Using Uncertain Sea Level Rise Projections: Adaptation in Rotterdam and New York

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ABSTRACT

Coastal cities, where much of the world’s population and economic activity is concentrated, are vulnerable to sea level rise and other impacts of climate change. While there has been increased attention on taking action to reduce the adverse impacts of climate change at the city-scale, one of the obstacles local authorities face is the inherent uncertainty in climate change projections. This thesis examined how Rotterdam and New York, two leading cities in climate change adaptation, used sea level rise projections in their adaptation plans and addressed the issue of uncertainty. These case studies showed that cities adopt different processes to obtain local sea level rise projections, influenced by their institutional and political structures. Rotterdam leveraged on projections and adaptation planning at the national level, while New York commissioned its own city-level climate change risk assessment and focused largely on adaptation policies that are to be implemented at the city level. Despite the emphasis in the literature on the role of science-based climate change impact assessments as the basis for adaptation planning, the case studies suggest that the inherent uncertainties in climate change science limit the usefulness of the specific projections from such assessments for adaptation planning. However, many adaptation strategies that cities could adopt require only a broad understanding of the potential local impacts of sea level rise and information about current conditions. To be prepared for future sea level rise, cities should consider alternative assessment approaches that are less dependent on specific sea level rise projections. They should also consider building in flexibility for adjustment in their adaptation policies and explore innovative design responses to variable and uncertain sea levels.

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I INTRODUCTION

In 2007, the Intergovernmental Panel on Climate Change (IPCC) stated in its Fourth Assessment Report (AR4) that “warming of the climate system is unequivocal” (p. 2). The term “climate” refers to the weather averaged over a long period, typically around thirty years. While there have been changes in the earth’s climate in the past, current climate change is different because it is more rapid and because it is anthropogenic, rather than natural (IPCC, 2007b). Greenhouse gases already in the atmosphere will continue to affect the climate due to the slow response time of the climate system.

The IPCC projected that global air temperatures would experience a “warming of about 0.2°C per decade” for the next two decades, for a range of emissions scenarios. The report projected warming of 1.1°C - 6.4°C, by the end of the 21st century, depending on emissions scenarios. The report also provided a model-based range of sea level rise of between 0.18 m - 0.59 m by the end of the 21st century, using different SRES emissions scenarios and models. This did not include “future rapid dynamical changes in ice flow” (IPCC, 2007a, p7). Since the AR4, further studies have concluded that “a global rise of sea level exceeding 1 m is a plausible scenario for the twenty-first century if the Greenland and/or Antarctic ice sheets are significant sources of sea level rise” (Nicholls, 2011, p145). Aside from changes in global mean temperatures and sea level, climate change is also expected to result in more extreme weather events. The report highlighted that climate change would affect ecosystems, water resources, agriculture, low-lying coastal areas and human health.

Increasing attention has been paid to the impacts of climate change on cities. According to the World Bank, cities will be affected by “an increase in extreme weather events and flooding to hotter temperatures and public health concerns” (2011, p. 3). Cities will also be affected by the indirect impacts on the surrounding areas and systems; for example, drought in water catchment areas would reduce water quantity and water supply. These exacerbate existing climatic and environmental stressors faced by cities, such as the urban heat island effect, air pollution and extreme weather events (Ibid.). The heightened vulnerability of cities to climate change stems from their concentration of population and economic activity. Urbanization itself also exacerbates climate change impacts (Carter, 2011).
Coastal cities face additional impacts from “the combined threat of sea level rise and storm surges” (The World Bank, 2011, p. 3). Sea level rise and increased extreme weather events will create new stresses for coastal cities. Sea level rise may cause coastlines to retreat inland, while increased storms would lead to increased temporary flooding from various sources – coastal (due to storm surge), pluvial (due to heavy precipitation), and fluvial (due to flooding from rivers). The threat of sea level rise is of great concern because the world’s population is concentrated in densely populated and growing coastal locations, due to the economic advantages offered by these locations (Beatley, 2009; de Sherbinin, Schiller, & Pulsipher, 2007).

At the city-scale, local authorities in coastal cities are faced with the difficult situation in which the projections from climate science indicate a clear imperative to take action, given the potentially severe consequences of sea level rise. However, given the range in the IPCC’s sea level rise projections and the high uncertainty surrounding the impact of the melting of ice sheets, a process that is not well understood, the inherent uncertainty in climate science is one of the obstacles that hinders action (Corfee-Morlot, Cochran, Hallegatte, Teasdale, 2011).

This thesis explored the following question:
How do cities factor in the inherent uncertainties in sea-level rise and storm surge projections in their formulation of climate change adaptation strategies?

I examined how the cities of Rotterdam and New York obtained and used sea level rise projections for adaptation planning, focusing on their treatment of uncertainty. Both of these cities had published adaptation plans - Rotterdam Climate Proof 2010 and PlaNYC. The case studies showed that cities obtain local sea level rise projections in different ways and that institutional and political structures are significant influences on this process. Rotterdam leveraged on projections and adaptation planning at the national level, while New York commissioned its own city-level climate change risk assessment and focused largely on adaptation policies that are to be implemented at the city level.

The case studies show that despite the emphasis in the literature on the role of science-based climate change impact assessments specific to the city as a basis for adaptation planning, the inherent uncertainties in climate change science limit the usefulness of the specific projections from such assessments. However, even a broad understanding of the potential local impacts of sea level rise can support the need for adaptation. Furthermore, many adaptation actions that cities
could adopt do not require detailed sea level rise projections, but can be developed based on information about current conditions. In the case studies, such adaptation actions included measures to reduce current vulnerability to coastal hazards, enhance community resilience and plug existing gaps. To enhance resilience to future sea level rise and storm surge events, cities should consider incorporating new approaches in policy formulation that consider how changes in adaptation policies would be made over time in response to new information. Cities could also consider developing design responses that cater to variability in sea levels.

The overall structure of this thesis takes the form of six chapters, including this introductory chapter. Chapter 2 provides a review of the literature on climate change projections, focusing on the issue of uncertainty, adaptation in cities and the interface between science and policy. In Chapter 3, I set out the case study methodology used in this thesis. Chapter 4 presents the case study of Rotterdam, followed by Chapter 5 on New York. The final chapter draws together the findings from both case studies and concludes with the implications of the findings for practice.
2 LITERATURE REVIEW

2.1 UNCERTAINTY IN CLIMATE CHANGE PROJECTIONS

2.1.1 SOURCES OF UNCERTAINTY

According to the National Research Council (NRC), "the term uncertainty should be used to describe situations without sureness, whether or not described by a probability distribution" (2000, p. 41). The study identified the following sources of uncertainty:

**Natural variability** – "deals with inherent variability in the physical world; by assumption, this 'randomness' is irreducible". This is also called "aleatory uncertainty", or "external, objective, random, or stochastic uncertainty".

**Knowledge uncertainty** – "deals with a lack of understanding of events and processes, or with a lack of data from which to draw inferences; by assumption, such lack of knowledge is reducible with further information". This is also called "functional, internal, or subjective uncertainty" (Ibid.).

Knowledge uncertainty can be further disaggregated into "parameter uncertainty", which "relates to the accuracy and precision with which parameters can be inferred from field data, judgment, and technical literature" and "model uncertainty", which "relates to the degree to which a chosen model accurately represents reality". The study listed the key contributors to parameter uncertainty as "(1) measurement errors, (2) inconsistent or heterogenous data sets, (3) data handling and transcription errors, and (4) non-representative sampling caused by time, space, or financial limitations." A final type of knowledge uncertainty, "decision model uncertainty" is identified, to describe "an inability to understand the objectives that society holds important or to understand how alternative projects or designs should be evaluated." Such uncertainty, for example, would include uncertainty in discount rates and the appropriate length of planning horizons' (NRC, 2000, pp. 41-45). Uncertainty about the future in this context appears only in "decision model uncertainty". The parameters values for the model refer to actual values that would be accurate save for possible constraints or errors in measurement, sampling and data handling.
2.1.2 Climate Change Projections and Impact Assessments

In projecting future climate change and its impacts, "uncertainties are associated with every step in the causal chain: emissions, climatic drivers (e.g. the carbon cycle), climate (mainly climate sensitivity and pattern of climate change), and impacts (including adaptive capacity)" (van Vuuren et al., 2011, p. 587). The sequential nature of this type of analysis compounds the uncertainties, as the outputs of models in earlier steps become the parameters used in subsequent steps. Wilby and Dessai (2010, p. 181) illustrate the sequential nature of the process using the diagram of "the cascade of uncertainty". They illustrate the compounding of uncertainties with the diagram of "the envelope of uncertainty" that starts with a narrow apex representing "future society" and a broad base representing a diversity of "adaptation responses" (see Figure 1).

**Figure 1: The Cascade of Uncertainty and the Envelope of Uncertainty**

![Figure 1](image)

Figure 1. A cascade of uncertainty proceeds from different socio-economic and demographic pathways, their translation into concentrations of atmospheric greenhouse gas (GHG) concentrations, expressed climate outcomes in global and regional models, translation into local impacts on human and natural systems, and implied adaptation responses. The increasing number of triangles at each level symbolize the growing number of permutations and hence expanding envelope of uncertainty. For example, even relatively reliable hydrological models can yield very different results depending on the methods (and observed data) used for calibration.

(Source: Wilby and Dessai, 2010, p. 181, Figure 1)

This graphical representation has some limitations. The single triangle for "future society" underrepresents the range of socio-economic, demographic and technology trends that would affect greenhouse gas emissions. Furthermore, the range of possible "adaptation responses" to "local impacts" would also depend on "future society" - in terms of the resources and technologies available, as well as the values held by society - a crucial linkage that is not reflected in the diagram.
As discussed above, the problem of uncertainty is heightened in the case of climate change projections because the parameters for the models are projected data. Furthermore, climate change science typically uses model-based probabilities – in which probabilities assigned to a particular value reflect the percentage of model runs that give that value or lower, which should not be mistakenly used as an indication of the likelihood of the projection actually occurring in the future (UK Climate Projections 2009, 2012).

2.1.3 FUTURE SOCIETY AND GREENHOUSE GAS EMISSIONS
The causal chain begins with emissions scenarios. Since the evolution of future society and the resultant impact on greenhouse gas emissions cannot be predicted, the IPCC developed several “equally valid” emissions scenarios in its Special Report on Emissions Scenarios (SRES), drawn from 6 “scenario groups” with different assumptions of population growth, economic growth and technology (IPCC, 2000, p4). These scenarios have since formed the basis for the IPCC’s climate change projections.

2.1.4 GLOBAL CLIMATE CHANGE PROJECTIONS
To understand the impact of greenhouse gases on the global climate system, General Circulation Models (GCMs) are used. GCMs refer to “numerical models...representing physical processes in the atmosphere, ocean, cryosphere and land surface”. The IPCC considers GCMs “the most advanced tools for this purpose”, although GCMs have a coarse resolution, with “a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans” (IPCC, 2011b). While GCMs clearly occupy a dominant position in climate science, Shackley, Young, Parkinson, and Wynne (1998) assert that this is not solely due to objective and scientific criteria for the best science, but also due to the way in which GCMs are able to provide linkages to other sciences and to policy issues, creating a mutually supporting network of relationships. They recommended a more rigorous approach to the treatment of uncertainty within GCMs.

Uncertainty in GCMs is attributed to the averaging of small-scale physical processes over a larger scale (known as parameterization), as well as different assumptions for feedback mechanisms regarding processes such as clouds, ocean circulation in different models. Due to these differences, different GCMs produce different results given the same assumptions regarding greenhouse gas emissions. Using the terminology of the National Research Council (2000) study, model uncertainties are more significant than parameter uncertainties, since the results of
different studies often yield larger differences than "those arising in a particular model under different emission scenarios" (van Vuuren et al, p. 587).

A significant source of model uncertainty is "climate sensitivity", which refers to the projected global warming for a doubling of climate sensitivity. Based on current models, this is "likely to be within a range of 2°C to 4.5°C, with a best estimate of about 3°C" (IPCC, 2007b, p. 12). Within the scientific community, substantial reductions in this range are not expected within a timeframe that policymakers can rely on (NPCC, 2010).

Global warming leads to rising sea levels because of "(1) the thermal expansion of seawater as it warms, and (2) the melting of land-based ice, comprising components from (a) small glaciers, (b) the Greenland Ice Sheet, and (c) the West Antarctic Ice Sheet" (Meehl et al., 2007, in Nicholls, 2011, p. 145). A key source of uncertainty in projecting global sea level rise is the uncertainty regarding the melting of the Greenland and Antarctic Ice Sheets as the processes are not well understood and are not adequately modeled.

2.1.5 LOCAL CLIMATE CHANGE PROJECTIONS

As highlighted above, GCMs typically have a resolution that is coarse relative to the scale of impact assessments. Shackley et al (1998) noted that although GCMs did not produce "robust regional climate simulations", their promise of being able to do so with further refinement could "strengthen the case for current continued development of GCMs as the only models that are potentially capable of producing regional simulations" (p. 184).

In the last decade, there has since been a rapid increase in the "volume of peer-reviewed research on regional climate downscaling" (Wilby & Dessai, 2010, p. 180). Although GCM-based approaches have been key in demonstrating the need for greenhouse gas emission reductions, they may have been "less helpful in informing how to adapt at regional and local scales". This is because there remain "serious practical limitations, especially where the meteorological data needed for model calibration may be of dubious quality or patchy, the links between regional and local climate are poorly understood or resolved, and where technical capacity is not in place" (Ibid.).

In addition to technical difficulties, further concerns arise in the use of such modeling results, as "high-resolution downscaling can be misconstrued as accurate downscaling". They may also be of
limited value where dealing with current climate variability is already of concern and considering future scenarios may seem to be of a lower priority (Ibid. p. 180). Aside from lacking resolution at the spatial scale, GCM-based modeling also does not provide sufficient temporal resolution to understand the changes in extreme weather events in the future. Modeling these extreme events for the end of the 21st century shows signals that “are relatively small compared to natural climate variability” or even have uncertain directionality (IPCC, 2011a, p. 5).

Projections of local sea level rise, also referred to as relative sea level rise, depend not only on global sea level rise projections, but also regional and local components, that include “(1) climate change and changing ocean dynamics, and (2) non-climate uplift/subsidence processes such as tectonics, glacial isostatic adjustment (GIA), and natural and anthropogenic-induced subsidence” (Emery and Aubrey, 1991; Peltier, 2000; Church et al., 2010; in Nicholls, 2011, p. 146).

As discussed above, the issues of uncertainty are compounded in adaptation planning at the local or urban scale. Despite the desire and need for more detailed information and greater certainty at the local level at which adaptation planning takes place, projections of climatic variables and their impacts are even more uncertain when applied to the shorter time-scale and spatial scale of extreme weather events and their impacts on cities or metropolitan areas (van Vuuren et al., 2011; Bosello & Chen, 2011). Furthermore, the reliability of models at the local and regional scales “is only expected to improve gradually as computer power and scientific understanding advance” (Committee on America's Climate Choices, 2011, p. 50).

2.2 ADAPTATION IN CITIES

2.2.1 DEFINITIONS OF ADAPTATION

The IPCC’s current definition of adaptation is as follows:

“In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate” (2011a, p. 3).

The IPCC’s earlier definition of adaptation is shown below:

“Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects” (2007a, p. 76).
These definitions show how the concept of adaptation has broadened in the IPCC’s usage in two respects. Firstly, the current definition emphasizes that adaptation is “a process of adjustment”. This recalls the concept of adjustment and readjustment in White (1945), where adjustment to floods refers to “an ordering of occupancy to floods and to the flood hazard” (p. 46), in which flood losses “can be avoided by staying out of the flood plain” and “be reduced if not eliminated by readjusting human occupancy to the flood hazard” (p. 50). The current definition connotes a continuous process that responds to new information regarding actual or expected climate – a critical factor given the uncertainties in climate change information. In contrast, the earlier definition suggests that adaptation comprises a set of initiatives and strategies taken at a particular point in time, that result in a state that can be considered as being adapted, inadequately adapted or maladapted. The possibility of such an assessment assumes some level of certainty regarding climate change effects or an ex post assessment.

Secondly, the current definition includes adjustments to “actual or expected climate and its effects”, while the earlier definition focused on “actual or expected climate change effects” (emphasis added). Burton (2004) articulated this conceptual difference by defining two types of adaptation - “Adaptation Type I refers to past and current adaptation strategy, policy, and measures without considering climate change.” This type of adaptation is associated with responding to a “stationary” climate, i.e. one which experiences variability, but where the mean does not change over time. Type II adaptation refers to adaptation to a rapidly changing, non-stationery climate. He highlighted that there was a large and growing “adaptation deficit” in Type I adaptation that warranted international attention. The difficulty in distinguishing how much climate change contributes to the occurrence of extreme events makes it difficult in practice to implement only Type II adaptation. Hence, rather than focusing only on actions to respond to the incremental changes due to climate change, he argued for Type I and Type II adaptation to be seen “as part of a seamless process of adaptation”, in which the consideration of climate risk is included in the development process (“mainstreaming”) (pp. 3-5). The IPCC’s earlier definition considered only Type II adaptation, whereas the expanded current definition includes Type I adaptation as well.
2.2.2 CITY-SCALE ASSESSMENTS

The World Bank's Guide to Climate Change Adaptation in Cities sets out a broad roadmap for adaptation comprising three key steps:

- Improving understanding of specific climate change impacts — by conducting an assessment of vulnerability, risk and adaptive capacity
- Developing city adaptation plans, policies and actions
- Moving from planning to action by setting performance indicators and evaluating and prioritizing potential adaptation actions in cities (2011, pp. 30-32)

The definitions of key terms used by the World Bank for these assessments, following the IPCC’s AR4 definitions, are shown below:

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

**Risk** is the combination of the probability of an event and its consequences.

**Adaptive capacity** is defined as the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (2011, pp. 99-100).

The recognition that adapting to extreme weather is similar to disaster risk management has helped the integration of climate change adaptation with the discipline of disaster risk management gain traction since AR4. The IPCC’s Special Report on Extreme Scenarios (SREX) focused on extreme events and disasters and recommended “close integration” between disaster risk management and climate change adaptation (IPCC, 2011a, p. 9). This recent report used the definition of disaster risk shown below, which emphasizes the interaction between the exposure to the natural hazards and the social aspects of vulnerability:

**Disaster Risk:** The likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC, 2011a, p.558).
There is a wide range of possible assessment tools that cities could use for climate change impact assessments. Some are primarily vulnerability assessments, including participatory methods of gather information, e.g. ICLEI’s ADAPT tool, while others are primarily risk assessments e.g. the World Bank’s Urban Risk Assessment framework. In practice, the distinction the different types of assessments may be combined in the same tool, for instance, the Urban Risk Assessment Framework also includes an assessment of adaptive capacity. However, despite the formulation of the guides for adaptation by international organizations and networks, there are as yet “no standards or norms for planning and adaptation action”. Instead, adaptation planning by cities has been marked by “experimentation and innovation” (Anguelovski & Carmin, 2011, pp. 170-171).

The role of scientific information is considered critical in the climate change impact assessment process - “a process that brings the best-available science and other information to bear on decision making” (The World Bank, 2011, p. 31). Recognizing that there is range of assessment tools of differing depth of analysis and corresponding resource requirements, a rough scoping is suggested as a cost-effective solution “for those cities without funds to pursue the more in-depth analysis immediately” although it cannot replace such an in-depth study (p. 32). This suggests that more rigorous and in-depth city-scale impact assessments are desirable if resources are available to support such a study. This is a widely held view in other international organizations, as well as within the research community (Carmin & Dodman, forthcoming). However, as the the National Research Council (2009) noted, not all jurisdictions or groups possess the technical or financial resources that enabled large public jurisdictions like the state of California and the city of New York to conduct their own climate projections (p. 30).

There is a growing body of academic and “grey” literature on city-scale climate change impacts. Hunt and Watkiss (2011) found that most studies were on coastal cities, with more studies on sea level rise than on other issues. They attribute this to a combination of “perceived current vulnerability to climate variability from coastal flooding”, “greater certainty” - since sea level is expected to rise under most climate scenarios, and to the ease of understanding the metrics of impact (e.g. the areas that may be flooded) (p. 20). A study of the world’s large port cities projected a tripling in the population exposed to a 1-in-100 year flood event by 2070 due to “the combined effects of sea-level rise, subsidence, population growth and urbanization” (Hanson, et al., 2011, p. 90). In terms of adaptation, the authors found that the level of protection was not only dependent on the wealth of the city, but also reflected differences in attitudes towards risk.
To obtain climate change impact assessments for urban adaptation planning, local authorities used a variety of approaches, relying on national, regional or local-scale level reports that are available. Otherwise, specific studies may be commissioned or carried out by the city (Carmin & Dodman, forthcoming).

### 2.2.3 ADAPTATION IN CITIES

To understand how local authorities incorporate sea level rise uncertainty in adaptation, it would be appropriate to consider materials that represent adopted policy. Hence, while reports and studies by academics or advisory bodies may inform the decision-making by local authorities, their recommendations or specific proposals should not be taken to represent the policy intent of the city.

Not all documents from local authorities represent adopted policy. Preston, Westaway and Yuen (2011) define three different types of what they term "adaptation plans" from institutions - "strategy documents", which are primarily aspirational in nature, "consultation papers" for review or consultation within government itself or externally, and "action plans" with "a structured list of tasks, steps or measures that are planned to be implemented so as to meet a defined adaptation target or goal, and therefore represent official policy prescriptions" (p. 415).

Tompkins, Boyd, Nicholson, Weatherhead and Adger (2009) classified adaptation into “building adaptive capacity” and “implementing adaptation actions”, building on the classification initially developed by the UK Climate Impacts Program. The former category refers to “steps to facilitate adaptation thinking and knowledge gathering”, while the latter category refers to “taking actions” in response to the stimuli of actual or expected impact of climate change, such as relocating properties (p. 12). Arguably, less certainty is needed to decide on taking steps to build adaptive capacity, compared to implementing adaptation actions.

There is a wide variation in how cities are incorporating adaptation planning in their climate action plan. Of the 15 climate action plans in megacities and country capitals analyzed by Katich (2009) that make reference to adaptation, only New York and London had implemented projects or programs on local adaptation, while Cape Town had a proposed framework for adaptation prepared by consultants. The plans of other cities only included references to local impacts, the need for adaptation, and general strategies to do so. More recently, Vrolijks, Spatafore and Mittal (2011) reviewed the climate action plans of Chicago, Miami, New York City, San Francisco,
Seattle, Amsterdam, London, Madrid, Seoul and Tokyo, produced between 2004 and 2010. They found that although all the ten plans included the intent to climate proof the city and most plans included actions to build adaptive capacity through studies, only a few plans included actions that actually reduce climate change risk. However, this may not be a complete picture, since by focusing only on climate action plans, crucial documents on adaptation might not have been covered.

The internal motivation local authorities have to pursue adaptation was found to be a key driver for initiating adaptation efforts in Quito and Durban, which embarked on climate adaptation action earlier than other cities. Furthermore, adaptation efforts may be strengthened if they are connected to priorities and programs that were already in place and by gaining support from a wide range of stakeholders (Carmin, Roberts, & Anguelovski, 2009).

How climate change adaptation is integrated within a city’s urban governance also depends on the city’s priorities and state of development in related areas of urban governance. Takemoto (2011) found that Tokyo and Bangkok had similar existing flood management efforts. However, Bangkok’s urban planning and watershed management was less developed than Tokyo’s, and this difference accounted for the difference in priorities perceived by officials in the two cities with regard to future flood management in a changing climate. Since the severe floods that hit Bangkok during the monsoon season in 2011, the Interior Ministry, the Bangkok Metropolitan Administration and other relevant agencies have reviewed flood prevention measures in Bangkok (Asia News Monitor, 2012).

A study on climate change adaptation in Cape Town highlighted the challenges of incorporating natural science findings and complex and dynamic social-ecological systems within spatial planning based on absolute and static boundaries (Colenbrander, Oelofse, Cartwright, Gold, & Tsotsobe, 2011).
2.3 THE INTERFACE BETWEEN SCIENCE AND POLICY

2.3.1 THE PRODUCTION OF SCIENCE FOR USE IN POLICY-MAKING

The challenges of integrating uncertain climate change science into the policy-making realm can also be seen within the larger context of science-intensive policy disputes, in which the increased involvement of stakeholders is recommended to provide legitimacy to the scientific inputs used for policy making. Functowicz and Ravetz (1993) drew attention to the emergence of a new type of science, which they termed "post-normal", that is characterized by the centrality of high uncertainty in comprehending or managing a complex reality, as well as high decision stakes to various stakeholders. Unlike the concept of "normal science", defined by Kuhn as a problem-solving enterprise, in "post-normal science", "uncertainty and quality are moving in from the periphery, one might say the shadows, of scientific methodology, to become the central, integrating concepts." (p. 472). Functowicz and Ravetz singled out climate change impacts as an example of "post-normal" science, given the inherent uncertainties in climate change projections and the long lead-time needed for policies to reduce the adverse impacts to be implemented. The authors assert that in the era of "post-normal science", appeals to scientific information as authoritative may lead to legitimation crises. Instead, the engagement of a wider community of stakeholders in determining risk assessment and policy recommendations becomes critical.

There are suggestions within the literature regarding how the scientific information on climate change should be produced, given its inherent uncertainties. These focus on the use of an iterative exchange between scientific experts and decision-makers or stakeholders. The National Research Council (2009) recommended the approach of "deliberation with analysis" as a learning model, defined as "an iterative process that begins with the many participants to a decision working together to define its objectives and other parameters, working with experts to generate and interpret decision-relevant information, and then revisiting the objectives and choices based on that information" (p. 73). The National Research Council also highlighted the role of "boundary organizations" that provide linkages between scientific experts and policy makers.

Focusing on urban adaptation policy, Corfee-Morlot et al (2011) suggested that boundary organizations could be valuable in overcoming one of the barriers to adaptation action at the local level – "lack of scale of relevant technical and scientific information, and capacity to use such information at local scales" by providing an institutional framework that allows analytic-deliberative practice (p. 180). The importance of engaging stakeholders in the process to define
the climatic variables that are relevant to adaptation planning has also been stressed (Horton, Gornitz, Bader, Ruane, Goldberg, & Rosenzweig, 2011).

Webb (2011) used the conceptual framework in which policy-makers are co-producers of knowledge, in interaction with scientists and consultants, to critically assess the use of risk assessment techniques in the first UK Climate Change Risk Assessment. Based on the categorization of “climate regime” knowledge into the domains of academic science, fiduciary science (“applied, policy-oriented knowledge specific to set purposes”) and bureaucratic knowledge, by Hunt and Shackley (1999), she found that the UK Climate Risk Assessment operated at “the interface between bureaucratic knowledge and fiduciary science” (p. 282). Through it, uncertain climate change parameters were framed into the language of risk, that fits within the discourse of policy, although “climate change events are not amenable to probabilistic estimation” (p. 297). This process could result in the outputs of heuristic devices such as adopting a particular scenario as a baseline for carrying out risk assessments being misunderstood by policy-makers as representing “reality”, and therefore “resulting in over-certainty among policy-makers, rather than recognition of significant unknowns.” To counter this, she argued for a co-production model which involves civil society, and recognises that values are central (p. 288).

2.3.2 THE USE OF UNCERTAIN SCIENCE IN ADAPTATION PLANNING

Scholars have recognized the challenges of using uncertain climate change science in adaptation planning and proposed different approaches to manage the uncertainty in climate change projections in adaptation planning. These approaches place less emphasis on GCM-based climate change information in the analysis of adaptation needed, and instead use other perspectives such a critical problems approach (Wescoat, 1991), a bottom-up vulnerability approach (Wilby & Dessai, 2010), adaptation tipping points (Kwadijk, et al., 2010), using “what if” scenarios “which incorporate indeterminacy and worst cases” (Webb, 2011, p.288), and backcasting from a desirable future (van der Voorn, Pahl-Wostl, & Jaco, 2012).

In practice, adaptation at the local level has incorporated routine updates, increased linkages with the scientific community, building in flexibility to adaptation options and the iterative testing of new ideas, to tackle the challenges of uncertainty (Carmin & Dodman, forthcoming).
3 METHODOLOGY

In this chapter, I explain the methodology used in this research, covering the information used, the rationale for a sample size of two case studies, and the criteria for selecting case studies. This is followed by a discussion on how the treatment of uncertainty in the climate change impact assessments and the formulation of adaptation strategies was analyzed.

3.1 SOURCE OF INFORMATION

To understand how local authorities address the inherent uncertainties in sea level rise projections in their formulation of adaptation strategies, I used secondary material, focusing on city-scale adaptation plans—specifically, what Preston, Westaway and Yuen (2011) call “action plans”, i.e. adopted policies. In addition, I examined the climate change impact assessments and other adaptation policies that were mentioned in these adaptation plans.

Only cities whose available adaptation documents included documents by local authorities that proposed specific measures for implementation were considered as case studies. Cities where available adaptation documents did not go beyond statements of intent to adapt, possible strategies under consideration, such as recommendations by consultants or advisory bodies, were excluded, because these would not provide a sufficient basis for analyzing how the local authorities chose to act in view of uncertain sea level rise information.

3.2 SAMPLE SIZE

Following Carmin, Roberts and Anguelovski (2009) and Takemoto (2011), I adopted a case study approach for a sample of two cities. Since my interest was in how cities use uncertain sea level rise projections, a sample of two case studies was appropriate, in balancing the need for providing a sufficient depth of analysis, such as considering the city’s adaptation efforts within a wider regulatory and institutional context, while also making some generalizations possible.

Studies of the climate change action plans of a larger number of cities typically focused exclusively on formal climate change action plan documents, providing only a limited understanding of each city’s adaptation efforts (Katich, 2009; Vrojlks, Spatafore & Mittal, 2011).
3.3 SELECTION OF CASE STUDIES

I referred to studies on climate change adaptation in cities and shortlisted coastal cities that were considered to be leaders in adaptation: Cape Town, Durban, London, Miami, New York and Rotterdam (Katich, 2009; Anguelovski & Carmin, 2011; Vrojilks, Spatafore & Mittal, 2011; Hallegeate & Corfee-Morlot, 2011). I then checked for readily accessible online documentation on the adaptation efforts in these leading cities that had been identified in earlier research.

I selected Rotterdam and New York City as the most suitable cities for this research. The city of Rotterdam's adaptation program, Rotterdam Climate Proof, was published in 2010. This included specific adaptation measures that the city would take in both knowledge development and implementation. The city of New York had included adaptation strategies as part of PlaNYC in 2007, with more detailed strategies in the update to PlaNYC in 2011. Furthermore, as both are port cities in developed countries, it would be reasonable to draw comparisons between them, for instance, studies on the vulnerability of port cities to sea level rise such as Hanson et al (2011) included both Rotterdam and New York.

Although the City of Cape Town had commissioned an adaptation study, the Framework for Coastal Adaptation, the City Adaptation Plan of Action it proposed did not appear to have been published by the City (Mukheibir & Ziervogel, 2006; The City of Cape Town, 2012). The City of London prepared a Draft Climate Change Adaptation Strategy for public consultation, but its final strategy was expected only in the summer of 2012 (Greater London Authority, 2010). In addition, its response to sea level rise and storm surge focused on a single piece of large-scale infrastructure – the Thames Barrier, so this may yield limited insight into other types of responses to sea level rise. The City of Miami's Climate Action Plan contained only a statement of intent to "incorporate climate change into long-term planning", rather than detailing specific strategies (The City of Miami, 2008). For the City of Durban, documents on how sea level rise projections are being used in the evaluation of coastal development proposals and preparation of coastal management plans, referred to in Roberts (2010), were not available online.

An online search is not exhaustive and it is possible that some of the documents for these cities were available in hard copy or upon request from local officials. However, given that there was sufficient secondary material for the two selected case studies, these other possibilities were not pursued. The key documents for each case study city is shown in the Table 1 below. It shows that
Rotterdam Climate Proof 2010 is presented as a stand-alone adaptation program, while its key recommendations are included in the City of Rotterdam's overall Sustainability and Climate Change Program 2010-2014. In New York, the adaptation “action plan” is presented as part of PlaNYC, the City of New York’s long-term sustainability plan. While both cities had city-level adaptation plans, the source of climate change projections for Rotterdam was from a national-level study, while the source of climate change projections for New York City was from a city-level study.

TABLE 1: COMPARISON OF KEY DOCUMENTS FOR THE CITIES OF ROTTERDAM AND NEW YORK

<table>
<thead>
<tr>
<th>Type of document</th>
<th>Rotterdam</th>
<th>New York City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td>Exploring high-end climate change scenarios for flood protection of the Netherlands, Vellinga, et al., 2008 (National)</td>
<td>Climate Change Adaptation in New York City: Building a Risk Management Response, NPCC, 2010 (City-level)</td>
</tr>
<tr>
<td>Advisory</td>
<td>The Delta Report by the Delta Committee, 2008 (National)</td>
<td>NPCC Workbooks to guide Adaptation Task Force members - Climate Risk Information - Adaptation Assessment Guidebook - Climate Protection Levels (City-level)</td>
</tr>
<tr>
<td>Policy</td>
<td>Rotterdam Climate Proof 2010</td>
<td>Adapting to climate change section in PlaNYC 2007 Climate change section in PlaNYC update 2011</td>
</tr>
<tr>
<td>Sustainability Plan</td>
<td>Rotterdam Programme on Sustainability and Climate Change 2010 - 2014</td>
<td>PlaNYC 2007 PlaNYC update 2011</td>
</tr>
<tr>
<td>Related Local Level Plans or Policies</td>
<td>Floating Buildings Desk</td>
<td>Vision 2020 Comprehensive Waterfront Program Waterfront Revitalization Program</td>
</tr>
<tr>
<td>Other Related Policies</td>
<td>Delta Program</td>
<td>Federal flood insurance program Coastal zone management</td>
</tr>
</tbody>
</table>

3.4 ANALYSIS OF LOCAL SEA LEVEL RISE PROJECTIONS AND IMPACT ASSESSMENTS

I examined the climate change projections that were referred to in its adaptation plan, referring to the background scientific assessments on sea level rise projections, to understand the treatment of uncertainty. In addition, I considered whether different types of uncertainty – natural variability and knowledge uncertainty (parameter uncertainty and model uncertainty) – were distinguished and factored into the impact assessments. One caveat to note is that while these
uncertainties may be theoretically distinct, they may or may not be separately addressed in the climate change impact assessments. Table 2 below provides greater detail on the issues and questions that the analysis of local climate projections and assessments sought to elucidate.

**TABLE 2: ISSUES OF INTEREST IN ANALYZING LOCAL SEA LEVEL RISE PROJECTIONS AND ASSESSMENTS**

<table>
<thead>
<tr>
<th>ISSUES</th>
<th>QUESTIONS</th>
</tr>
</thead>
</table>
| **Overall** | To understand how uncertainty is considered in developing local projections and assessments | - Is uncertainty considered a concern?  
- What types of uncertainty were explicitly factored in the range of values for sea level rise impact and/or storm surge used?  
- What provisions are made for monitoring to enable actual changes to be compared against projected changes? |
| **Natural variability** | Climate change impacts can be hard to discern when the effects are smaller than natural variability. | - How does the analysis of coastal impacts consider uncertainty due to natural variability? |
| **Knowledge Uncertainty** - Parameter uncertainty | A key component of uncertainty in climate change is the future level of GHG emissions, which will depend on demographic change, social and economic development, and broad technological developments. For the IPCC, these uncertainties are addressed by working with six scenario groups in the SRES to span the range of uncertainties. Another aspect of parameter uncertainty is the adequacy of local historical data for the analysis. | - What is the rationale for the choice of scenarios for GHG emissions adopted?  
- How is the uncertainty in emission scenarios factored into the assessment and the sea level rise or storm surge information used for adaptation planning?  
- Is uncertainty in existing data accounted for in the assessment and the sea level rise or storm surge information used for adaptation planning? |
| **Knowledge Uncertainty** - Model Uncertainty | The IPCC addresses model uncertainty by utilizing many different models e.g. six different models and modeling teams were used to develop the SRES scenarios, several models were used to project the climate impacts based on the different SRES scenarios. At the local level, it is demanding in terms of technical capability, resources (time and financial) to work with the full range of available models. Nevertheless, this is still a significant source of uncertainty that needs to be addressed. | - Is model uncertainty explicitly discussed in the adaptation plan?  
- How is model uncertainty factored into the assessment and the sea level rise or storm surge information used for adaptation planning?  
- Is there an expectation for model refinement to be made to "reduce" these uncertainties? |
| **Decision-making uncertainty** | Uncertainty as to how society or decision-making entities would value the adaptation actions would affect the implementation and eventual impact of the adaptation strategies. | - Are uncertainties in adaptation decisions considered? |
3.5 ANALYSIS OF ADAPTATION PLANS AND STRATEGIES

The next part of the analysis considered how local authorities responded to the local sea level rise projections, specifically how uncertainty was incorporated in the identification of priorities, as well as in the specific measures to be implemented. I considered the way in which the sea level rise projections were presented in the adaptation plans, as an indication of the level of sensitivity to the uncertainties discussed in the background scientific documents. Table 3 below provides greater detail on the issues and questions that this analysis aimed to cover.

**TABLE 3: ISSUES OF INTEREST IN ANALYZING ADAPTATION PLANS AND STRATEGIES**

<table>
<thead>
<tr>
<th>Climate change adaptation plan</th>
<th>Issues</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The adaptation plan represents how the city is framing and responding to the impact of climate change, and the challenges of climate change uncertainties.</td>
<td>- What decisions are made regarding the range of values for sea level rise impact and/or storm surge used?</td>
</tr>
<tr>
<td></td>
<td>Since local risk and vulnerability assessments are developed in order for the city to be able to develop adaptation strategies, looking at how the data are eventually used would provide insights into what types of data are needed or most useful.</td>
<td>- How dependent were the proposed measures on the precise values of sea level rise or storm surge developed through the localized climate risk and vulnerability assessments?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- How is the range of possible uncertainty from the various sources of uncertainty factored into the data used for developing adaptation strategies?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- How do the methods used to prioritize between different adaptation actions address the issue of uncertainty?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- How is the robustness of specific adaptation actions in the face of uncertainty ensured?</td>
</tr>
</tbody>
</table>

| Linkage between climate change adaptation plan and other policy areas at the local and higher levels – i.e. "mainstreaming" | This will provide a more complete understanding of how a city is adapting to climate change, as it shows how other policy areas are being modified by the incorporation of climate change adaptation concerns. | - To what extent is dealing with uncertainty to be resolved in the other areas of regulation, rather than in the "adaptation plan"? |
|                                                                                                                      | | - What are the issues and challenges faced by local agencies in incorporating uncertain climate change adaptation into pre-existing plans and strategies? |
3.6 LIMITATIONS

Some of the limitations of the adopted methodology highlighted include: evaluating the information found only the adaptation plans themselves, rather than other “behind the scenes” reports and documents. Focusing on “formal efforts” excluded efforts that may be “implicit, informal and may not be recognized as climate adaptation per se” (Preston, Westaway, & Yuen, 2011 p.421). However, this was beyond the scope of this study since secondary sources were used.

This chapter covered the methodology adopted for the case studies. The next chapter presents the case study of Rotterdam. This is followed by the case study of New York in Chapter 5.
4 CASE STUDY – ROTTERDAM

4.1 INTRODUCTION

Rotterdam is the second most populous city in the Netherlands, after Amsterdam. It had a population of over 587,000 persons in 2009. The area of Rotterdam is 319 sq km (123 sq miles), of which 206 sq km (79 sq miles) is land, and the remainder, water (Center for Research & Statistics, 2009 in Rotterdam Facts & Figures). The port of Rotterdam is one of the largest in the world.

Rotterdam is on the estuary of the river Maas and close to the North Sea. It is Europe’s “lowest-lying delta metropolis”. Today, Rotterdam and its surrounding region is protected by a network of water defences, comprising “the levees, the dunes and the Maeslantkering” (The Rotterdam Climate Initiative, 2010). The Maeslantkering is a large storm surge barrier.

This chapter begins with an overview of Rotterdam Climate Proof 2010, the city’s adaptation plan. This is followed by a discussion of the use of climate change scenarios in Rotterdam’s flood management planning. The next section covers the adaptation strategies proposed in response to sea level rise – in the areas of flood management and adaptive building and considers the influence of the sea level rise projections on policy. The final section in this chapter explains how these adaptation strategies relate to policies at the national level.

4.2 ROTTERDAM CLIMATE PROOF 2010

The City of Rotterdam’s adaptation plan, Rotterdam Climate Proof 2010, seeks to prepare the city for the future impacts of climate change - heavier precipitation, sea level rise, varying river levels and higher temperatures. It aims to frame climate change as an opportunity rather than a threat, and focuses on knowledge building and implementation. Rotterdam Climate Proof 2010 is presented as a stand-alone adaptation plan. It is part of the Rotterdam Climate Initiative – a partnership between the City of Rotterdam, the Port of Rotterdam, DCMR Environmental Protection Agency Rijnmond, and employers’ organization Deltalinqs “with the objective of reducing CO2 emissions by 50% and climate proofing the city”, i.e. covering both mitigation and adaptation (The Rotterdam Climate Initiative, 2011).
The city’s adaptation program began in 2008, in response to its International Advisory Board’s recommendation that “adaptation to the consequences of climate change is essential to Rotterdam, and proper, ambitious water management will offer economic opportunities”. This shows that for Rotterdam, the potential for an “economic spin-off” that leverages on its existing expertise in water management was a key driver for initiating adaptation action. Rotterdam Climate Proof has been part of the Climate Office of the City of Rotterdam since 2009 (The Rotterdam Climate Initiative, 2010, p. 5). It is also included in the City’s overall Program on Sustainability and Climate Change 2010-2014 (The City of Rotterdam, 2011, p. 42; The City of Rotterdam, 2011).

4.3 CLIMATE CHANGE PROJECTIONS — THE DELTA COMMITTEE & OTHER SCENARIOS

Rotterdam’s adaptation plan refers to sea level rise projections developed for the whole of the Netherlands, rather than to a set of city-specific projections. It states, “Dutch experts project a sea level rise between 65 and 130 cm by the year 2100 for the Dutch coast (compared with the level in 1990)” (The Rotterdam Climate Initiative, 2010, p. 12).

There is no reference to the source of these figures. I referred to other reports from which these figures could have been derived and found that the figures were the same as those used by the Delta Committee in 2008 for projected sea level rise in 2100. However, at the time that Rotterdam Climate Proof 2010 was published in early 2010, there were at least two sets of projections for sea level rise by Dutch experts that were being referred to in discussions about flood management in response to climate change – the KNMI’06 scenarios developed by the Royal Netherlands Meteorological Institute (KNMI) in 2006 and the 2008 Delta Committee scenarios. The next sections provide further detail on these scenarios.

4.3.1 KNMI’06 SCENARIOS

The KNMI’06 scenarios were developed by KNMI in 2006 to describe “the most likely changes in the Netherlands, including associated uncertainties”. They were intended to guide “the process of climate proofing the Netherlands” and “for general use by a wide community”. These were reviewed in 2009 and found to still describe “the most likely changes in the Netherlands, including associated uncertainties” (KNMI, 2009, p. 4).

The four KNMI’06 scenarios, G, G+, W and W+, were developed as a response to various uncertainties affecting predictions of future climate. These included uncertainty regarding future
emissions (which depend on socio-economic developments), model uncertainty on the processes within the complex climate system, and external factors such as solar activity and volcanic eruptions. In addition, whether air circulation patterns will change contributes additional uncertainty at the regional scale, such as Western Europe or the Netherlands.

The KNMI'06 scenarios are differentiated by global temperature rise. The G and G+ scenarios (derived from "Gematigd", Dutch for "Moderate") are based on a temperature increase of 1°C around 2050 and 2°C around 2100, while W and W+ scenarios (for "Warm") are based on a temperature increase of 2°C around 2050 and 4°C around 2100. This approach of using temperature rise as a starting point for the scenarios is unique as other countries typically use emissions scenarios to differentiate climate impact scenarios. The KNMI assessed that the biggest uncertainty for 2050 was model uncertainty in calculating climate sensitivity, because the range of global mean temperature rise for different emission scenarios (about 0.5°C) was smaller than the range of projections for the same emission scenario (about 1°C). While there was more differentiation between the emission scenarios by 2100, "the range for each emission scenario is at least as wide due to the uncertainty in climate sensitivity". Consequently, the KNMI adopted the approach of using global temperature increase to provide "better insight into the combined uncertainties about greenhouse gas emissions and the response of the climate system" (KNMI, 2009, pp. 9, 36).

Because of the model uncertainty indicated by the large differences between climate models "with regard to the sensitivity of sea level rise to increased air temperatures", the estimates for sea level rise for each scenario of temperature increase was given as a range, rather than a single figure. For the G scenario, the absolute increase in sea level rise was estimated to be 35 - 60 cm by 2100; while for the W scenario, the absolute increase in sea level rise was estimated to be 40 - 85 cm by 2100, compared to 1990 levels (KNMI, 2012).

The other variable was whether or not air circulation patterns would change. The G and W scenarios assumed no change in air circulation patterns, while the G+ and W+ scenarios assumed that air circulation patterns over Western Europe would change. This variable does not affect the sea level rise projections as sea level rise is not affected by air circulation patterns (Ibid.).
Storm surges were also studied but the models used for the four scenarios showed only small changes in the number of storms from the western and northern directions that affect the Dutch coast (Ibid.).

4.3.2 DELTA COMMITTEE SCENARIOS 2008

The Dutch government established a second Delta Committee, chaired by Cees Veerman, to develop “recommendations on how to protect the Dutch coast and the low-lying hinterland against the consequences of climate change”. The committee was asked to consider the timeframe of “centuries to come” (The Delta Committee, 2008, p. 9). As a basis for its recommendations, the Delta Committee commissioned national and international experts to develop “plausible upper limits based on the latest scientific insights” (Ibid. p. 10). These projections were intended to supplement the KNMI'06 regional scenarios.

The reports reveal that the criteria by which to judge whether climate change information is based on the “best-available science” (The World Bank, p.31) are not straightforward. The background report by Vellinga et al (2008) stressed in its abstract the involvement of “20 leading climate scientists from different countries around the North Sea, Australia and the USA”, showing that the credibility of the research team is an important factor. The report explained that, “it explores, at the request of the Delta Committee, the upper end of the sea level rise scenarios and longer term projections, using modeling and expert judgment, without the limitation, under which the IPCC was drafted, that the work presented is already published in the scientific literature” (p. 15). The work is referred to as a “state-of-the-art scientific assessment” (Ibid., p. 7). The report also adds the caveat that, “It is by no means guaranteed that these high-end scenarios will remain valid as science progresses, that we bound the possibilities, or that the scenarios are agreed upon by the entire scientific community” (Ibid. p. 35). This suggests that in this assessment, using the latest research was given higher priority than using research that had achieved consensus within the wider scientific community.

Vellinga et al (2008) discuss the types of uncertainties involved in developing local sea level rise projections, following Manning and Petit (2003) (see Figure 2). An ensemble of models was used to address the uncertainties due to “inaccurate prescriptions of known processes”, i.e. a type of model uncertainty. Specifically, “the estimated ocean thermal expansion depends on the parameterization of small-scale mixing, large scale ocean circulation and heat uptake from the atmosphere (type 3), which differs from model to model” (Ibid. p. 16). The response to this type
of uncertainty was to use an “ensemble of climate models”. The different processes that contribute to sea level rise, along with their uncertainties, were considered separately.

**FIGURE 2: UNCERTAINTIES IN CONTRIBUTORS TO SEA LEVEL RISE**

<table>
<thead>
<tr>
<th>Contributor to sea level rise</th>
<th>Type of Uncertainty</th>
<th>Response to Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contribution of global mean thermal expansions using analysis of coupled climate models</td>
<td>1. Incomplete or imperfect observations</td>
<td></td>
</tr>
<tr>
<td>Contribution from small glaciers</td>
<td>2. Incomplete conceptual frameworks</td>
<td>Ensemble of models</td>
</tr>
<tr>
<td>Large ice sheets</td>
<td>3. Inaccurate prescriptions of known processes</td>
<td></td>
</tr>
<tr>
<td>Assessment of ocean circulation changes under a changing climate</td>
<td>4. Chaotic or inherently unpredictable responses</td>
<td></td>
</tr>
<tr>
<td>Vertical land motion</td>
<td>5. Lack of predictability due to non-physical factors (e.g. policy decisions, socio-economic factors)</td>
<td></td>
</tr>
<tr>
<td>Contribution of changing terrestrial water shortage</td>
<td>IPCC: range of emission scenarios Vellinga et al: range of future atmospheric temperature rises</td>
<td></td>
</tr>
</tbody>
</table>

(Source: Adapted from Manning & Petit (2003) in Vellinga et al (2008), pp. 16-17)

Since the scenarios were intended as upper values – “values that can serve as a reference for long-term tests of the robustness of future measures and investments” (The Delta Committee, p. 106), a higher range of global mean temperature increase by 2100 of 2°C to 6°C was used, corresponding to the IPCC’s A1Fl high economic growth scenario with the use of fossil fuels. The committee considered that this scenario was not unrealistic since actual emissions since 2000 were in line with or had exceeded the A1Fl scenario. Like the KNMI'06 scenarios, the projections used a range of future temperature increases, rather than the greenhouse gas emissions, as a starting point for developing the projections.

For the development of local sea level rise scenarios, the Delta Committee requested analysis that was “explicitly concerned with the upper limit of possible values under certain assumptions, rather than the bandwidth of most probable values” (Ibid. p.110). Thus, the scenarios included the accelerated melting of the Greenland and Antarctica ice sheets. The estimate of local sea level rise also took into account “possible extra local expansion of the ocean as a result of changed ocean
currents”. This resulted in a projected absolute local sea level rise to be between 0.55 m and 1.2 m by 2100. More than 10 cm of mean land subsidence was estimated along the Dutch coast “due to glacial isostasy and subsoil compaction”. From this, the committee noted that, “an upward trend can be seen in the estimates as our knowledge advances” (Ibid. pp. 23-25). It decided that for 2100, “a regional sea level rise of 0.65 to 1.3 m” should be taken into account, including land subsidence (Ibid. p. 10).

Although storm scenarios were considered, the study concluded that extreme surge heights would not change from current patterns because the models did not show any increase in the strength or frequency of northerly winds – the direction relevant for the development of storm surge along the Dutch Coast (Vellinga et al, 2008). Furthermore, the modeled results showed small future changes relative to natural variability and were inherently uncertain due to “the statistical processing of relatively short observational series” (The Delta Committee, p. 115).

In view of these uncertainties in the sea level rise scenarios, Vellinga et al (2008) recommended “flexible coastal management strategies” and “comprehensive monitoring” that would function as an early warning system for changes in sea level.

4.3.3 Choice of Scenarios

In view of the differences in the assumptions on which the two sets of scenarios discussed above were premised, the choice between the scenarios could be seen as a choice between adapting to what is most likely (represented by the KNMI’06 scenarios) or adapting to the plausible worst case (represented by the Delta Committee 2008 scenarios). This is a choice that faces any agency that seeks to incorporate climate change into its strategies and plans. However, it is a choice that cannot be resolved using more updated scientific knowledge. The KNMI website describes the Delta Committee scenario as “an extreme scenario supplementing the existing KNMI’06 scenarios which describe the most likely outcomes”, to be used only for the specific purpose of “long-term safety against flooding” (KNMI, 2012).

After Rotterdam Climate Proof 2010 was published, the Dutch government’s Delta Program developed a set of “Delta Scenarios”, to be used in this national-level program to address both flood protection and freshwater supply for the Netherlands in the long term. The “Delta Scenarios” are based on the KNMI’06 scenarios, combined with socio-economic scenarios (a higher scenario with 2% growth per annum and population increase, and a lower scenario with
slight economic growth up to 2050, followed by a “minor squeeze”, accompanied by population stagnation and decline) as a set of common “uniform forward outlooks”. This indicates that the “most” likely scenarios will guide adaptation planning in the Netherlands, rather than the extreme scenarios.

4.4 USE OF PROJECTIONS IN THE ADAPTATION PLAN AND STRATEGIES

As mentioned earlier, Rotterdam Climate Proof 2010 cited the sea level rise projections from the Delta Scenarios. However, it did not indicate that this was based on the upper-range of estimates or mention the methodology for deriving these projections, including the assumptions and uncertainties embodied within these projections.

Five thematic areas of adaptation were covered in the plan: flood management, accessibility, adaptive building, the urban water system, and the urban climate. Flood management – in terms of “sustainable protection against flooding in the areas inside and outside the levees” – was considered the foremost priority in Rotterdam’s climate adaptation. The other area most relevant to sea level rise was adaptive building. These adaptation strategies are shown in Table 4 below.

TABLE 4: ADAPTATION STRATEGIES RELEVANT TO SEA LEVEL RISE & STORM SURGE IN ROTTERDAM

<table>
<thead>
<tr>
<th>Activities in 2010 and other initiatives</th>
<th>Need for detailed climate change projections</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flood Management</strong></td>
<td></td>
</tr>
<tr>
<td>Study by the “Knowledge for Climate Program” on consequences of climate change with respect to flooding risks and projected damage</td>
<td>High</td>
</tr>
<tr>
<td>Collaboration with Delft University of Technology and “HKV Lijn in Water” on the possibilities for a lockable alternative to protect the Rijnmond-Drechtsteden region</td>
<td>High</td>
</tr>
<tr>
<td>Feasibility study on climate-resilient levees</td>
<td>High</td>
</tr>
<tr>
<td>Perception study on flood protection in Rotterdam</td>
<td>Low</td>
</tr>
<tr>
<td>Flood Control 2015 – research program on real-time flood risk management in an urban environment</td>
<td>Low</td>
</tr>
<tr>
<td>Strengthen all water defences to current standards by 2015</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Adaptive Building</strong></td>
<td></td>
</tr>
<tr>
<td>Design driven research on high water level resilient strategy in four case study locations</td>
<td>Medium</td>
</tr>
<tr>
<td>Research into possibilities for floating constructions in specific harbor basins in Rotterdam</td>
<td>Medium</td>
</tr>
<tr>
<td>Translation of experiences from construction of the Floating Pavilion to other projects</td>
<td>Low</td>
</tr>
<tr>
<td>Establishment and set up of a Floating Buildings Desk</td>
<td>Low</td>
</tr>
<tr>
<td>Plans for floating urban districts within the Stadshavens district, with some 13,000 climate resilient homes, with some 1,200 homes built on water</td>
<td>Medium</td>
</tr>
</tbody>
</table>

(Source: Rotterdam Climate Initiative, 2010, pp. 12-13, 15)
To provide a rough sense of how dependent the strategies were on the local sea level rise projections, I classified these as having a high, medium or low need for detailed climate change projections (see Table 4). Many of the strategies focus on knowledge building rather than implementation, or require implementation at the regional or national level. The specific adaptation actions proposed showed that the precise projections for sea level rise may not have been critical for developing Rotterdam's adaptation strategies this stage.

As shown in Table 4, the proposed activities for flood management in the 2010 program were mainly knowledge-building activities. No specific changes were proposed for flood safety standards or defences. This could be because Rotterdam’s flood management actions have to be considered within the context of regional and national flood management planning. An example of this is the “feasibility survey of the lockable alternative with flexible flood defences for the Rijnmond-Drechtsteden region” that was recommended by the Delta Committee in 2008, with the alternatives being considered as part of the National Water Plan and the Delta Program. In terms of near-term implementation, the aim was for Rotterdam to strengthen all water defences to current standards by 2015 (The Rotterdam Climate Initiative, 2010, p. 12).

Adaptive building refers to floodwater proof construction, and applies to areas outside the levees. The Rotterdam adaptation strategy identified floating buildings as “one example of adaptive buildings that is ideal for Rotterdam”. Unlike the flood protection strategies that are managed at the national level, floating buildings are an adaptation strategy that can be managed at the local level. The construction of the Rotterdam Floating Pavilion provided a landmark for Rotterdam that gained international attention and demonstrated Rotterdam’s technical expertise in this area. The pavilion is climate-proof because “as the water level rises, the floating pavilion will automatically rise accordingly” (The Rotterdam Climate Initiative, 2011). This suggests that uncertainty in the rate of sea level rise does not pose a problem for this form of adaptation, although it is not stated whether there is a “tipping point” beyond which this technology no longer works.

The immediate actions in adaptive building focus on developing designs and pilot projects in case study locations to develop knowledge on various aspects of floating constructions, such as identifying suitable locations to develop floating houses, with the Rotterdam Stadshavens - where some 1,200 out of the 16,000 homes planned by 2040 could potentially be built as floating districts - as one possible location (The Rotterdam Climate Initiative, 2010, p. 15).
The proposed actions in *Rotterdam Climate Proof 2010* are initial adaptation strategies, as Rotterdam plans develop a more detailed "Rotterdam Adaptation Strategy: RAS 2.0" by 2014. RAS 2.0 will aim to make Rotterdam climate proof by 2025 (Ibid. p. 12). This detailed strategy document is intended to align with adaptation planning at the national level – the topic of the next section.

4.5 **LINKAGES WITH NATIONAL ADAPTATION PLANNING**

4.5.1 **FLOOD PROTECTION IN THE NETHERLANDS**

In the Netherlands, the Rijkswaterstaat, under the Ministry of Infrastructure and the Environment, manages the main waterway network and is responsible for flood protection – including maintaining and inspecting flood defences such as “dunes, dams and storm surge barriers and some of the dikes, river dams and riverbanks (Rijkswaterstaat, 2011, p. 19).

Current flood protection standards for the Dutch coast are based on the work of the first Delta Committee, set up by the Dutch government in the wake of the 1953 storm surge disaster that claimed more than 1800 lives and flooded 165,000 hectares of land (VanKoningsveld et al, 2008, p. 374). Tasked with preventing future disasters, the Delta Committee “recommended a series of engineering works to protect low-lying areas, including the closure of several sea inlets, and made plans to reinforce and expand many of the dykes” (Kabat, et al., 2009, p. 450). This extensive program for flood protection was called the “Delta Plan” and the proposed infrastructure projects referred to as the “Delta Works”. The Maeslant Storm Surge Barrier, which protects Rotterdam, was the last of the Delta Works completed in the Netherlands, about 50 years after the plans were first developed.

In general, the design of these coastal defence structures considered natural variability – with safety levels defined with reference to extreme storm surge levels based on observed data covering more than a 100 years. Significantly, design levels “incorporated the consequences of future sea level rise” based on the historical rate of increase in relative sea level rise of 10-20 cm per century over the last few centuries. However, “no acceleration in sea level rise was considered at that time” (VanKoningsveld et al, 2008, p. 374).
Over the course of the implementation of the Delta Plan over the second half of the twentieth century, growing concerns with environmental issues led to a revision to the original plan, to take "a more integrated approach" towards flood protection with "natural values being weighed against socioeconomic interests" (Ibid., pp. 367, 374). This led to the introduction of sand nourishment as a key "protective measure" in 1990 and the movement towards an integrated coastal zone management approach from 2002 onwards.

Since then, partly in response to the projections of accelerated sea level rise, "the strict protection strategy" of the original Delta Plan has evolved to a combined strategy comprising both accommodation and hard protection - the concept of "working with nature", in which soft protection is used to maintain the coastline if applicable (Ibid., p. 378).

In response to concerns regarding climate change, the Dutch government convened the second Delta Committee. As discussed earlier, the Delta Committee considered the implications of sea level rise over the next two centuries based on the "plausible upper limit" scenarios discussed earlier. Considering not only future sea level rise, but also the increase in the value of the interests to be protected due to development that had occurred and was planned within low-lying areas since the first Delta Committee's assessment, the second Delta Committee recommended that "the level of flood protection must be raised by at least a factor of 10 with respect to the present level".

4.5.2 THE DELTA PROGRAM AND THE ADAPTIVE DELTA MANAGEMENT APPROACH

Following the recommendations of the second Delta Committee, the Dutch government created the Delta Program. The Delta Program will develop proposals to be decided on in 2014 in three generic nation-wide programs - flood risk management, freshwater strategy and spatial adaptation, and two area-specific strategies – for the Rhine-Meuse delta (which includes Rotterdam) and the Ijsselmeer region. These are referred to as the "Delta Decisions".

The development of RAS2.0 is expected to contribute to developing regional adaptation strategies for the Rhine-Meuse delta in which Rotterdam is located. The 2014 timeframe for the RAS 2.0 thus dovetails with the timeline for the Delta Decisions. The active participation of Rotterdam in the national-level plans is intended to align the plans and projects within Rotterdam Climate Proof with the national plan wherever possible (The City of Rotterdam, 2011, p. 42).
To support the process, there is ongoing research through the national Knowledge for Climate Research Project, co-financed by the Ministry of Infrastructure and the Environment. The project includes nine studies relevant to Rotterdam, one of the identified “hotspots”, within its first tranche of research (The Rotterdam Climate Initiative, 2010, p. 8).

The Delta Program has adopted an approach called “adaptive delta management” as a response to the uncertainty in climate change impacts. This is defined as “an operating approach designed to transparently include uncertainties around future developments in the decision-process”. For the Delta Program 2012, this means “a focus on 2050, with a forward view to 2100”, rather than implementing interventions “tailored to worst-case scenarios” or taking 2100 as “a fixed end-point”. The approach is described as follows:

Starting with the current situation, this scheme charts out the next decision. Moving further ahead it looks at possible amending or adaptive strategies at a later stage, including conditions under which it would be wise to shift strategies. Next, it focuses on possibilities for linking realization of the strategies with other investment agendas (The Delta Commissioner, 2011, p. 48).

Determining when to shift strategies is tied to the concept of “adaptation tipping points” – beyond which current policies are no longer satisfactory. Based on this approach, the Delta Program report states, “It is not the exact figures for rising sea levels that matter as much as the question of whether or not our current water management and water policy are still satisfactory for the changing climate and if so, for how long” (The Delta Commissioner, 2010, p. 36).

The “adaptive delta management” approach was inspired by the approach taken for the Thames Estuary in the UK – with a series of decisions regarding the Thames Barrier for different levels of sea level rise. The two specific examples used in the Delta Program to detail the concept were: the evaluation of alternative supplementary measures (increased water storage or heightening of dykes) for the South-west delta, and the replacement of the barrages in the Meuse. Like the Thames Barrier, both these examples concern flood protection infrastructure that is managed by a public agency. There are no examples of how this approach may be implemented for other types of adaptation decisions, for instance, construction or zoning regulations that affect many individual private entities.
With this integrated way of developing strategies for flood management involving national, regional and local levels in the Netherlands, the decisions regarding the treatment of uncertainty in sea level rise will be taken at the national level rather than independently at the local level. The "adaptive delta management" approach is not reflected in Rotterdam’s adaptation plan, as it was proposed after the publication of Rotterdam’s adaptation strategy in early 2010.

In the case of Rotterdam, a city-level adaptation plan was produced using projections of local sea level rise developed through a national-level process. In addition, adaptation planning by the city was closely linked to and driven by national adaptation planning. The next chapter on New York City shows a process in which both the projections and adaptation strategies were driven primarily at the city level.
5 CASE STUDY - NEW YORK CITY

5.1 INTRODUCTION

New York City, located on the eastern coast of the United States, has a population of more than 8.2 million within its area of 305 square miles. It has 520 miles of coastline (The City of New York - Department of City Planning, 2011). The proximity to the coast and the concentration of population, economic activity and infrastructure make the city potentially vulnerable to coastal hazards (The City of New York - Office of Emergency Management, 2009).

This chapter begins with an overview of New York's city-wide adaptation efforts, starting with PlaNYC, published in 2007. This is followed by a discussion of the climate change projections developed by the New York Panel for Climate Change (NPCC), and its suggested approaches for adaptation. The next section details how these projections were used in the updated PlaNYC (2011) and covers the adaptation strategies proposed in the plan. The chapter concludes with how the adaptation strategies in PlaNYC (2011) relate to other areas of regulation within New York City, and at the state and federal levels.

5.2 PlaNYC

New York City’s climate change adaptation is part of the City’s long-term sustainability plan, PlaNYC. This plan was developed by the City of New York in 2007 to tackle the challenges of population growth, ageing infrastructure and climate change. It recognized that inaction in the face of climate change was costly, in part, because “cities that don’t have strong climate change strategies in place may face lower credit ratings, increased insurance costs, and reduced bonding capacity” (The City of New York, 2007, p. 139).

Proposed as one of the adaptation initiatives in PlaNYC (2007), the New York City Climate Change Adaptation Task Force was convened in 2008 by the Mayor of New York City, Michael Bloomberg, to “identify climate change risks and opportunities for the city’s critical infrastructure and to develop coordinated adaptation strategies to address these risks” (NPCC, 2010, p. 21). The Task Force consisted of over 40 stakeholders from the public and private sectors. The NPCC was established to advise the Mayor and the Climate Change Adaptation Task Force on climate change and adaptation (NPCC, 2010, p. 14). To do so, it carried out several studies and prepared three guidance workbooks, published in its 2010 report, Climate Change Adaptation in
New York City – Building A Risk Management Response. The findings were incorporated into the update of PlaNYC, released in 2011. The two versions of PlaNYC thus allow for a comparison of the adaptation strategies adopted in New York City before and after a detailed city-scale climate risk assessment study.

5.3 CLIMATE CHANGE PROJECTIONS - THE NPCC'S CLIMATE RISK INFORMATION

5.3.1 STAKEHOLDER INVOLVEMENT

The work of the NPCC was undertaken with reference to the National Research Council's recommended approach of "deliberation with analysis" discussed earlier in Section 2.3 (NPCC, 2010, p. 277). The NPCC recognized that "New York City has the good fortune to include within its boundaries some of the world's leading practitioners of climate science". Hence, local officials can benefit from the resources of "this local knowledge base" in adaptation planning. Conversely, "scientists can learn a great deal about climate change adaptation on an empirical level by working closely with New York City's infrastructure workers, managers, and other professionals" (Ibid. p. 60).

The NPCC took the approach of engaging stakeholders from the New York Adaptation Task Force to "preselect the climate variables most likely to impact urban infrastructure". The Task Force also determined the presentation of climate hazard information – preferring a range of projections to "a single 'most likely' outcome" – as they were familiar with risk management approaches and decision-making using uncertain projections such as "revenues, expenditures and population trends" (Horton et al, 2011, pp. 2247-2249).

5.3.2 TREATMENT OF UNCERTAINTY

The assessment of New York City's risks to climate change was based on climate change projections derived for New York City from the outputs of GCMs. These regional projections were "based on GCM output from the single land-based model gridbox covering New York City and its surrounding area, which are then applied to observed data from the region". The study used the change, rather than absolute values, from the GCMs, as the spatial variation in baseline climate in the surrounding area was larger than the spatial variation of the projected climate changes. In general, the gridboxes applied to approximately ~ 100 miles from New York City, as each GCM had a different spatial resolution ranging from "as fine as ~75 x ~100 miles to as coarse as ~250 x ~275 miles, with an average resolution of approximately 160 x 190 miles" (NPCC, 2010, p. 48).
The NPCC report is explicit about the uncertainties involved in climate change projections. It states, “Climate change projections are characterized by large uncertainties”. These include global scale uncertainties – due to “uncertainties in future GHG concentrations and other climate drivers” and “uncertainties in how sensitive the climate system will be” (NPCC, 2010, p. 44).

The report explains that these uncertainties may be reduced, although not eliminated, “by providing projections that span a range of GCMs and GHG scenarios” (Ibid). The NPCC selected three GHG emissions scenarios, the A2, A1B, and B1 emissions scenarios. These “were used as drivers for many GCMs and available from the World Climate Research Program (WCRP) and the Program for Climate Model Diagnosis and Intercomparison (PCMDI)” (Ibid p. 44). Additionally, the A1FI scenario was discussed qualitatively, but was not included because very few GCM simulations were available. Using the three GHG scenarios and 16 GCMs (7 GCMs for sea level rise), the NPCC developed “local climate change information” for key climate variables – temperature, precipitation, and sea level and associated extreme events (Ibid. p. 44). These were used to create a “48 (16 × 3)-member matrix of outputs for temperature and precipitation”, which provided a “model-based” probability function for each scenario time period and variable (Ibid. p. 50).

Although the approach of using “a suite of GCM simulations and GHG profiles” to provide a range of climate outcomes is described by IPCC as reflecting “the current level of expert knowledge”, in the case of New York City, the range of scenarios used was more limited than the full range of SRES scenarios. This raises the issue of how many model runs are needed to derive a sufficiently robust set of model-based probabilities on which subsequent adaptation decisions are based. Furthermore, the use of these probabilities was accompanied with the following qualifier: “Although the model-based frequency distribution should not be mistaken for the true probability distribution, the model-based quantitative approach provides valuable information for many climate variables” (Ibid. p. 41).

The study recognized that uncertainties are increased in “planning adaptation at the local and regional scale” due to “climate variability” and “local physical processes” that operate at finer scales than captured in the GCMs. While presenting the projections as changes over multi-year time slices (30-year time slices for climatic variables, 10-year time slices for sea level rise) reduces these uncertainties, the report noted the limitations of GCMs in including all relevant local-scale
processes, so that “it is possible that the regional climate of New York City may change in ways not captured by the models, leading to temperature, precipitation, and sea level rise changes outside the model-based range presented” (Ibid. p. 50).

Both types of knowledge uncertainty – parameter uncertainty and model uncertainty are represented in these uncertainties detailed above. The report also mentions other types of uncertainties – “those associated with impacts, adaptations, adaptation policies, and societal factors” (Ibid. p. 33).

5.3.3 SEA LEVEL RISE PROJECTIONS

The NPCC provided two sets of projections for sea level rise. The first used the results from 7 GCMs and considered both global components (thermal expansion and meltwater from ice caps, and ice sheets) and local components (local land subsidence and local water surface elevation). A second set was developed to account for the “potential for land-based ice-sheets to melt owing to dynamic (motion-related) processes. A “rapid ice melt” approach was adopted, using observed trends in melting of the West Antarctic, Greenland ice sheets and “paleoclimatic studies of ice melt rates during the most recent postglacial period’ (Ibid. p. 51) (see Table 5 below). Higher average sea levels were assessed to be “extremely likely” using IPCC’s definitions of probability. In reporting these results, emphasis was placed on the “central range” (i.e. the central 67% range) of these projections - reported in the summary and main report on climate risk information, while the full range was reported only in the Annexes.

**TABLE 5: BASELINE CLIMATE AND MEAN ANNUAL CHANGES RELATIVE TO BASELINE YEARS**

<table>
<thead>
<tr>
<th></th>
<th>Baseline 2000-2004</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sea level rise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Central range)</td>
<td>NA</td>
<td>+1 (2 to 5) 6 in</td>
<td>+5 (7 to 12) 14 in</td>
<td>+9 (12 to 23) 26 in</td>
</tr>
<tr>
<td><strong>Rapid ice melt</strong></td>
<td></td>
<td>~ 5 to 10 in</td>
<td>~19 to 29 in</td>
<td>~41 to 55 in</td>
</tr>
<tr>
<td><strong>scenario</strong></td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Based on 7 GCMs and 3 emission scenarios. Sea level data are from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available). The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections.

2 Minimum, central 67% range, and maximum values from model-based probabilities – rounded to the nearest inch.

3 Based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

(Source: Columbia University Center for Climate Systems Research, in NPCC, 2010, p. 172 & 199)
5.3.4 COASTAL STORMS AND STORM SURGE

Coastal flooding was derived by "superimposing future changes in mean sea level onto the historical data set", using the critical thresholds of the 1-in-10 year, 1-in-100 year and 1-in 500 year floods (Ibid. p. 208). The report noted that unlike the 1-in-10 year flood event, the lack of hourly data from tide gauges with sufficiently long time series meant that different approaches were taken for the more extreme floods (see results in Table 6 below). The report concluded that more frequent and intense coastal flooding and a shortened 100-year flood occurrence were both "very likely" (using IPCC's definitions).

TABLE 6: FULL RANGE OF QUANTITATIVE CHANGES IN EXTREME EVENTS

<table>
<thead>
<tr>
<th>Extreme Event</th>
<th>Baseline</th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1971-2000)</td>
<td>~once every</td>
<td>~once every</td>
<td>~once every</td>
</tr>
<tr>
<td>1-in-10 yr flood to recur, on average</td>
<td>~once every 10 yrs</td>
<td>8 (6 to 10) 10 yrs</td>
<td>3 (3 to 6) 8 yrs</td>
<td>1 (1 to 3) 3 yrs</td>
</tr>
<tr>
<td>Flood heights (in ft) associated with 1-in-10 yr flood</td>
<td>6.3</td>
<td>6.5 (6.5 to 6.8) 6.8</td>
<td>6.8 (7.0 to 7.3) 7.5</td>
<td>7.1 (7.4 to 8.2) 8.5</td>
</tr>
<tr>
<td>1-in-100 yr flood to recur, on average</td>
<td>~once every 100 yrs</td>
<td>~once every 60 (65 to 80) 86 yrs</td>
<td>~once every 30 (35 to 55) 75 yrs</td>
<td>~once every 15 (15 to 55) 45 yrs</td>
</tr>
<tr>
<td>Flood heights (in ft) associated with 1-in-100 yr flood</td>
<td>8.8</td>
<td>8.7 (8.8 to 9.0) 9.1</td>
<td>9.0 (9.2 to 9.6) 9.7</td>
<td>9.4 (9.6 to 10.5) 10.7</td>
</tr>
<tr>
<td>1-in-500 yr flood to recur, on average</td>
<td>~once every 500 yrs</td>
<td>~once every 370 (380 to 450) 470 yrs</td>
<td>~once every 240 (250 to 330) 380 yrs</td>
<td>~once every 100 (120 to 250) 300 yrs</td>
</tr>
<tr>
<td>Flood heights (in ft) associated with 1-in-500 yr flood</td>
<td>10.7</td>
<td>10.9 (10.9 to 11.2) 11.2</td>
<td>11.2 (11.4 to 11.7) 11.9</td>
<td>11.5 (11.8 to 12.6) 12.9</td>
</tr>
</tbody>
</table>

Source: Columbia University Center for Climate Systems Research

The minimum, central range (middle 67%), and maximum of values from model-based probabilities across the GCMs and greenhouse gas emissions scenarios is shown. More information on the methods used to define extreme events can be found in Annex B.

1 Decimal places shown for values less than 1, although this does not indicate higher precision/certainty. More generally, the high precision and narrow range shown here are due to the fact that these results are model-based. Due to multiple uncertainties, actual values and range are not known to the level of precision shown in this table.

5.3.5 LIMITATIONS OF THE PROJECTIONS VIS-À-VIS STAKEHOLDER REQUIREMENTS

The NPCC's interactions with stakeholders, as represented by the New York Adaptation Task Force, helped to produce projections that were of interest to stakeholders. They also revealed that these stakeholders' requirements for climate change information could not be fully catered to given the available science. Horton et al (2011) pointed out that stakeholders “wanted to know the probability of the rapid ice melt scenario relative to the IPCC-based method”. In response, “it was emphasized that such probability statements are not possible given current scientific understanding” (p. 2260).

Furthermore, the current state of extreme event projections that are “so frequently sought by stakeholders for impact analysis” does not yet meet stakeholder requirements, although Horton et al (2011) expect these to improve with the evolution of statistical and dynamical downscaling approaches (p. 2263). Horton et al (2011) concluded with the significant caveat that “The precise projections should not be emphasized given the uncertainties, but they are of sufficient magnitude relative to the historical hazard profile to justify development and initial prioritization of adaptation strategies” (p. 2262).

5.4 THE NPCC’S RECOMMENDATIONS ON ADAPTATION

As the NPCC was convened to give advice on climate change and adaptation, its findings go beyond localized climate projections and included “suggested approaches to create an effective adaptation program for critical infrastructure, including ways to assess risks, prioritize strategies, and examine how standards and regulations may need to be adjusted in a changing climate” (NPCC, 2010, p. 7).

The report recognized the additional complexities created by climate change for urban planning. It stated, “Although urban decision makers are used to managing uncertainty in economic growth and population dynamics, climate change brings further uncertainties due to the evolving nature of the climate system, its potential impacts on many aspects of urban life, and the untested effectiveness of adaptation strategies” (Ibid. p. 14).
To identify at-risk infrastructure and develop adaptation responses, the NPCC recommended the adoption of eight “adaptation assessment steps” (Ibid. p. 239):

1. Identify current and future climate hazards
2. Conduct inventory of infrastructure and assets
3. Characterize risk of climate change on infrastructure
4. Develop initial adaptation strategies
5. Identify opportunities for coordination
6. Link strategies to capital and rehabilitation cycles
7. Prepare and implement adaptation plans
8. Monitor and reassess

Step 1 would be conducted ideally using “a science-based understanding of the risks and uncertainties involved” drawn from the climate change projections for New York City (Ibid. p. 247), while Step 3 focused on the likelihood of the impact on infrastructure and the magnitude of consequence. These formed the basis for the climate risk assessment approach detailed in the next sub-section.

5.4.1 CLIMATE CHANGE RISK ASSESSMENT APPROACH

Referring to the IPCC’s recommendation that “responding to climate change involves an iterative risk management process that includes both adaptation and mitigation, and takes into account climate change damages, co-benefits, sustainability, equity and attitudes to risk”, the NPCC explicitly adopted a risk management approach to the uncertainties in climate change projections (IPCC, 2007; quoted in NPCC, 2010, p. 29).

The risk management approach was adopted because of its advantages such as providing a systematic way of quantifying risks in a manner conducive for analysis using economic-efficiency criteria familiar to city authorities. The risk management approach supported risk-spreading through insurance and viewing investment in adaptation as a form of “hedging” against climate risks (NPCC, 2010, p. 31) This would then support expenditure “to reduce risks from both high-probability events and low-probability events” (Ibid. p. 29). However, there are some caveats as to whether risk-based approaches are appropriate for climate adaptation, at least in part due to the lack of requisite data (Ibid. p. 31-32). Nonetheless, the NPCC recommended taking into account “low-probability but high-risk outcomes when developing risk management strategies even in circumstances when we know little about likelihood” (Ibid.).
The NPCC report uses the term “risk” in two different ways. A formal definition of risk is provided as follows: Risk = the probability of an event multiplied by some measure of its consequence (NPCC, 2010, p. 31). However, the report refers mainly to the evaluation of climate risk is based on what are termed “climate risk factors” — defined as “the subset of climate hazards that are of most consequence for New York City’s infrastructure”. These were not “complete statements of ‘risk’” because they did not explicitly include magnitude of consequences or impacts. Instead, they were based on expert judgment in response to the climate change information (Ibid. p. 159).

To aid stakeholders (agencies and organizations that manage and operate critical infrastructure) in carrying out the risk of climate change on infrastructure, the NPCC developed a risk matrix tool (see Table 7 and Figure 3) comprising these three dimensions:
- The probability of the climate hazard (Step 1 of the Adaptation Assessment Steps)
- The likelihood of an impact (Step 2 of the Adaptation Assessment Steps); and
- The magnitude of consequence should the impact occur (Step 2 of the Adaptation Assessment Steps).

### Table 7: Definition of Risk Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of the Climate Hazard</td>
<td>The general probability for change in a climate hazard occurring over the lifespan of the infrastructure</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Likelihood of Impacts</td>
<td>The likelihood that a given climate hazard will result in infrastructure vulnerability</td>
<td>Virtually certain/ already occurring, High likelihood, Moderate likelihood, Low likelihood</td>
</tr>
<tr>
<td>Magnitude of Consequences</td>
<td>The overall consequence, should an impact occur</td>
<td>Internal operations (to the stakeholder), Capital and operating costs (for the stakeholder), Number of people affected (to the city), Public health and worker safety (to the stakeholder and city), Economy (to the city), Environment (to the city)</td>
</tr>
</tbody>
</table>

(Source: Adapted from Table 3: Defining Risk Factors, NPCC, 2010, p. 251 & 254)
5.4.2 PROPOSED ADAPTATION APPROACH - FLEXIBLE ADAPTATION PATHWAYS

The NPCC recognized that “The multiple facets of climate change hazards, impacts, and adaptation strategies, as well as the uncertainty associated with each, limit our ability to create one standard timeless policy that will work for all situations”. For climate policies, given that the uncertainty in critical parameters such as climate sensitivity are thought unlikely to be narrowed in a timely fashion, flexible, iterative policies were considered more robust than inflexible policies (Ibid. p33).

The NPCC used the concept of “Flexible Adaptation Pathways” to refer to policies that are continuously reassessed using updated information of climate hazards, in order to make repeated “corrections” to readjust the risk trajectory back to an acceptable level in response to changing climatic information. The example cited of this approach in practice is the “series of escalating responses” for the Thames Barrier coastal defences that protect London from coastal storms, in the form of “an iterative decisions tree” calibrated against increasing sea level rise levels. Implicit
in use of ‘Flexible Adaptation Pathways’ is the need to identify ‘triggers’ for action, and to identify monitoring mechanisms (Ibid. p. 34-37).

5.4.3 PROPOSED ADAPTATION ACTIONS - CLIMATE PROTECTION LEVELS

The NPCC highlighted the need “to develop design standards that incorporate climate change projections, a concept referred to as Climate Protection Levels (CPLs), to ensure that infrastructure built today can operate in the future” (Ibid, p. 307). This focused on incorporating climate change into the climate extremes and climate variability accounted for in design and performance standards. Coastal flooding and storm surge were one of four types of hazards that were associated with “major cross-cutting risks to the region” – the others being inland flooding, heat waves and extreme wind events (Ibid, p. 308).

The assessment pinpointed the 1-in-100 year flood defined by the Federal Emergency Management Agency (FEMA) as “the primary standard”, as areas within it have been “subject to special building codes and insurance and environmental regulations” for the last 40 years (Ibid. p313). FEMA “coordinates the federal government's role in preparing for, preventing, mitigating the effects of, responding to, and recovering from all domestic disasters, whether natural or man-made, including acts of terror” (FEMA, 2012). Its Flood Insurance Rate Maps are used to regulate development within flood-prone areas and purchase of flood insurance is mandatory for property located in the Special Flood Hazard Areas demarcated in the maps – areas within the 1 in 100 year flood zone.

To estimate the impact of sea level rise on the 1-in-100 year flood, the NPCC adopted the 90th percentile of model-based projections of sea level rise. For the “rapid ice melt” scenario, the average meltwater estimate of 43 inches per century was added. Adding these to the existing 1-in-100 year FEMA Flood Insurance Rate Maps provided the extent of possible flooding with sea level rise. However, the maps provided presented as being “purely illustrative” - to draw attention areas that could potentially experience the 1-in-100 year flood in the future, including those already at risk and these which will become at risk in the future, as well as areas which are not likely to experience flood risk in the future. While not accurate, these maps helped to support the need to update the current 1-in100 year flood zone used by federal agencies to incorporate projections of sea level rise (Ibid. p. 315-317).
The report notes that “using the 90th percentile of the model-based component of the rapid ice melt scenario in the 2080s provides a very high probability that sea level rise will not exceed the protection level before that time” (Ibid. p315). This seems to be the main rationale for adopting the 90th percentile. However, given that the high-end AIFI scenario is not included, this statement seems to provide more certainty than perhaps is warranted. Also, if the operating principle is to establish a threshold that is unlikely to be exceeded, it seems unnecessary to include the BI scenario of lower greenhouse gas emissions.

The NPCC also called for the updates of FEMA’s Flood Insurance Rate Maps to include updates to the A- and V-zones since these are used to determine construction standards. The other recommendations included:

- Incorporate rapid ice melt sea level rise in the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model used for hazard mitigation planning;
- Incorporate sea level rise projections and potential for more frequent storm events in design standards and regulation governing bridges; and
- Incorporate sea level rise projections into the delineation of New York City Coastal Zone Boundary.

The recommendation to “incorporate sea level rise projections into regulatory maps of coastal areas, including FEMA Flood Insurance Rate Maps, A- and V-zones, and the SLOSH model” was billed as “the single most significant CPL recommendation for coastal flooding and sea level rise.” (Ibid. p. 315). These recommendations to define boundaries suggest that it is possible to determine a specific sea level rise level (e.g. based on the 90th percentile) with which to update relevant boundary maps. However, the NPCC report stops short of making this recommendation, stating, “recommendations for specific CPLs are not included in this workbook as the work required to determine the cost-benefit, feasibility, or environmental impact of potential CPLs was beyond the scope of this work” (Ibid. p. 299). While the determination of specific CPLs may need to be further studied, the emphasis on the “central range” in reporting the sea level rise (and other projections) seems at odds with the decision to adopt the 90th percentile range in specific adaptation actions.

Given the extensive discussion of uncertainty and model-based probabilities in the development of the sea level rise projections, the lack of a fuller discussion on how policy makers should use the
range of sea level rise estimates for different purposes - whether the “central range”, the minimum and maximum, or some other definition (e.g. the 90th percentile used here) means that it is unclear how the climate change projections and their attendant uncertainties should be incorporated in adaptation responses. More fundamentally, it would be problematic to recommend that adoption of any particular CPL, given that the “precise projections” from sea level projections should not be emphasized (Horton et al, p. 2262).

5.5 USE OF PROJECTIONS IN THE ADAPTATION PLAN AND STRATEGIES

The 2011 update to PlaNYC included the findings of the NPCC. The text of the report states, “Our sea levels have already risen a foot in the last 100 years and are projected to rise by up to 10 inches more in the next two decades” (Ibid. p.10). It also highlights that “by mid-century” – “sea levels could rise by more than two feet”. The climate change projections are placed in the context that “New York has always faced climate risks” (Ibid. p. 150).

PlaNYC (2011) understated the uncertainties in the projections since it showed only the “central range” in the estimates of sea level rise, the rapid ice-melt scenario and the average recurrence rate of the 1-in-100 year flood included in the report (The City of New York, 2011, p. 154). Furthermore, although the NPCC projections were intended to be a common set of projections to be used for planning, PlaNYC does not state whether adaptation initiatives should seek to address the model-based sea level rise scenarios or also the higher rapid ice-melt scenario.

The updated PlaNYC (2011) contains an extensive list of initiatives for climate change adaptation. The table that follows lists those that respond to sea level rise and/or storm surge. Using the same approach as for Rotterdam, I classified each of the strategies as having a high, medium or low need for detailed climate change projections, to provide a rough sense of how dependent the strategies were on the NPCC’s detailed sea level rise projections.
### TABLE 8: ADAPTATION STRATEGIES RELEVANT TO SEA LEVEL RISE & STORM SURGE IN PlaNYC

<table>
<thead>
<tr>
<th>Initiatives and Milestones</th>
<th>Need for detailed climate change projections</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assess Vulnerabilities and Risks from Climate Change</strong></td>
<td></td>
</tr>
<tr>
<td>Regularly assess climate change projections</td>
<td>High</td>
</tr>
<tr>
<td>Partner with FEMA to update Flood Insurance Rate Maps to represent current climate exposure*</td>
<td>Low</td>
</tr>
<tr>
<td>Develop tools to measure the city's current and future climate exposure</td>
<td></td>
</tr>
<tr>
<td>- Climate risk assessment tool</td>
<td>High</td>
</tr>
<tr>
<td>- Updated digital elevation model using LIDAR data</td>
<td>Low</td>
</tr>
<tr>
<td>- Publicly available projected flood maps that incorporate sea level rise projections for planning purposes</td>
<td>High</td>
</tr>
<tr>
<td><strong>Increase the Resilience of the City's Built and Natural Environment</strong></td>
<td></td>
</tr>
<tr>
<td>Update regulations to increase the resilience of buildings</td>
<td>Medium</td>
</tr>
<tr>
<td>- Study on urban design implications of enhanced flood protection for buildings, followed by exploration of amendments to the Zoning Resolution</td>
<td>Medium</td>
</tr>
<tr>
<td>- Pursue amendments to Building Code on freeboard requirements to require freeboard for a wider range of buildings to account for climate change projections</td>
<td>Medium</td>
</tr>
<tr>
<td>- Incorporate consideration of climate change within the policies of the City's Waterfront Revitalization Program (WRP)</td>
<td>Medium</td>
</tr>
<tr>
<td>- Launch study on effects of rising water tables, inland flooding, wind and extreme heat events on buildings</td>
<td>High</td>
</tr>
<tr>
<td>Work with insurance industry to develop strategies to encourage use of flood protection in buildings</td>
<td>Medium</td>
</tr>
<tr>
<td>Protect New York City's critical infrastructure</td>
<td></td>
</tr>
<tr>
<td>- Complete Climate Change Adaptation Task Force assessment and report and begin to implement its recommendations*</td>
<td>High</td>
</tr>
<tr>
<td>- Assess the opportunities for the incorporation of climate change projections into design specifications and standards for critical infrastructure</td>
<td>High</td>
</tr>
<tr>
<td>Identify and evaluate city-wide coastal protective measures</td>
<td></td>
</tr>
<tr>
<td>- Develop an inventory of best practices for enhancing climate resilience in coastal areas</td>
<td>Low</td>
</tr>
<tr>
<td>- Coordinate with academic institutions, scientists, engineers, and designers to develop pilot projects to test potential strategies and evaluate their costs and benefits</td>
<td>High</td>
</tr>
<tr>
<td><strong>Increase City's Preparedness for Extreme Climate Events</strong></td>
<td></td>
</tr>
<tr>
<td>Integrate climate change projections into emergency management and preparedness</td>
<td>Medium</td>
</tr>
<tr>
<td>- Integrate climate change projections into the City's emergency management and preparedness plans and procedures</td>
<td>Medium</td>
</tr>
<tr>
<td>- Launch a process to include climate change as a hazard assessed under the Natural Hazard Mitigation Plan</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Create Resilient Communities Through Public Information and Outreach</strong></td>
<td></td>
</tr>
<tr>
<td>Work with communities to increase their climate resilience</td>
<td></td>
</tr>
<tr>
<td>- Ensure that outreach efforts target appropriate communities and provide up-to-date climate risk information*</td>
<td>Medium</td>
</tr>
<tr>
<td>- Improve the access to publicly available data on the locations of hazardous material storage in flood zones throughout the city</td>
<td>Low</td>
</tr>
</tbody>
</table>

*Indicates strategies found in PlaNYC (2007)

(Source: The City of New York, 2011, pp. 150-159, 196-197)
As shown in Table 8, some of the strategies such as developing a climate risk assessment tool and developing publically available projected flood maps that incorporate sea level rise depend very much on the precise figures that result from a detailed set of projections. However, there are several initiatives where it seems the key task is to consider how the consideration of climate change can be incorporated into existing regulations such as the Zoning Code, Building Code, Waterfront Revitalization Program and the Natural Hazard Mitigation Plan. It is conceivable for these relevant regulatory areas to be identified and the work on assessing how climate change projections can be integrated e.g. through freeboard requirements in the Building Code, even with a general set of climate change projections. Finally, there are initiatives relating to updating of current information, such as updating FEMA’s Flood Insurance Rate Maps to current data, developing an updated digital elevation model using LIDAR data, and improving access to publically available data on the locations of hazardous material storage in flood zones throughout the city, that do not depend on climate change projections. A few of the strategies, such as updating the Flood Insurance Rate Maps, were in PlaNYC (2007), before the detailed climate change projections were developed, while others were developed into further detail, for instance, narrowing down the amendments to the Building Code being considered to freeboard requirements.

Although the NPCC’s recommendations on CPLs called for the incorporation of sea level rise projections into “the regulatory maps of coastal areas” including FEMA Flood Insurance Flood Maps, the PlaNYC strategies call for this only for the city-level regulations, such as the Waterfront Revitalization Program. This could reflect the institutional realities that city officials may be more attuned to. However, as discussed in the next section, this means an added layer of local regulations is needed to implement adaptation to climate change, over and above the required building or construction guidelines pertaining to the current climatic hazards recognized in the Flood Insurance Rate Maps.

In addition to these regulatory changes, PlaNYC (2011) recommended developing an inventory of best practices for enhancing climate change resilience and to collaborate with “academic institutions, scientists, engineers and designers to develop pilot projects to test potential strategies and evaluate their costs and benefits. The report cited the example of the On the Water: Palisde Bay project as a new, creative solution to increasing climate resilience. This project drew on the projections developed by the NPCC and explored soft infrastructure solutions that meet
both storm protection and ecological concerns, as an alternative to traditional hard engineering solutions (Nordenson, Seavitt, & Yarinsky, 2010).

The conclusion of the section on climate change in PlaNYC (2011) states: "Our strategy will remain flexible so it can be adapted to changing needs, but we are taking steps now that have tangible benefits today and will have even greater benefits as the climate changes" (The City of New York, 2011, p. 159). This suggests that the need for action is rooted in improving resilience to current climate hazards, rather than in anticipation of future hazards, and that considering the future serves mainly to confirm that that the actions taken are needed since the impacts of climate hazards will worsen further with climate change. Also, despite the mention of a flexible strategy, responding to changing needs does not quite capture the concept of the "Flexible Adaptation Pathways" recommended by the NPCC, with an "iterative decision tree". Operationalizing the concept would need to occur within each initiative since it is not done at the level of the overarching sustainability and climate change action plan.

### 5.6 Linkages with Federal and Other Local Regulatory Areas

As shown in Table 8, the adaptation strategies proposed in PlaNYC (2011) to respond to sea level rise refer to several areas of existing regulation. These are:

- FEMA's Flood Insurance Rate Maps
- The Building Code
- The Zoning Resolution
- The Natural Hazard Mitigation Plan
- The Waterfront Revitalization Program

These show that operationalizing the consideration of future sea level rise in the planning and development for New York City's coastal areas will need to take place through amendments and changes to existing regulations. These are detailed in the sub-sections that follow.

#### 5.6.1 FEMA's Flood Insurance Rate Maps

The FEMA Flood Insurance Rate Maps for New York "have not been significantly revised since 1983" and sea levels have since already risen by three inches (The City of New York, 2011, p. 155). The initiative in PlaNYC to work with FEMA to update the Flood Insurance Rate Maps for New York to current levels will help to respond to current climate hazards, but not anticipate future ones. However, the anticipated future increases in sea levels give added urgency to minimally have the flood maps up-to-date.
Incorporating sea level rise or storm surge due to climate change into the regulation of developments city-wide without revising the FEMA Flood Insurance Rate Maps to include climate change would require a separate set of local regulations. For instance, city infrastructure agencies potentially have the discretion to exceed FEMA defined standards in their own operations e.g. relocating facilities, raising street entrances into the transit system to prevent flooding etc.

5.6.2 THE BUILDING CODE AND ZONING RESOLUTION

City-wide, the Building Code sets out the requirements for flood-resilient design for developments within the flood-prone zones identified in the FEMA Flood Insurance Rate Maps. The Base Flood Elevation used in the Code is “the elevation of the base flood, including wave height, as specified on FEMA Flood Insurance Rate Map 360497”. Additional elevation above this level is known as “freeboard”. The Code was recently reviewed, and in respect to provisions that address flooding, the revised 2008 code “clarifies current flood regulations and adopts the latest national standards, meeting or exceeding state and federal flood regulations” for construction within flood zones”. It requires the elevation of critical facilities such as fire stations and hospitals, to protect the structures” (The City of New York - Office of Emergency Management, 2009, Section III, p. 58).

Since FEMA's Flood Insurance Rate Maps are not expected to include sea level rise projections, inclusion of future sea level rise in the regulations governing the construction of buildings is being pursued through the expansion of freeboard requirements. The PlaNYC adaptation strategies include pursuing amendments to widen the range of buildings for which freeboard is required, and also considering whether zoning changes are needed because “in some locations zoning height limits can restrict a building from providing freeboard” (The City of New York, 2011, p. 156.)

5.6.3 THE NATURAL HAZARD MITIGATION PLAN

New York City has in place a comprehensive Natural Hazard Mitigation Plan. This plan was approved by FEMA and formally adopted by the City in 2009, making New York City eligible for federal mitigation funding. Drawing from the list of hazards in the 2008 New York State Standard Multi-Hazard Mitigation Plan, the planning team considered which hazards would affect the “facilities or operations” of the agencies represented in the Steering Committee and concluded on the following hazards to be included in the New York City Hazard Mitigation Plan: (1) Coastal Erosion (2) Coastal Storms (3) Drought (4) Earthquakes (5) Extreme Temperatures (6) Flooding
Like the Building Code, the Natural Hazard Mitigation Plan relies on FEMA’s Flood Insurance Rate Maps to show the extent of flood-prone zones. To evaluate the flood hazard, “the extent of a 100-year flood was delineated horizontally using FEMA Digital Flood Insurance Rate Map boundaries and vertically using a New York City digital elevation model” (Ibid. p. 71). To predict the effects of storm surge during coastal storms, OEM used a computer model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes). The area that may experience flooding from storm surge covers a larger area than the 100-year floodplain defined in the FEMA Flood Insurance Rate Maps as it “represents locations that experience natural coastal flooding, which may be unrelated to hurricanes” (Ibid. p. 83).

PlaNYC proposes to include climate change as a hazard in the review of the plan, which is due to be updated in 2014. Hence, like the recommendations for “freeboard” in the Building Code, it seems that the approach taken is to consider climate change over and above current flooding hazards, rather than integrate the consideration of climate change in the evaluation of flooding or coastal storms.

5.6.4 THE WATERFRONT REVITALIZATION PROGRAM

The Waterfront Revitalization Program (WRP) is the city’s principal coastal zone management tool and establishes the city’s policies for “development and use of the waterfront”. The WRP adopted in 1982 was the local implementation of the State of New York’s Waterfront Revitalization and Coastal Resources Act, which was adopted in 1981. This was in response to the federal Coastal Zone Management Act of 1972, which established the Federal Coastal Zone Management Program. The Department of City Planning of New York developed a comprehensive waterfront plan in 1992 to guide land use along the waterfront, and as a foundation for the subsequent revision of the WRP in 2002. (The City of New York - Department of City Planning, 2002).

The Coastal Zone Management Act was amended in 1990 to state that, “because global warming may result in a substantial sea level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence” (16 U.S.C. 1451, et seq.). In 2010, the Office of Ocean and Coastal Resource Management in the National Oceanic and Atmospheric
Administration (NOAA) which administers the program, released a guidance document “Adapting to Climate Change: A Planning Guide for State Coastal Managers”.

In line with directions at both the federal and state levels to respond to sea level rise, and with the focus of the City of New York on climate change adaptation, the new comprehensive waterfront plan, Vision 2020, released in March 2011, includes as one of its eight broad goals: “Identify and pursue strategies to increase the city’s resilience to climate change and sea level rise.” (The City of New York - Department of City Planning, 2011, p. 7). The report states, “The New York City Panel on Climate Change projects that by the 2050s, sea levels could be 12 inches higher than they are today or, in the event of rapid melting of land-based polar ice, as much as 29 inches higher than today. By the 2080s, increases of up to 23 to 55 inches are projected.” – referring to the central range of the model-based projections and the rapid ice melt scenario. It discusses the implications of sea level rise scenarios on New York City’s diverse waterfronts, and provides an overview of possible strategies for resilience – covering retreat, accommodation and protection, and the need for a “wide range of potential strategies” to deploy as appropriate in different contexts (Ibid. p. 111).

The specific recommendations for climate resilience in Vision 2020, such as studying best practices, and zoning and building code changes to promote freeboard, were largely incorporated into PlaNYC’s adaptation strategies. As with earlier revisions of the comprehensive waterfront plan, this plan is also intended to be the foundation for revising the next WRP. The incorporation of climate change within the revised WRP can thus be seen as following through with both the federal direction to anticipate and plan for sea level rise in coastal zone management, as well as the city-level adaptation plan.

This chapter showed how the city of New York carried out its climate risk assessment study and incorporated the results in the climate change section of the updated PlaNYC (2011). The next and final chapter provides a comparative analysis of the two case studies and concludes with the implications of the findings.
6 DISCUSSION AND CONCLUSIONS

6.1 DISCUSSION

6.1.1 SIMILARITIES AND DIFFERENCES

The case studies of Rotterdam and New York describe how two cities have used sea level rise projections in the formulation of their climate change adaptation strategies. The cities share obvious similarities that make a comparison reasonable. They are both coastal port cities in developed countries, and are potentially vulnerable to sea level rise. Both of these cities published adaptation “action plans” – documents detailing the city’s adopted policies on adaptation.

However, on closer examination, there are significant differences between the two cities. In terms of physical vulnerability to sea level rise, Rotterdam is largely protected by large-scale coastal protection defences, including the Maeslant Storm Surge Barrier, levees and dunes. In contrast, New York does not have large coastal protection structures, although some parts of its coast, particularly maritime and industrial areas have hard erosion protection such as bulkheads.

Institutionally, the responsibilities at the local level for the coastal flood protection also differ. The coastal defences that protect Rotterdam, also protect its surrounding region, the Rhine-Meuse region, and are managed at the national level. In contrast, New York City’s flood protection in the form of restrictions on development within flood prone areas is implemented through local building regulations, and its coastline is managed largely at the local level. The case studies show that institutional factors exert significant influences on how each city’s used climate change projections in developing its adaptation strategies.

6.1.2 COMPARISON OF LOCAL CLIMATE CHANGE PROJECTIONS AND ASSESSMENTS AND TREATMENT OF UNCERTAINTY

Rotterdam adopted national-level projections of sea level rise for the Dutch Coast in its adaptation plan, whereas New York undertook its own extensive climate risk information study at the city-scale. Both studies emphasized the use of the state-of-the-art scientific knowledge and the involvement of leading experts. The sets of projections were “local” sea level rise projections as they considered influences that operate at the regional or local scale, such as land subsidence, in addition to global mean sea level rise.
As shown in Table 9, *Rotterdam Climate Proof 2010* used projections from a study by local and international scientific experts, Vellinga et al (2008), which had been commissioned by the Delta Committee – an advisory body convened by the Dutch government to develop recommendations on flood protection with a long-term horizon. Further detailed region-specific climate impact studies to be carried out for the Rotterdam region will also be supported at the national level, through the “Knowledge for Climate” research project.

In New York, *PlaNYC* (2007) recommended starting the process to develop a comprehensive climate change adaptation policy – including the detailed risk assessment for the city. The New York Panel on Climate Change was then convened by the Mayor of New York to conduct a detailed assessment of climate change risks for the City of New York, and provide advice to the Mayor and the New York Climate Change Adaptation Task Force. The NPCC’s findings were published in 2010 and were included in the updated *PlaNYC* (2011).

**TABLE 9: COMPARISON OF LOCAL SEA LEVEL RISE PROJECTIONS**

<table>
<thead>
<tr>
<th>Scale of local assessment used</th>
<th>Rotterdam Climate Proof 2010</th>
<th>PlaNYC 2011 update</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Dutch Coast</td>
<td>New York City</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Source of local climate information used</th>
<th>Rotterdam Climate Proof 2010</th>
<th>PlaNYC 2011 update</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Stakeholder requirements</th>
<th>Rotterdam Climate Proof 2010</th>
<th>PlaNYC 2011 update</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper-end of plausible scenarios</td>
<td>Range of values rather than single &quot;most likely&quot; outcome</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Types of uncertainty considered in the projections</th>
<th>Rotterdam Climate Proof 2010</th>
<th>PlaNYC 2011 update</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Incomplete or imperfect observations&lt;br&gt;- Incomplete conceptual frameworks&lt;br&gt;- Inaccurate prescriptions of known processes&lt;br&gt;- Chaotic, or inherently unpredictable responses&lt;br&gt;- Lack of predictability due to non-physical factors (e.g. policy-decisions, socio-economic factors affecting GHG emissions).&lt;br&gt;- Future GHG projections&lt;br&gt;- Model uncertainty - climate sensitivity&lt;br&gt;- Climate variability&lt;br&gt;- Uncertainties in impacts, adaptations, adaptation policies, and societal factors</td>
<td>Use of an ensemble of climate models with different estimated ocean thermal expansion. Use of 7 GCMs for sea level rise</td>
<td>Use of GCM outputs for A2, A1B and B1 projections. A1FI not modeled, as few GCM simulations were available, but was described qualitatively where relevant.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Approach to uncertainty in future GHG emissions (parameter uncertainty)</th>
<th>Use of a range of future temperature increases, corresponding to the A1FI scenario</th>
<th>Use of GCM outputs for A2, A1B and B1 projections. A1FI not modeled, as few GCM simulations were available, but was described qualitatively where relevant.</th>
</tr>
</thead>
</table>

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Uncertainty was a central issue in the background scientific reports on sea level rise in both cities. Different types of uncertainty were identified (see Table 9) covering both parameter uncertainty (from uncertainty in future greenhouse gas emissions) and model uncertainty. This supports the classification of climate change impact projections as "post-normal science" defined by Functowicz and Ravetz (1993) as being characterized by both high uncertainty and high decision stakes, and in which a greater engagement of stakeholders is beneficial.

The sea level rise projections for the Dutch Coast by Vellinga et al (2008) and the sea level rise projections for New York City by the NPCC were both shaped to some extent by the requirements of stakeholders. The Delta Committee decided that the upper-end of the range of plausible scenarios was appropriate for its purpose of assessing the long-term implications of climate change on the Netherlands for several generations. Thus, the team of scientific experts they commissioned was asked specifically to explore the upper range, leading to the adoption of a range of global mean temperatures that corresponded to the high-end A1FI scenario. In New York, the mandate for the NPCC was to provide climate change projections for New York City. The NPCC engaged its stakeholders, the New York Adaptation Task Force, to preselect the relevant variables for the projections and also established that stakeholders preferred a range of projections to "a single 'most likely' outcome". The main report focused on the central range estimates (i.e. the central 67% of the full range of projections), with the full range was reported only in the Annexes. However, the approach of focusing on the most likely range was not applied throughout the study, since the illustrative flood maps that the NPCC developed were based on the 90th percentile of the model-based projections for sea level rise.

Decisions regarding how to treat the range of plausible estimates — whether to use the "most likely" part of the range or the "worst case" — are significant as these would have implications on the specifics of adaptation strategies e.g. design flood heights. Hence, in addition to considering the scale-relevance of climatic projections, local authorities would also have to consider how to define the range of plausible outcomes that is salient to the adaptation issue at hand. This issue does not seem to be discussed in the literature, where the concern is with uncertainty in general, as well as the lack of scale-relevant data for urban adaptation — both in terms of spatial scale (sufficiently high resolution) and temporal scale (information about extreme weather events).
Technical approaches were employed in both studies to address uncertainty (see Table 9). Given the uncertainty in the level of greenhouse gas emissions, Vellinga et al (2008) adopted the approach of using a range of future temperature increases as input to the models on the various contributors to sea level rise to develop the Delta Committee scenarios. This range corresponded to the A1FI scenario, which was appropriate since the interest was in the 'upper end' of plausible scenarios. The NPCC took the approach of using three different emission scenarios, A2, A1B and B1, in its GCM simulations, and describing the A1FI qualitatively where relevant since there were few GCM simulations available.

The general response in both cities to the issue of model uncertainty was to use many models in the projections, following the approach taken by the IPCC. This is a resource-intensive approach. Rotterdam leveraged on a study initiated at the national level, while the assessment for New York was supported by a generous contribution from the Rockefeller Foundation and drew on the expertise of New York-based academic institutions.

In addition to the uncertainties in the GCM-based simulations, a significant contributor of uncertainty to sea level rise was the limited understanding of the melt rates of the Greenland and Antarctic ice sheets. Since the Delta Committee was concerned with the upper-end range of values, the scenario developed by Vellinga et al (2008) included accelerated melting of these ice sheets. For the NPCC, an estimate of rapid ice melt was added to the model-based results, to create a separate scenario. Horton et al (2011) document that stakeholders wanted to know the relative probabilities of these two scenarios. However, such a comparison could not be made on the basis of available science.

Fundamentally, there is an inherent tension between developing detailed scientific projections for the purpose of guiding adaptation decisions, and yet, due to the uncertainties and assumptions involved, de-emphasizing the use of the specific values that result from these studies in adaptation decisions. The concept of focusing instead on adaptation tipping points, recommended by the Delta Commissioner in the Netherlands, could be a way in which to avoid an over-emphasis on the outputs of climate change impact projections. Ironically, it may be more difficult in the case of New York, with its emphasis on detailed city-scale projections, to consider only the relative magnitudes of the projections and not emphasize "precise projections" (Horton et al, 2011, p. 2262). While close interaction between the scientific experts and stakeholders may help create
awareness of the appropriate use of the projections, there is still a significant gap between the requirements of stakeholders and the current state of climate science.

6.1.3 COMPARISON OF ADAPTATION PLANS AND STRATEGIES

In reporting the local sea level rise projections, the adaptation plan documents in both cities understate the uncertainties involved in the projections. Rotterdam Climate Proof 2010 stated that, “Dutch experts project a sea level rise between 65 and 130 cm by the year 2100 for the Dutch coast (compared with the level in 1990)”, without indicating that this was based on the upper-range of estimates. PlaNYC (2011) highlighted the central range of values from the NPCC study, with a note to explain that this represented “the middle 67% of values from model-based probabilities” (p. 154). However, the model-based scenarios only covered three emissions scenarios, but not the A1FI scenario.

Table 10 summarizes the proposed adaptation strategies adopted in the two cities. It shows that many of the proposed adaptation measures were not heavily dependent on the detailed estimates of future sea level rise. For example, strategies to build local knowledge and capacity, and strategies to reduce vulnerability to the current risks of coastal flooding, could have been undertaken on the strength of existing knowledge.

In fact, some of the strategies in PlanNYC (2011) — on updating the Flood Insurance Rate Maps and conducting outreach efforts to local communities — had been proposed in the earlier PlanNYC (2007). PlanNYC (2007) had also proposed some initial strategies to increase resilience such as amending the building code. This was further detailed in PlanNYC (2011) as focusing on the urban design implications of the more extensive use of freeboard and the need to resolve the conflict between provision of freeboard and zoning height limits.
TABLE 10: COMPARISON OF PROPOSED ADAPTATION STRATEGIES FOR SEA LEVEL RISE

<table>
<thead>
<tr>
<th>Building Adaptive Capacity</th>
<th>Rotterdam Climate Proof 2010</th>
<th>PlaNYC (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk and vulnerability assessment</td>
<td>- Study on flooding risks and projected damage - Perception study on flood protection</td>
<td>- Update projections - Develop climate risk tools - Study on impacts on buildings</td>
</tr>
<tr>
<td>Study on feasibility of possible adaptation measures</td>
<td>- Study on lockable flood protection - Study on climate-resilient levees - Research on high water level resilient strategy - Research on floating constructions - Plans for floating urban districts in Stadshavens</td>
<td>- Inventory of best practices - Pilot projects - Study on urban design implications of increased flood protection – more extensive freeboard requirements</td>
</tr>
<tr>
<td>Build local knowledge and capacity</td>
<td>- Translation of experiences from Floating Pavilion to other projects - Floating Buildings Desk</td>
<td>- Work with local insurance industry to develop strategies to encourage use of flood protection - Outreach efforts to local communities - Make accessible data on hazardous material storage in flood zones</td>
</tr>
<tr>
<td>Increasing resilience to climate risks (Current climate)</td>
<td>- Real-time flood risk management - Strengthen water defences to current standards</td>
<td>- Update Flood Insurance Rate Maps</td>
</tr>
<tr>
<td>Increasing resilience to future climate risks</td>
<td></td>
<td>- Incorporate climate change considerations into Waterfront Revitalization Program - Integrate climate change into emergency management and preparedness</td>
</tr>
</tbody>
</table>

Innovative design approaches are being explored in both cities to increase resilience to rising sea levels. Rotterdam has proposed an approach of adaptive building – designing the areas that are outside the levees to resistant to high water levels, in particular through floating buildings. Several of the city’s adaptation strategies support this effort. The experience from building the Floating Pavilion is being shared to other projects and the city has set up a Floating Buildings Desk to facilitate floating construction. This is coupled with research on floating constructions – including design driven research in four case study locations. The end objective is to develop floating urban districts within the Stadshavens district by 2040. PlaNYC (2011) cited the example of the On the
Water: Palisde Bay project, which explored soft infrastructure options to mitigate storm surge, as a new, creative solution to increasing climate resilience. The plan proposed to develop pilot projects in collaboration with "academic institutions, scientists, engineers and designers" (p. 158). Floating buildings and soft infrastructure could be seen as design responses to variable and uncertain sea levels.

At a general level, the need for flexible adaptation policies in the face of uncertainty was recognized in both cities. Rotterdam Climate Proof 2010 was described as having "a focus on flexibility and resilience". The Dutch Delta Program proposed the approach of "adaptive delta management" for adaptation planning in the Netherlands. For New York, the NPCC proposed the concept of "flexible adaptation pathways". These approaches were modeled on the flexible approach adopted for the Thames Barrier in Greater London, with various flood risk management options for different heights of sea level rise. However, there is little discussion on how the specific adaptation strategies proposed in the adaptation plans for Rotterdam and New York would be adjusted and readjusted, in response to changing information on actual or expected sea level rise, for instance, in determining how much freeboard to require in New York or how to update the level of flood protection for Rotterdam.

6.1.4 THE DIFFERING ROLES AND RESPONSIBILITIES OF LOCAL AUTHORITIES IN ADAPTATION

Although both Rotterdam and New York have produced adaptation "action plans" at the city-scale, the roles and responsibilities for coastal flood protection are quite different in each of the two cities. Rotterdam's large-scale coastal protection defences, including the Maeslant Storm Surge Barrier, the levees and dunes, are regulated and managed at the national-level. There is thus no pressing need for the City of Rotterdam to take the lead in integrating climate change projections into adaptation, as this would be done at the national level, through the Delta Program. Hence, adaptation strategies at the local level emphasize active participation in the national-level Delta Program, including the detailed studies for the Rhine-Meuse delta region, to ensure that local plans are aligned with the national plans. The proposed detailed studies for the Rhine-Meuse delta listed in Rotterdam's adaptation plan will also be undertaken through a research program, "Knowledge for Climate", that is supported at the national level.

In contrast, the responsibility for protecting New York against increasingly severe and frequent coastal floods in a changing climate will need to be taken primarily at the local level. While federal
regulations under FEMA set out the baseline flood protection, the Flood Insurance Rate Maps are expected to be updated only to current sea levels. This means that additional requirements to build resilience to climate change will need to be imposed on top of what is required by federal flood protection regulations at the local level.

The case studies suggest that the preparation of city-scale adaptation plans is motivated not only by the need for local authorities to take adaptation action, but also by other considerations, in particular the external positioning of the city. For Rotterdam, one of the key motivations for developing a city-scale adaptation plan was the potential economic spin-off from profiling the city's expertise in water management, including technologies such as floating construction. For New York, PlaNYC (2007) cited the financial implications that cities without strong climate strategies may face due to poor credit ratings.

6.1.5 LIMITATIONS OF THIS RESEARCH AND SUGGESTIONS FOR FUTURE RESEARCH

These findings were based on case studies of only two cities – Rotterdam and New York. As discussed earlier in this chapter, the institutional and political structures in these cities proved to be a significant point of contrast that influenced the process by which sea level rise projections were obtained for developing the local adaptation plans, as well as how these projections were factored into the adaptation strategies for the cities. Exploring this aspect systematically would require a larger sample of cities. These could be drawn from the list of shortlisted coastal cities in Section 3.3 that are considered to be leaders in adaptation – Cape Town, Durban, London and Miami. Further research could consider a sample based on a country-level comparison, with a small number of cities for each country as case studies.

A related limitation was the focus on published documents from the cities on their adaptation strategies, i.e. the adaptation plans, following the approach adopted in other studies such as Katich (2009) and Vrojilks, Spatofore and Mittal (2010). While the current study sought to consider the wider institutional context by considering the linkages to other areas of adaptation planning mentioned in the adaptation plans, these may still not encompass the full range of actions being undertaken to reduce vulnerability, as these may be taken by other departments or levels of government, or may simply not be fully documented within the published plans.
6.2 CONCLUSIONS

This thesis has investigated how the cities of Rotterdam and New York have used sea level rise projections in formulating their published adaptation plans. This concluding section discusses the implications of the findings for adaptation in cities. Firstly, cities can make use of a variety of approaches to obtain climate change impact assessments for local adaptation planning. The choice between city-level and national or regional-level approaches would depend on institutional and political structures. Secondly, alternative assessment approaches that are less dependent on specific climate impact projections should be adopted in city-scale adaptation planning. This is necessary because detailed local sea level rise assessments are unable to produce precise figures for use in adaptation planning due to the inherent uncertainties in climate change science. Thirdly, a broad understanding of the potential local impacts of sea level rise can provide sufficient support for the need for take adaptation action, in particular, to reduce known vulnerabilities to coastal hazards such as storm surge. Many of the adaptation strategies that cities could take do not require detailed local sea level rise projections. Finally, building resilience for future climate change will require new approaches in both policy formulation and design responses that emphasize flexibility to respond to uncertain sea level rise and storm surge events.

As discussed in the literature review, the increased attention being paid to urban adaptation planning is linked to an emphasis on rigorous and in-depth city-scale climate change impact assessments. Both Rotterdam and New York made reference to local sea level rise projections in their adaptation plans. As Carmin and Dodman (forthcoming) observed, cities use a variety of approaches to obtain climate change impact assessments for adaptation planning. Rotterdam is an example of a city that relied on available national-scale sea level rise projections, using the projections by Vellinga et al (2008) that had been commissioned by the Delta Committee. Subsequent research for Rotterdam and the Rhine-Meuse region in which Rotterdam is located will be driven at the national level through the “Knowledge for Climate” project. New York is an example of a city that commissioned an extensive city-specific climate change impact study – the research carried out the New York Panel on Climate Change (NPCC).

The case studies show that institutional and political structures are significant in influencing the processes by which cities obtain climate change impact assessments for adaptation planning. In the Netherlands, coastal flood protection is managed at the national and regional levels, and the
response to climate change is being reviewed through the Dutch Delta Program. In contrast, New York's coastal flood protection and coastal management is implemented mainly at the city-level.

Local sea level rise assessments provide a better understanding of the local and regional components of sea level rise, such as land subsidence. These would help policy-makers understand what the projections of global mean sea level rise could mean at the local scale. The literature suggests that interactions between the scientific community and the policy-making community promote learning and help produce decision-relevant information (Functowicz & Ravetz, 1993; NRC, 2009; Corfee-Morlot et al. 2011). In the two case studies, the sea level rise projections conducted by scientific experts were influenced by the requirements of stakeholders. The Delta Committee requested sea level rise projections at the upper-end of the range of plausible estimates, and this determined to a large extent, the parameters and assumptions used by Vellinga et al. (2008) to develop the sea level rise projections. The New York Adaptation Task Force determined the relevant variables for the NPCC to focus on and asked for a range of projections, rather than a single value. Such interactions provide opportunities for an exchange of knowledge that builds up local capacity (Horton et al., 2011). However, some of the learning concerned issues in climate science in general, such as whether relative probabilities could be assigned to different scenarios, rather than issues specific to the local assessment. An important practical implication that this raises for cities considering commissioning specific studies, is the benefit of interaction between the scientific community and the policy-making community prior to a commissioned study – so that more targeted research may be commissioned.

The findings support the case that uncertainty is a central issue in developing sea level rise projections. This was recognized in the scientific reports by Vellinga et al. (2008) and by the NPCC (2010). In developing local sea level projections, technical methods were employed to address parameter uncertainty and model uncertainty. In the study for New York, three SRES emissions scenarios, A2, A1B, and B1, were used for GCM simulations, while the climate change impact for the A1FI scenario was described qualitatively. To address model uncertainty, 7 GCMs were used to project sea level rise. For the study on the Dutch Coast, Vellinga et al. (2008) used a range of temperature increases to account for uncertainty in climate sensitivity and an ensemble of climate models to account for uncertainty in modeling sea level rise. Since the study focused on upper values, the range of temperature increase corresponded to the high-end A1FI scenario. Since model uncertainty is a significant source of uncertainty, the case studies suggest that the
robustness of GCM-based local assessments would be severely limited without the technical and financial resources to conduct a large number of model runs using different models.

In addition to the uncertainties involved in GCM-based modeling discussed above, a source of significant uncertainty in both sets of projections was the limited understanding concerning the melt rates of the Greenland and Antarctic ice sheets. As highlighted by Horton et al (2011), these uncertainties mean that adaptation planning should not depend on the precise values generated in these local scientific assessments. This suggests that despite the emphasis in the literature on the importance of specific climate change impact assessments for cities, the actual contribution of such studies in providing precise figures that policy makers can use to implement adaptation actions is rather limited. Consequently, assessments of the impact of climate change at the local level need to be complemented by alternative approaches in which climate change projections play a less central role. Policy makers would thus benefit from exploring alternative approaches for assessments that focus on possible adaptation responses or current vulnerabilities, such as those discussed in Section 2.3.2.

Nevertheless, an understanding of the potential local impacts of sea level rise in broad terms – such as the direction and sense of magnitude of the potential change, provides sufficient information to justify the need for adaptation action. Furthermore, many adaptation actions do not require detailed sea level rise projections. In Rotterdam Climate Proof 2010 and PlaNYC (2011), these included identifying current vulnerabilities, enhancing community resilience, and taking actions to plug existing gaps. Recalling the concern with the “adaptation deficit” in Burton (2004), this suggests that coastal cities should place high priority on reducing their vulnerability to current climate hazards. This is especially urgent where current climate hazards have already severely affected the city’s functioning, as in the case of Hurricane Irene’s impact on New York City in August 2011.

Cities should also consider studying innovative design responses that emphasize flexibility and resilience in response to the uncertainty in the threat of future sea level rise. For Rotterdam, floating constructions are the focus of adaptation strategies at the city level. For New York, the On the Water: Palisde Bay project helped people to visualize the possibilities offered by soft infrastructure, as a more flexible form of coastal protection to the rising sea levels than hard infrastructure. The reference made to this project in PlaNYC (2011) and the follow-up strategy of developing collaborative pilot projects suggests that such imaginative and creative visions may
have a role to play in inspiring policy makers to consider innovative, flexible design responses to sea level rise.

Incorporating more flexibility and responsiveness at the policy level will be critical in enabling the adjustment and readjustment needed to the impacts of sea level rise, given the uncertainties in the projections. This is recognized in the NPCC's concept of "flexible adaptation pathways" and the Delta Program's "adaptive delta management". Such approaches have been already been used to inform decisions regarding the implementation of large-scale coastal protection infrastructure. Cities should also consider operationalizing the approach of flexible and adaptive adaptation policies in other policy contexts, such as regulations on development for flood protection.
REFERENCES


KNMI. (2009). *Climate change in the Netherlands; Supplements to the KNMI’06 scenarios*. (Klein Tank, A., & Lenderink, G., Eds.) De Bilt, The Netherlands: KNMI.


The City of New York - Department of City Planning. (2002). The New Waterfront Revitalization Program.


