capacity (Zhang & Peralta, 2019). Hence, based on this indicator, the vulnerability to floods decreases and there is a positive contribution to the anticipation of negative consequences of floods (Itsukushima et al., 2018).

Finally, for the **GI**, the DEP and agency partners design, construct and maintain a variety of sustainable GI practices such as green roofs and rain gardens on city owned properties such as streets, sidewalks, schools, and public housing (NYC DEP, 2019a). In 2019, 30% of the total GI projects were constructed (3,723/12,424) in nearly all community board districts from the city (NYC DEP, 2019b). Despite this increase, in 2018 there were 11,403 CSOs events in NYC, which shows an increase in 20% respect to 2016 and a 51% increase in volume between

2016 and 2018 (Open Sewer Atlas NYC, 2019). In fact, the number of CSOs has been increasing since 2015 and the volume since 2016 (Open Sewer Atlas NYC, 2019).

Based on the most recent data about CSOs, their increasing trend in both volume and events show an increase in vulnerability (EPA, 1999). However, the efforts done by the city in the number of GI projects, shows an anticipation of negative consequences (European Environmental Agency, 2017).

Under ecosystem services, half of the indicators (protection of ecosystems and GI projects) increase V, whereas all the indicators analyzed increase A. This locates NYC between the two highest levels of flood adaptation (upper and upper middle) of the framework under this category.

5.2.4. Governance

The first indicator analyzed is **political support**. Table 7 shows information about projects, years and budget of the two strategic plans for NYC: the PlaNYC, a sustainability plan to achieve ten overarching goals to improve the infrastructure, environment, and quality of life in the city (UNDESA, 2007); and the OneNYC, an update of PlaNYC which focuses on NYC's climate crisis, equity and democracy to achieve a stronger and fairer city (City of New York, 2019).

Table 7. PlaNYC and OneNYC

Mayor and years	**Plan and years**	**Number of initiatives floods/ total initiatives (approx..)**	**% of completed (flood related) (approx..)**	**Budget allocation from the city**
Bloomberg (2002-2013)	PlaNYC (2007-2013)	45/127[60]	16/45[61]	$1.6 billion[62]
De Blasio (2014-currently)	OneNYC (2015-2025)	45/101[63]	16/45[64]	$22 billion[65]

[60] The City of New York (2013)
[61] The City of New York (2013)
[62] The City of New York (2011)
[63] The City of New York (2019)
[64] The City of New York (2019)
[65] The City of New York (2016)

As seen by the increase of budget and completion of initiatives, the political support to NYC in flood and CCA is increasing. In fact, the economic power (ICLEI, 2010) and CC awareness in NYC (CRED, 2016) allows the political support it has to protect the city against future and current impacts of CC. Moreover, given this awareness, there does not seem to be politization of actions when protecting the city against CC. This contributes to a decrease in vulnerability and shows how the city is anticipating these threats (Frerks et al., 2011).

Assessing the **engagement of population in decision-making**, OneNYC was developed, among others, with civilians' inputs, through meetings, roundtable discussions, forums and surveys (City of New York, 2019). Out of its 101 initiatives, five directly aim at increasing civic engagement, one of which is about strengthening community based organizations (City of New York, 2019). Despite non-of the initiatives where civic engagement is mentioned tackle floods in the report, all the projects that aim at increasing resilience[66] and hazard-mitigation planning in the city are done in collaboration with communities (NYC Planning, 2018a; NYC Emergency Management, 2019). One example is the Flood Resilience Zoning rules that were implemented after Hurricane Sandy, where the city organized over 110 public meetings with more than 2,500 citizens from all the boroughs (NYC Planning, 2018a). Other initiatives that engage with the community include Rebuild by Design (Rebuild by Design, 2020) and the East Side Coastal Resiliency and Hunts Point Resiliency projects that increase flood adaptation (C40 Cities, 2015).

Considering the goals from OneNYC and the engagement in the initiatives, one can conclude that civic engagement is included in all or most of the projects that aim at increasing flood adaptation in NYC. Inclusion of civilians in these projects reduce vulnerability to future floods, since they better address their needs (Haghebaert, 2007) and, hence, anticipate for the negative consequences (ICLEI European Secretariat, 2011, p. 52).

For the **flood risk in areas of big economic activity,** Lower Manhattan is identified as the most economically vital and influential area of NYC but one of the most vulnerable to CC. Among the major investments for flood protection done in the area, the following are highlighted:

Table 8. Flood protection projects in Lower Manhattan (City of New York, 2020b)

Project	**Years of construction**
Two Bridges Coastal Resilience[67]	2021-2024
The Battery Coastal Resilience[68]	2021-2023
Interim Flood Protection Measure (IFPM)	*Completed*

[66] All the projects that aim at increasing resilience are part of the Resilient Neighborhoods initiative (NYC Planning, 2017).
[67] https://www1.nyc.gov/site/lmcr/progress/brooklyn-bridge-montgomery-coastal-resilience.page
[68] https://www1.nyc.gov/site/lmcr/progress/battery-coastal-resilience.page

Financial District and the Seaport Climate Resilience Master plan[69]	*Master plan to be done*
<u>Battery Park City Resilience Projects</u>	
• North Battery Park City Resiliency	2021-2023
• BPC Ballfields Resiliency	2019- November 2020
• West Battery Park Resiliency	2021-2024
• South Battery Park City Resilience	2020-2022

The Two Bridges Coastal Resilience, the IFPM and the Battery Coastal Resilience aim at protecting the neighborhood from a 100-year storm surge in the 2050s (City of New York, 2020b). The rest of the projects protect the area from storm surge and sea level rise (City of New York, 2020c). Furthermore, the city is currently replacing copper cables with fiber-optic cables that are fully water-resistant, to protect the functioning of the power grid, subway system, and telecommunications in the event of future storms (NYC Mayor's Office of Recovery & Resiliency, 2019). These actions implemented by the city, together with the fast completion rate of the projects, show how the city is anticipating future negative consequences (Arent et al., 2014).

Despite none of the projects are yet constructed, NYC still protects this area with the IFPM, which lowers its vulnerability. The IFPM is a temporary flood protection that includes just in time water-filled dams to be deployed in the event of a storm and pre-deployed sand-filled barriers, employed along an alignment of just over a mile and protect against a 10-year flood (New York City, 2020).

For the **strength of the environmental department (DEP)[70],** the fiscal capital budget allocated yearly between 2018-2022 for the DEP is around $3B (The Council of the City of New York, 2018a). For the year 2019-2022 the preliminary capital budget is $11.2B, which represents around 25% of the City’s total $45.9 billion capital budget for 2019-2022 (The Council of the City of New York, 2018a). Considering that more departments also contribute to an increase in flood adaptation, the city is allocating at least 25% of its budget for the years 2019-2022. Furthermore, DEP receives additional support from the State, the Federation and others (The Council of the City of New York, 2018b), which contributes with additional strength to these departments.

[69] https://www1.nyc.gov/site/lmcr/progress/financial-district-and-seaport-climate-resilience-master-plan.page

[70] Although the DEP is identified as more active in flood adaptation, there are more departments working towards flood adaptation, such as the department of transportation, buildings and city planning (NYC Council, 2019). However, to simplify, only DEP was chosen.

Furthermore, the DEP did not have any budget issues for the fiscal budget in 2020 nor in 2019 (The Council of the City of New York, 2019a, 2018b), while others, like the department of parks and recreation, was rejected more than $500M for the Fiscal 2020 Executive Project (The Council of the City of New York, 2019b). More money allocated to departments that tackle CC allows the city to address more of the present and future issues that the city is and will face (European Commission, 2013). Based on this indicator, the city is anticipating most of the negative consequences of floods through the investments that are possible with the budget awarded.

Governance gives to NYC the highest level of flood adaptation, since all the indicators that could be analyzed under this category reduce V and increase A.

5.3. Conclusions

Given the scope of this research, all the indicators were given the same weight. This assumes that all indicators contribute in the same way to the final level of flood adaptation, which is not an assumption that should be applied if the framework is to be used for an actual flood adaptation assessment. Under a real application of such framework, the indicators should have different weights interpreted and determined by a collaborative process with the stakeholders. Given this acknowledgment, the results illustrated in this section only aim at offering an example of how the results could be presented. From the 16 indicators evaluated, 9/15 decreased vulnerability and 13/15 increased the anticipation of the negative consequences from the city.

Table 9. Contribution of indicators to vulnerability and anticipation

Category	Indicator	Vulnerability	Anticipation
Economy	Investment efforts in flood adaptation	N.A.	+
	Public and private insurance mechanisms against floods	+	+
	Flood adaptation investment in public transportation (bus, train, subway)	-	+
	Stage of sewer system	+	+
	Condition of buildings and protection	-	+
Society	Poverty	+	-
	EWS	+	-
	Borough discrimination in flood adaptation projects	-	+
Ecosystem services	Street trees	-	+
	GI projects	+	+
	Protection of ecosystems	+	+

	Percentage of sealed soil	-	+
Governance	Political support in flood adaptation efforts	-	+
	Engagement of population in decision making	-	N.A.
	Flood risk in areas of big economic activity	-	+
	Economic strength of departments working for flood adaptation	-	+

This analysis identifies some of the vulnerabilities in NYC due to floods, by using the relations established in the conceptual framework. Those indicators that revealed a lack of resilience or societal response capacity, such as poverty and the conditions of ecosystems, increased the level of vulnerability (Brooks, 2003), which is the direct effect of adaptation (Birkmann et al., 2014). Finally, following the definition used for adaptation, those indicators that revealed an anticipation of the negative consequences by starting to act now, increased the current level of flood adaptation.

Special caution should be given when interpreting the results, since an upper level of flood adaptation does not mean that no more action is needed by the city (ND-GAIN, 2018a; Brooks, 2003). Hence, for an effective interpretation of the results, they should be disaggregated by the categories and not interpreted jointly (Chawla, 2018). As could be seen by the case study, although reaching the highest level of flood adaptation, it has still many areas to improve. These results have some implications from the city that should be considered to further reduce vulnerabilities. Considering that reductions in risk in the face of increased hazard requires a more significant adaptation effort, a failure to address these vulnerabilities, may reduce the flood adaptation level of NYC in the future (Brooks, 2003).

Firstly, despite not identifying any geographical discrimination in the implementation of flood adaptation projects, the EWS mentioned does not cover enough people (around 6% of population) and, with the information available, it is not clear whether the organizations subscribed to it act upon the information they receive. Moreover, the constant number of people in the poverty rate, the increased number of homeless in the last ten years and the mentioned conditions of the shelters, reveals that the city may not be providing enough protection to the homeless and the poor.

Secondly, despite the efforts of the city in flood adaptation investments, as seen by the flood protection mechanism against floods in the subway system, the condition of buildings and its efforts to keep the sewer clean, it seems that the city needs to increase awareness of the population in the use of the sewer, to further reduce disruptions. Another area to improve is the flood insurance, which does not cover all households that are in the 100-year floodplain (NYC Neighborhoods, 2014). Furthermore, with increasing insurance rates, lesser amount of people may afford it in the future, increasing the vulnerability of people located in the 100-year floodplain (Schwob, 2019).

Thirdly, the city should further protect its ecosystems, since more than half are either threatened, in transition or degraded (Natural Areas Conservancy & NYC Parks, 2020). Finally, NYC uses GI to reduce CSOs which, according to the data analyzed, show an increase of them. Considering that more GI projects will be completed in the future, it is possible that the CSOs will be reduced as well, reducing future social vulnerability. This relation appears in the conceptual background, in the formula of future vulnerability, which is positively determined by current vulnerability and negatively determined by current adaptation capacity (Brooks, 2003).

Finally, in NYC there is political support to increase adaptation to floods, which may be explained by the available financial resources and general awareness with flood issues in the city (AECOM, 2019), common barriers for adaptation (Eisenack et al., 2014) that NYC do not have. These characteristics may have also allowed a success in the performance of other indicators, such as the reduced flood risk in the main financial district and the strength of the DEP and other departments working on adaptation. Civilians participate in many flood adaptation projects in different ways, as explained earlier. However, a survey about infrastructure networks and services done by AECOM (2019) to over a thousand of New Yorkers, reveals that 19% provided feedback in the last year and that requests for feedback about infrastructure improvements or investments came too late in the planning stage for their influence to be meaningful (AECOM, 2019). Hence, despite performing well in this indicator, the city still needs to improve in this area.

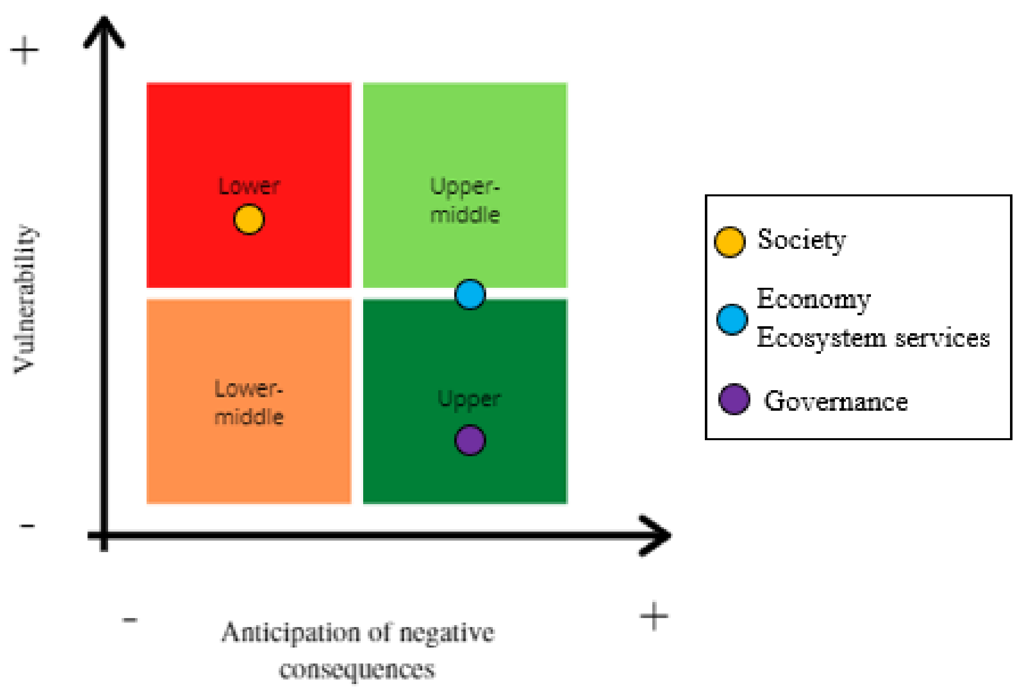

Figure 8. Level of adaptation of NYC by categories

Looking at the results by categories, the picture about the situation of the city changes. Considering only society, NYC would have the lowest level of adaptation. The result achieved in this indicator may result in the perception of the population that they are fighting CC alone[71]. For the categories of economy and ecosystem services, NYC is located between the upper-middle and the middle levels. Finally, NYC obtains the highest level in governance, which may be explained by the economic power of the city and great awareness at the political level (AECOM, 2019).

6. Conclusions

This thesis develops a universal framework to assess flood adaptation at the municipal level, with the aim to guide decision-making in public investment and policy and to identify changes that can improve the situation of a city to increase its flood adaptation level and capacity. This framework is an adaptation of the framework for CCA used in the NYPCC 2019 Report and has two integrated processes that describe the steps for the flood adaptation assessment and the selection of indicators. For the selection of indicators, the framework uses a set of quantitative and qualitative indicators under five categories (economy, society, ecosystem services and governance) developed by the ICLEI European Secretariat (2011). Furthermore, it has four different levels of flood adaptation, which looks at the vulnerabilities and anticipation of negative consequences addressed, taken from the definition of CCA.

After developing the framework, it was applied to NYC. Despite not being able to determine a final and real level of flood adaptation of NYC, the assessment performed offers some lessons learned for the city. . NYC has been implementing numerous plans and programs for flood adaptation, which aim especially at protecting its infrastructure, such as the Big U project in Lower Manhattan, Rebuild by Design, NYC Build it Back and the numerous GI projects implemented. However, as seen in the assessment NYC does not prioritize as much social programs that aim at reducing the vulnerability of those more in need. Furthermore, despite all the investments and programs in place, the city should increase efforts in the protection of its ecosystems, since there are very few of them in a healthy condition.

These results should be considered by NYC to further reduce vulnerabilities. Some examples include the increase of protection for the poor and the homeless to flood risks, of the coverage of homes with flood insurance, of the protection of ecosystems and an earlier integration of civilians' feedback in urban planning processes. Considering that reductions in risk in the face

[71] See articles 1 (https://www.theguardian.com/environment/2019/sep/20/new-york-city-sinking-climate-crisis-waterfront) and 2 (https://theconversation.com/climate-change-adaptation-in-global-megacities-protects-wealth-not-people-55516).

of increased hazard requires a more significant adaptation effort (Brooks, 2003), a failure to address these vulnerabilities, may reduce the flood adaptation level of NYC in the future.

The assessment of these plans and the final level of flood adaptation are determined by indicators selected based on the context of the city, the feedback from field experts and data available. As mentioned by the interviewed, only those indicators that are relevant to the city should be assessed in the long-term, and those that are identified as more relevant in the future should be included.

One of the most important limitations to keep in mind when applying this framework is related with its last step, since the framework assumes that all indicators contribute the same way. One way to overcome this issue is to give different weights to the indicators in collaboration with stakeholders. This last step was not developed further since it was beyond the scope of this paper. Hence, further research is required to assess the real contribution of each indicator to flood adaptation and to develop a methodology to translate qualitative and quantitative assessments into a concrete level, as suggested in this research or into something that allows the decision-maker to easily read and interpret the results achieved. Acknowledging the limitations of this research, given more time and resources, this framework could be further developed, and its application further investigated.

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Appendixes

Appendix 1

This appendix shows a comparison between different organizations/researchers about the determinants of adaptation. Although some reports do not explicitly mention “Governance” as a sector or determinant, they take it into account in the analysis of some indicators. For instance, in the Report, they talk about “environmental governance”.

Table 10. Cross-comparison of the determinants used to analyze adaptation.

Sources	**Different factors/determinants/sectors/components or benefits to consider when analyzing adaptation**			
ICLEI European Secretariat (2011, p. 25)[72] (determinants)	Economy	Society	Ecosystem services	Governance
UNDP (2019, pg. 18)[73] (factors)	Agriculture, energy/industry, infrastructure	Housing	Environment, water supply and sanitation	Governance
NYPCC 2019 Report[74] (sectors)	Energy, Telecommunications, Transportation	Social infrastructure	Water, sewer, waste;	*Not explicitly mentioned as a sector*
EPA (2017, p.44)[75] (Benefits of adaptation)	Transportation	Life and property	Natural coastal areas, habitats and beaches	Efficient investment
Munyai et al. (2019)[76] (components)	Economic	Social	Physical/environmental	*Not explicitly mentioned as a component*
Brooks (2003, p.12)[77] (contexts)	Economic	Social	Environmental	Political

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[72]http://ccsl.iccip.net/SWITCH_Adaption-Handbook_final_small.pdf
[73]http://www.cap-net.org/wp-content/uploads/2019/01/Cap-Net-CCA-and-IWRM.pdf
[74]https://www.nyas.org/annals/special-issue-advancing-tools-and-methods-for-flexible-adaptation-pathways-and-science-policy-integration-new-york-city-panel-on-climate-change-2019-report-vol-1439/
[75]https://www.epa.gov/sites/production/files/2017-01/documents/smart_growth_fixes_climate_adaptation_resilience.pdf
[76] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6620490/
[77] https://www.researchgate.net/publication/200032746_Vulnerability_Risk_and_Adaptation_A_Conceptual_Framework

Appendix 2

Looking at the natural causes, **rainfall** that drives urban and flash flooding in the Northeast is typically temporally and spatially concentrated and is most often caused by thunderstorms (New York Academy of Sciences, 2019e). Rainfall on flooding days is at a maximum 3 centimeters over the geographic center of the city (North Brooklyn and Northwest Queens), while some areas of high rainfall extend to the northeast (New York Academy of Sciences, 2019e). Short-duration heavy rainfall that produces flooding in urban areas is typically driven by warm-season thunderstorms, which are the most influenced by urbanization and have the most extreme rain rates occurring in the evening (New York Academy of Sciences, 2019e).

Predictions show that in the future **hurricanes** will increase both in size and intensity (Garner et al., 2018). According to the National Hurricane Center, on average, hurricane winds have impacted New York City every nineteen years, and major hurricanes (Category 3 or higher) every 74 years (NYC Emergency Management, 2014). A Category 5 hurricane is not expected to occur under current climate conditions (NYC Emergency Management, 2014). When it comes to **nor'easters**, despite having weaker surface winds than hurricanes, occur more often and may develop more quickly and affect larger geographic areas (NYC Emergency Management, 2014).NYC is typically hit by several nor'easters each year and although most of them are relatively weak, they can produce significant rainfall or snowfall and minor to moderate coastal storm tides and related damage (NYC Emergency Management, 2014).

Finally, **high tides** are increasing due to sea level rise and it is becoming chronic and disruptive to coastal communities (NOAA, 2019). In NYC there are three tide gauges: Kingston Point (between Bronx and Queens), The Battery (Manhattan) and Bergen Point (Staten Island), all of them with a flood threshold of sixty centimeters above the average daily highest tide or the Mean Higher High Water (MHHW) or daily tidal flooding (NOAA, 2018). This implies that the coastal infrastructure from these areas is vulnerable to flooding at heights of about 0.6 meters above the MHHW (NOAA, 2018), which is exceeded hundreds of times per year (New York Academy of Sciences, 2019e).

On the other hand, the Monthly High Water or monthly tidal flooding has only between 25 and 35 exceedances per year and, according to the NYPCC 2019 Report, it is more useful as a threshold indicator for when sea level rise will first affect neighborhood habitability and require adaptation. Although monthly flooding will not be a widespread problem until 2050 or later, by late in the century, it could impact most of the neighborhoods around Jamaica Bay, as well as several other low-lying neighborhoods of the city (New York Academy of Sciences, 2019e). Under the new Antarctic Rapid Ice Melt scenarios, sea level rise by the end of this century could raise daily tidal flooding to an average of three and a half meters, which constitute more severe levels than the ones in Hurricane Sandy (average of three meters) (New York Academy of Sciences, 2019e).

Apart from the natural hazards mentioned that affect NYC, there are other factors that contribute to flooding which are human. The first presented is the **drainage and sewer capacity**. In NYC there are mainly two types of sewer systems in NYC: the **combined sewer system** (in almost 60% of the city), and the **separate storm sewer system** (in almost 40% of the city) (NYC DEP, 2019c). The combined system, which is 150 years old (Chaisson, 2017), uses a single pipe to carry the flow of both wastewater and stormwater to the 14 local wastewater treatment plants (NYC DEP, 2019c). These local wastewater treatment plants, which also collect water from the separate sanitary sewer, have a total capacity of almost seven billion liters per day, from which five of them are being currently treated (AECOM, 2018).

The danger of this system is that, when water flows surpass twice the design capacity of the wastewater treatment plant, a mix of stormwater and untreated sewage flows directly into local waterways preventing the damage of the wastewater infrastructure but polluting the surrounding water bodies and ecosystems (EPA, 2018) of up to 4 hundred and sixty locations throughout the five boroughs (Chaisson, 2017). This fact is known as combined sewer overflow (CSO), which implies a major water pollution concern (EPA, 2017) for the health risks it imposes (EPA, 2011). In those areas with a **separate sewer system and other**, more street flooding is reported (NYC Emergency Management, 2019), as seen in maps 3 and 4 from the Report. Others include any other means of stormwater conveyance, including direct drainage into local waterways (New York Academy of Sciences, 2019e).

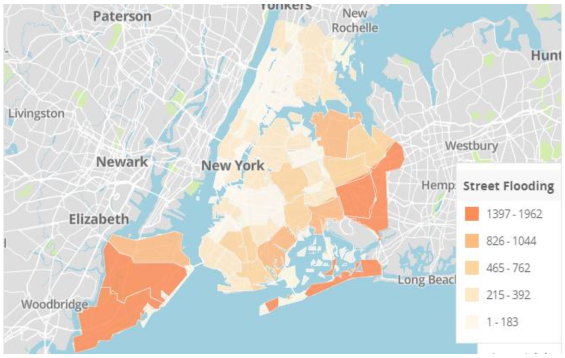

Figure 9. Map of NYC's street flooding. New York Panel on Climate Change 2019 Report (2019)

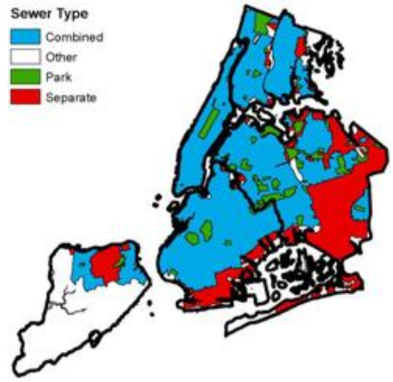

Figure 10. Map of NYC's sewer type. New York Panel on Climate Change 2019 Report (2019)

The second factor is the **lack of permeability**. Although more than 20% of the City's surface is formed by parks *(NYC Planning, 2019)*, 72% of its surface is impervious, which does not absorb water, resulting in stormwater runoff *(NYW, 2018)*. This poses challenges by triggering CSOs, washing pollutants into the waters through the separate storm sewer system, and causing flooding *(NYW, 2018)*.

The last human factor presented is the **location and characteristics** of its buildings. NYC has a diverse building stock of about one million structures of multiple different types and combination of uses and constitute NYC's homes, workplaces, museums, historic landmarks, community centers, and places of worship (City of New York, 2013). However, due to its location, more than 67,700 buildings lie in the 100-year floodplain created by FEMA in 2015 – the area that has a 1% or greater chance of flooding in any given year (City of New York, 2013). Furthermore, looking at future predictions, it is expected that those buildings affected will rise to more than 313,000 buildings by 2050s (NYC Planning, 2016b). From those affected, residential units are the ones more affected in (NYC Planning, 2016b).

Low-rise buildings (one to two stories) are more vulnerable to structural damage than mid-rise (three to six stories) and high-rise (seven stories or higher) buildings (NYC Emergency Management, 2014). Additionally, in low-rise buildings, the ground floor is mostly used for the household's primary activities, putting themselves at greater risk buildings (NYC Emergency Management, 2014). Low-rise buildings also tend to be constructed with lighter, wood-stud frames, which are more prone to structural damage – and to fire from electrical shorts that can be caused by flooding – than those built with steel, masonry, or concrete frames characteristic of larger, more recent building types buildings (NYC Emergency Management, 2014). New wood-frame housing is generally not permitted in New York City buildings (NYC Emergency Management, 2014).

While coastal protection measures are a significant and critical part of the City's efforts to protect buildings from current and future climate risks, they will not eliminate completely those impacts under all potential storm conditions (City of New York, 2013). Additionally, they also take time to design, fund, and build, as can be seen by NYC's Build it Back program[78], which to date it has not been completed (NYC Recovery, 2019). For this reason, the government leaves to the owners with the responsibility to retrofit their buildings to reduce the risk of damage and disruption from coastal flooding. This fact implies that the current characteristics of those buildings in the floodplain are still vulnerable to floods, which is also shared in many periodical articles[79].

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[78] The Build it Back program is an initiative launched by the NYC Mayor's Office of Housing Recovery Operations in the wake of Hurricane Sandy, to return families to their homes, and assist Sandy-impacted residents with their recovery needs (NYC Recovery, 2019)

[79] See articles 1 and 2.

Appendix 3

This appendix shows the changes applied to the original selection of indicators (Table 11), before performing the interviews. Furthermore, one can find the rationale behind the final indicators (Table 12) and additional indicators that could be added in the assessment.

Table 11. Changes in the preliminary indicators

Category	Indicator	Changes
Economy	1. Resource availability and resource use efficiency and effectiveness: 1.1 Investment efforts in flood adaptation. 1.2 Efficiency and effectiveness of investment (the project ends when expected and protects the areas exposed).	1. Investment efforts in flood adaptation: 1.1 Number of public projects that aim at reducing the exposure against flood adaptation (during the last 5 years). 1.2 Type of project (structural flood protection measure -barriers, EWS, nature-based solution, social protection and risk financing instruments).
	2. Economic diversity and sensitivity: 2.1 Sectoral GDP. 2.2 Location of main economic activity.	Indicators erased and substituted by: 5. Condition of buildings and protection: 5.1 Percentage of retrofitted buildings and new constructions in the 100-year floodplain. 5.2 Property protection projects against floods: amount and % completed.
	3. Economic inequalities: 3.1 Wealth distribution: Gini Coefficient. 3.2 Population at poor risk.	
	4. Public and private insurance mechanisms against floods: 4.1 What the insurance covers. 4.2 Who is covered.	2. Public and private insurance mechanisms against floods: 2.1 Percentage of people covered. 2.2 Who and what is covered.
	5. Number and duration of transportation disruptions.	3. Flood adaptation investment in public transportation (bus, train, subway):

		3.1 Investments done. 3.2 Stage of the projects.
	6. Sewer system improvements: 6.1 Evolution of the number of complaints due to sewage flooding. 6.2 Projects/Initiatives to improve the sewer.	4. State of the sewer system: 4.1 Evolution of sewage flooding due to blocked or broken sewer. 4.2 Projects/Initiatives to improve the sewer.
Category	**Indicator**	**Changes**
Society	1. Demographics: 1.1 Population density. 1.2 Geographic distribution of population density. 1.3 Percentage of households at reduced flood risk due to construction of new or enhanced defenses.	5. Waterproofed homes: 5.1 Percentage and evolution of population that live in a waterproofed home.
	2. Vulnerable population: 2.1 Location of people at poor risk.	1. Poverty: 1.1 Evolution of people at poor risk and homeless. 1.2 Evolution of flood risk in their location.
	3. Education: 3.1 Climate change education.	Substituted by: 4. Social networks: 4.1 Percentage of people not included in social networks when floods take place (new immigrants, people living for less than 2 years in the city, homeless, minorities, people with two jobs or more…).
	4. Community 4.1 Presence of a cohesive social network in an informal settlement, including strong communications channels in times of crisis.	2. EWS: 2.1 Percentage of people that receive the alerts.

	5. Neighborhood discrimination in flood adaptation projects: 5.1 Geographical implementation of projects that aim to reduce flood risk.	3. Borough discrimination in flood adaptation projects: 3.1 Number of flood adaptation projects implemented by borough. 3.2 Number of flood adaptation projects completed by borough.
Category	**Indicator**	**Changes**
Ecosystem services	1. Buffer zones to floods: 1.1 Location. 1.2 Capacity. 2. Natural spaces: 2.1 Location. 2.2 Capacity. 3. Dams and reservoirs: 3.1 Location. 3.2 Capacity. 4. Levees, bunds and weirs: 4.1 Location. 4.2 Capacity.	Indicators 1-4 were replaced by: 1. Street trees: 1.1. Location and amount. 1.2. Water absorption capacity. 2.GI projects: 2.1 Percentage of GI projects completed. 2. 2 Evolution in number and volume of CSOs. 3. Protection of ecosystems: 3.1 Level of protection of ecosystems. 3.2 Percentage of ecosystems with healthy conditions. 4. Infiltration capacity 4.1 Evolution of infiltration capacity
	5. Integrated water resource management: 5.1 Coordination of water resource management across municipalities around NYC.	*Moved to governance*
Category	**Indicator**	**Changes**

Governance	1. Participation in global networks for CC	1. Political support in flood adaptation efforts: 1.1 Assessment of the government's efforts to provide protection to the population (percentage of flood-related programs completed by the current and the first previous mayors). 1.2 Politicization of actions (money invested by mayor in flood adaptation programs).
	2. Well-informed decision making: 2.1 Policy coherence with expected CC impacts with a focus on water and urban policy.	*Integrated in other indicators*
	3. Political will - seen by policy development and application, investment for flood adaptation.	4. Economic strength of departments working for flood adaptation: 4.1 Budget departments/total budget (from the city). 4.2 Budgetary issues
	4. % Building codes updated and accomplishment.	Substituted by: 3. Flood risk in areas of big economic activity: 3.1 Current protection mechanism 3.2 Stage of completeness of projects
	5. Stakeholder engagement at all levels.	2. Engagement of population in decision making: 2.1 Importance of civilians’ voice that live in flood risk areas (number of projects that include community engagement).

Table 12. Rationale of final indicators

Category	Indicator	Rationale
Economy	1. Investment efforts in flood adaptation	Despite not reducing current vulnerability, the more investment a city does, the more adapted will be in the future (Banhalmi-Zakar & Rissik, 2017). Hence, this indicator measures how the city is anticipating for the negative consequences of CC (European Commission, 2012, p. 15).
	2. Public and private insurance mechanisms against floods	Adaptation measures implemented by both the state and private agents may be insufficient to allow households to cope with the impacts of large climate events (The World Bank, 2008). It is important, then, that governments put in place programs that can provide additional incomes at such times (The World Bank, 2008).
	3. Flood adaptation investment in public transportation (bus, train, subway)	Lack of adapted transportation means can cause disruptions in their services (EPA, 2016). Disruption of transportation are one of the risks associated with climate vulnerability and CC (New York Academy of Sciences, 2019c; Finley & Schuchard, 2011). Considering that adaptation aims at reducing losses and damages (Doroszkiewicz & Romanowicz, 2017), a high number and duration of disruptions show a lack of adaptation.
	4. Stage of sewer system	The expected increase in the intensity of precipitations, makes the sewage system as vital to reduce pluvial flooding (Brockho et al., 2019). Hence, a better adapted sewer system reduces flood risks.
	5. Condition of buildings and protection	More sensitivity increases the risk of disaster or disruptions that populations can face (PreventionWeb, 2015). Thus, if the conditions of the buildings and level of protection remains the same, the adaptation of the city to future floods decreases.

Category	Indicator	Rationale
Society	1. Poverty	Aggregated personal incomes and poverty rates are important influences on adaption (Reckien et al., 2015).
	2. Early Warning Systems (EWS)	EWS are key elements of CCA and disaster risk reduction and aim to avoid or reduce the damages caused from hazards (Climate Adapt, 2019). To be effective, early warning systems need to actively involve the people and communities at risk from a range of hazards, facilitate public education and awareness of risks, disseminate messages and warnings efficiently and ensure that there is a constant state of preparedness and that early action is enabled (Climate Adapt, 2019).
	3. Borough discrimination in flood adaptation projects	Discrimination is categorized as one of the barriers of social adaptation (Jones L. , 2010). Hence, those areas exposed to floods that are discriminated, lowers the level adaptation of the city.
	4. Social networks*	The effectiveness and efficiency of both mitigation and adaptation measures can be boosted by promoting local and regional active social policies that lead to greater social cohesion between specific or potentially affected rural and urban communities (Vega-López, 2012).
	5. Waterproofed homes*	Flood protection infrastructure is recognized as an effective adaptation strategy that, together with nature-based solutions and risk financing schemes, allow cities to better manage floods and buffer their economic impacts (Jongman, 2018).

Category	Indicator	Rationale
Ecosystem services	1. Street trees	Street trees reduce flooding intercepting and storing rainfall, filtering runoff in the canopy and in the root-zone, and drawing moisture from the soil, increasing the soil water storage capacity for rainfall events (Salmond et al., 2016). They also modify the below-ground environment, improving the permeability of soils (Salmond et al., 2016).
	2. GI projects	GI has a significant role in improving the urban microclimate, whilst also helping to reduce the risk of natural disasters (Salata & Yiannakou, 2016).
	3. Protection of ecosystems	Biodiversity and ecosystem services help in the adaptation and mitigation to CC (European Commission, 2009). They are therefore a crucial part to combat CC (European Commission, 2009).
	4. Infiltration capacity	Urbanization causes an increase in the flood discharge because of the decline of infiltration capacity by pavement (Itsukushima et al., 2018). Hence, an increase in the infiltration capacity reduces flood risk and vulnerability, which increases flood adaptation.
Category	**Indicator**	**Rationale**
Governance	1. Political support in flood adaptation efforts	Governments' actions are critical for successful adaptation (Cimato & Mullan, 2010).
	2. Engagement of population in decision making	Integrating population in decision making in flood adaptation programs addresses better their needs identifying societal problems that are not easy to identify for decision makers (The City of New York, 2019; Few et al., 2007).
	3. Flood risk in areas of big economic activity	Apart from increasing CCA, it also improves climate resilience of cities (CDP, 2014).

	4. Economic strength of departments working for flood adaptation	The more strength and influence they have, the more programs they can implement to protect the areas from floods (Johannessen A. , 2020).
	5. Integrated water resource management*	To avoid negative consequences, there is the need for an integration in the decision making of those areas affected by CC (Ho et al., 2017).

Other indicators that could have been added but they could not be because of lack of data:

- Percentage of non-English speaking population
- Undocumented people
- Number and location of the elderly and conditions of their homes
- Indicator related to hospitals
- Climate change education
- Percentage of waterproof buildings
- Location of schools and hospitals and their connectivity
- Energy (backups, protection against floods, etc.)
- Hospitals: capacity, location, and connectivity

Appendix 4

This Appendix includes the interview questions and the interviewed key informants.

1. How many indicators would you recommend adding for each category in this research and in real life?
2. Is there any suggestion you would have to improve my current selection of indicators? Is there something you would change or add? *This question is about the requirements that indicators should have.*
3. When should indicators change, if at all? How this process should be done?
4. Do you think, by just keeping the categories of indicators, the level of flood adaptation from this framework could be comparable across cities?
5. Do you think that indicators could be generalized to cities with the same context (similar risk level and source of the risk)? If so, which indicators do you think could be generalized?
6. Do you think, in order to be comparable across cities, this assessment should be done during the same years? Why?
7. What do you think should be the frequency of such assessments at the city level? Why?

Participants:

Out of the more than fourty people and organizations contacted, a total of nine field experts were interviewed.

Table 13. Field experts interviewed

Name	Position	Organization	Date
Karen Pilgrim	Adaptation specialist	Global Climate Adaptation Partnership	07/02/2020
Thomas E. Downing	President and chief executive officer	Global Climate Adaptation Partnership	11/02/2020
Arno Rosemarin	Senior Research Fellow	Stockholm Environment Institute	03/03/2020
Yaella Depietri	Researcher	Israel Institute of Technology	03/03/2020
Maria Caffrey	Climate Specialist	Union of Concerned Scientists	06/03/2020
Åse Johannessen	Post-Doctoral Fellow	Lund University	12/03/2020
Eva Crego Ruiz	Senior Planner	Catalan Water Agency	17/03/2020
Patrick Gonzalez	Associate Adjunct Professor	University of California, Berkeley	18/03/2020
Rolf Larsson	Senior Lecturer	Lund University	19/03/2020

Appendix 5

In this appendix, some of the programs that NYC is implementing to increase flood adaptation are briefly explained by area of coverage, responsibility and years of implementation. To know more about them, each program has a link to its website.

Table 14. Flood adaptation programs in NYC

Program	Area of coverage	Responsibility	Years
Climate Resiliency Design Guidelines	Design of facilities, for new constructions or improvement of buildings (NYC Mayor's Office of Recovery and Resiliency, 2019).	Engineers, architects, landscape architects, and planners. Not mandatory to apply because they are not integrated in building codes (Acclimatise news, 2019).	From 2017 and it keeps updating
Rebuild by Design	Resilience building projects. Projects funded: the big U, Hunts Point Resiliency (pilot project), Living Breakwaters (in progress) and Living with the Bay (in progress) (Rebuild by Design, 2020).	Collaborative competition with community and local government stakeholders	From 2014 to now
Redesigned flood maps and zones	To address specific types of development or the design and quality of public spaces (NYC Planning, 2019). For example, some initiatives allow the modification of underlying regulations when developing large sites, while others fine-tune those same regulations to address lower-density areas or the challenges and opportunities at the water's edge (NYC Planning, 2019).	NYC Planning	NA

Program	Area of coverage	Responsibility	Years
NYC Build it Back	Buildings (NYC Sandy Funding Tracker , 2018).	NYC's Mayor's Office of Housing Recovery Operations	2013-2020
RISE (Resiliency Innovators for a Stronger Economy)	Small businesses. It helps them to adapt and mitigate the impacts of CC using innovative technologies (NYCEDC, 2014). It is a competition and the winning teams receive $30 million in funding only to local small businesses that were impacted by Superstorm Sandy (NYCEDC, 2014).	Developers, manufacturers or providers of technologies or applications	2014 (because of Superstorm Sandy)-2019
Mayor's Office of Resiliency	Policies, programs, capital projects, and public engagements (NYC Mayor's Office of Resiliency, 2020).	Mayor's Office of Resiliency	NA
The Waterfront Revitalization Program (WRP)	It establishes a set of ten policy categories for the development and use of waterfront areas within NYC's Coastal Zone (NYC Planning, 2018b). These provide a framework for evaluating whether actions are consistent with the WRP's goals (NYC Planning, 2018b).	NYC Planning	NA
NYC Retrofit Accelerator	Energy use and greenhouse gas emissions in buildings (NYC Retrofit Accelerator, 2018).	NYC Retrofit Accelerator	NA