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Flood-resilient waterfront development in New York City: Bridging flood insurance, building codes, and flood zoning

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Waterfronts are attractive areas for many—often competing—uses in New York City (NYC) and are seen as multifunctional locations for economic, environmental, and social activities on the interface between land and water. The NYC waterfront plays a crucial role as a first line of flood defense and in managing flood risk and protecting the city from future climate change and sea-level rise. The city of New York has embarked on a climate adaptation program (PlaNYC) outlining the policies needed to anticipate the impacts of climate change. As part of this policy, the Department of City Planning has recently prepared *Vision 2020: New York City Comprehensive Waterfront Plan* for the over 500 miles of NYC waterfront (NYC-DCP, 2011). An integral part of the vision is to improve resilience to climate change and sea-level rise. This study seeks to provide guidance for advancing the goals of NYC *Vision 2020* by assessing how flood insurance, flood zoning, and building code policies can contribute to waterfront development that is more resilient to climate change.

Keywords: waterfront; flood; New York City; building codes; flood zoning; insurance; NFIP

Lists of Abbreviations: **ASCE, American Society of Civil Engineers; BFE, base flood elevation; BFL, base floor level; CEDS, Cadastral-based Expert Dasymetric System; CRS, Community Rating System; CWP, comprehensive waterfront plan; CZM, Coastal Zone Management Act; DCP, New York City Department of City Planning; DEC, New York State Department of Environmental Conservation; DEM, digital elevation model; DFE, design flood elevation; DoITT, Department of Information Technology and Telecommunications; FAR, floor area ratio; FEMA, Federal Emergency Management Agency; FIRMs, flood insurance rate maps; LIRR, Long Island Rail Road; MNRR, Metro-North Railroad; MOMA, Museum of Modern Art; MTA, Metropolitan Transportation Authority; NFIP, National Flood Insurance Program; NYC, New York City; NYS, New York State; OEM, Organization for Emergency Management; OSR, open space ratio; PAD, property address directory; SEQRA, State Environmental Quality Review Act; SFHA, special flood hazard area; SOC, structural occupancy category; TDRs, transfer of development rights; TFA, tradable floor area**

Extended Summary

The main outcome of this study is that flood-zoning policies, flood insurance, and building codes are powerful tools for controlling changing future land use, and hence the potential vulnerability of land use to flood risks. Waterfronts are already subject to many more zoning and insurance regulations than landward areas, and waterfronts with a mixed use are more complex to design. This study has, therefore, focused on recommendations that are rooted in existing legislation on flood insurance, zoning policies, and building codes. It also illustrates the need for improved cooperation among the National Flood Insurance Program (NFIP) coordinated by the Federal Emergency Management Agency (FEMA), the NYC Department of Buildings, and the NYC Department of City Planning to ensure that all existing regulations are applied with maximum efficiency. International examples of such cooperation are presented together with how such cooperation would apply to the situation in New York City.

The NFIP and climate change

The federal government provides flood insurance through the NFIP in the United States, which insures a value of about US$31.6 billion in New

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York State (NYS) and US$8 billion in New York City (NYC). FEMA administers the program, sets flood insurance premiums, and sets minimum building standards on the basis of the special flood hazard areas (SFHA: the 1/100 flood zone). The NFIP is an important program for achieving risk reduction because it imposes the minimum requirements for local governments' flood zoning and flood building codes, and it provides incentives to homeowners to invest in risk reduction beyond these minimum standards. The NFIP sets the minimum building requirements in the 1/100 flood zone, and the local governments are allowed to impose zoning regulations and building codes in addition to these minimum standards. For example, the base flood elevation (BFE) level of the 1/100 flood is used to determine the minimum height of the ground floor of new structures in the SFHA.

The NFIP has been quite successful in providing flood insurance to many households in the United States to which flood insurance would otherwise not be available. Furthermore, the NFIP has been rather effective in limiting the vulnerability of new constructions to flood hazards through floodproofing measures. By contrast, the program is generally evaluated as being ineffective in limiting new developments in high-risk areas and in reducing the vulnerability of existing buildings to flood hazards. In addition, many buildings that are exposed to flooding but are located outside the 1/100 year flood zone are not covered by the NFIP. This indicates that there is a need for an assessment of how zoning policies can be better geared toward reducing flood risk.

Climate change or other future developments, such as urban development, are not addressed in the NFIP. The general recommendation for the NFIP program is the need for a thorough assessment of how the NFIP can be geared toward accommodating and ameliorating the impact of increased flood risk. Moreover, there seems to be considerable scope to improve the current program even if flood risk would not increase as a result of climate change.

Cooperation between the NFIP and NYC zoning policies

An important recommendation for improved cooperation among the NFIP, the NYC Department of Buildings, and the NYC Department of City Planning is to take into account future flood-risk maps (e.g., the future 1/100 year floodplain) in flood insurance, zoning, and building code policies. Currently, FEMA produces flood hazard maps that show the 1/100 year flood zone. This task consists of delineating flood hazard areas, mapping floodways, flood elevations, and flood velocity. These studies form the basis for creating flood insurance rate maps (FIRMs).

In view of climate change, the geographical extent of the 1/100 year flood zone is likely to increase, and insurance and zoning regulations could be made applicable to what is expected to be the future 1/100 year floodplain. Knowing the future 1/100 flood zone offers the possibility to impose the same requirements that apply to the current 1/100 year flood zone, such as the elevation of new buildings and floodproofing measures, to the future 1/100 year flood zone. Such a policy could ensure that adequate mitigation measures be undertaken in what is expected to be the future floodplain. Each new development or revitalization program could then be overlaid with the future 1/100 flood zone maps, and the current NFIP regulation with BFE requirements could be applied to these future flood zones. Currently, freeboard is added for certain new constructions in the current 1/100 year flood zone, which means additional elevation of the base floor level (BFL) above the BFE level determined by FEMA. Freeboard is, however, not required for buildings currently outside this zone that are expected to be within the 1/100 year flood zone in the future. Allowing for freeboard in the future 1/100 zones anticipates future climate risk. Apart from mapping future flood zones, it is also recommended that expected damage be mapped, using catastrophe models, and the expertise of insurance companies and academics in these risk assessments.

An alternative policy to mapping the future 1/100 flood zone is to regulate not only the current 1/100 flood zone, but also other flood zones, such as the current 1/500 year flood zone. The advantage of doing this is to avoid a discussion on the selection of a climate change scenario that determines the calculation of the future 1/100 flood zone. Regulating the current 1/500 year flood zone may be justified by the high number of flood losses that have already occurred in that zone, and the arbitrary nature of the decision of the NFIP to regulate only the 1/100 year flood zone.

Flood insurance rate maps

FIRMs are often inaccurate, which results in premiums that do not completely reflect actual risk. Moreover, the decision not to map certain risks, such as the failure of flood protection, results in an underestimation of flood risk and premiums that are too low, which contributes to the operating losses experienced by the NFIP and distorts incentives for damage mitigation measures. Moreover, the lack of detail of the maps is problematic for local governments if they wish to implement stricter building codes than the NFIP regulations and regulate land use in floodplains.

A continuous process of updating maps may be especially important not only if risk changes over time because of socioeconomic developments in floodplains, as has been the case in the past, but also if there are changes in the frequency and intensity of the flood hazard due to changes in precipitation, storms, and sea-level rise. The availability of accurate and up-to-date FEMA flood hazard maps is important in steering appropriate waterfront development in NYC.

Premiums and base flood elevation

The NFIP provides homeowners an incentive to invest in elevation of their property above the BFE level because this can lower their premiums. It is recommended, however, that the NFIP should reevaluate flood insurance premium discounts for buildings in A zones, because A zone discounts effectively cease at 1 to 2 ft above the BFE, but a higher elevation is desirable owing to climate change. Furthermore, increasing flood risk coverage because of climate change requires updates of FIRMs over time and will imply a shift in the zone classification for many properties. The current regulation for such properties is that property owners who are remapped to a more costly zone classification are charged the lower insurance premium of the former flood zone, which is also referred to as *grandfathering*. It may, therefore, be considered necessary to abolish this grandfathering mechanism, since it would result in an increase in subsidized policies over time.

FEMA mitigation grants

FEMA has been actively involved with funding flood prevention through state and local governments in their efforts to mitigate potential flood damage to structures. The availability of the grant programs is often a motivation for communities to join the NFIP. It seems unlikely, however, that the current grant programs will free up sufficient financial resources to finance the required climate adaptation policies for the NYC waterfronts. Moreover, the grants mainly focus on mitigating flood damage to existing buildings.

Increasing the market penetration of the NFIP

The market penetration of flood insurance is rather low, which is an impediment for using insurance to stimulate flood-risk reduction measures, such as premium discounts. The low market penetration has, moreover, the adverse effect of impairing the spread of risk, which generally results in higher premiums for the remaining pool of insured. If climate change increases flood risk, then this would imply that more uninsured households would suffer flood damage, which would either increase the need for federal disaster assistance or leave many households uncompensated and in financial distress. This problem can be resolved in three main ways: (1) more strictly enforce the mandatory purchase requirement for homeowners with federally backed mortgages who live in the 1/100 year flood zone; (2) make insurance compulsory in the expected future 1/100 year zone or a current flood zone with a larger flood return interval, such as the 1/500 year zone, given that the 1/100 year flood zone is expected to increase in the future; (3) alternatively, coverage against flooding could be made compulsory in all existing building and home contents insurance policies that, for example, cover fire risks.

Setting risk-based insurance premiums

In general, the premiums of the NFIP do not completely reflect risk. Incentives for homeowners to implement risk reduction measures are distorted if premiums do not accurately reflect risk, which can be especially troublesome if more investments in mitigation are needed in the future because of increased risk. The NFIP could set actuarially fair premiums that are high enough to not only cover losses in an average loss year, but that are also, on average, capable of covering losses of catastrophic floods, and could better differentiate premiums according to the actual flood risk faced by policyholders. Moreover, the current subsidies given to premiums of pre-FIRM buildings could be phased out over time. Changing the premium structure of the NFIP by charging homeowner's premiums that fully reflect risk raises important equity and affordability issues. Some form of income support or compensation could be given to low-income households that would face large rate increases. However, in order to provide adequate incentives for risk reduction, any treatment should come from public funding, for example, in the form of tax incentives or insurance vouchers and not from subsidies on insurance premiums.

Long-term insurance

The short-term nature of the current flood insurance policies of only one year may restrain active collaboration between insurers and policyholders in reducing exposure to flooding. Several scientific experts have suggested introducing long-term flood insurance contracts with a duration of, for example, 5, 10, or 20 years that are tied to properties instead of individuals. Such a long-term contract would establish a long-term relationship between insurers and policyholders, which gives both parties incentives to implement cost-effective risk-reducing measures. A challenge for long-term policies is how to price future risk if the risk landscape changes as a result of climate change. Further research could examine whether climate change projections are currently sufficiently reliable to price future flood risk.

Restrictions for vital infrastructure

Infrastructure damage is not adequately addressed by the NFIP, although potential flood damage is, for the most part, determined by the infrastructure at risk. The NFIP only recommends restrictions for the development of critical infrastructure through the Community Rating System (CRS), but these recommendations are not strictly enforced. The reason for the limited involvement of the NFIP in reducing the vulnerability of infrastructure to flooding is that infrastructure is not covered in its flood insurance policies. Additional zoning policies could describe which type of infrastructure can be assigned as critical, and clearly divide responsibilities between the NFIP and NYC concerning the enforcement of zoning restrictions.

Adjusting zoning controls

Eliminating the zoning building height penalty

The zoning resolution could provide additional flexibility for buildings in flood-risk areas to allow for freeboard, indicating the additional elevation of the BFL above the FEMA BFE level in order to earn a discount on insurance premiums. However, these elevated buildings are also subject to zoning height limits, which prohibits buildings from increasing their elevation above a maximum height. A logical next step would be to eliminate this zoning penalty. To eliminate it requires a zoning text amendment, which must go through a public review process. The public might be concerned about allowing high-rise buildings on the waterfront. It would ultimately be up to the City Planning Commission and then the City Council to approve the text amendment.

Existing buildings: restrictions and enforcement

For existing buildings, set-back, relocation, or elevation in areas at danger of flooding is perceived as infeasible. There are, however, a few policies relating to existing buildings that could enhance flood resilience. First, additional regulation could stimulate homeowners to implement measures to floodproof telephone and electricity switchboards, and heating and gas installations above the BFE level. Second, alterations of buildings in certain high-risk areas can be limited (e.g., V zones—high risk coastal areas), although this is difficult to implement.

Lowering urban density

An option is to preserve—or encourage—open space on lots in order to reduce flood risk by limiting the buildings' footprints. For this, zoning controls such as the open space ratio (OSR) and lot coverage exist, which are now only applied to residential areas. The option of further stimulating a market-based system of tradable floor area (TFA) in order to shift the potential new floor area to nearby landward lots is not seen as a feasible option. In NYC, density can be traded between high-risk waterfront properties and lower-risk properties further inland if the properties are adjacent to one another. The problem with that approach is that it is uncertain which properties will accept the increased density; hence this mechanism does not lend itself to controlled flood risk–reducing measures.

Infrastructure

Large parts of the infrastructure system in NYC (e.g., rail, subway, airports, naval bases) lie within the current 1/100 and 1/500 flood zones and determine for a large part the potential flood damage of a coastal storm surge. Zoning policies and especially building codes should, therefore, better address flood risk for at least critical infrastructure projects. This is sometimes a difficult issue because infrastructure planning often does not involve a formal role for government agencies. However, there is scope for the improved fine-tuning and cooperation among agencies involved in developing zoning policies and NFIP policies and transportation authorities; for example, tunnel entrances and ventilation grates can be protected and/or elevated. Furthermore, NFIP restrictions for the development of critical infrastructure are only encouraged through the CRS but are not enforced. A common policy could aim at describing what infrastructure can be assigned as critical.

Waterfront development and environmental legislation

Climate change and sea-level rise place an additional burden on waterfront developments and policies, and the challenge is to create a greener waterfront that is more resilient to climate change and attractive for business and residents. One issue is that both urban development and flood protection measures (e.g., levees and flood walls) are often perceived as activities that disturb environmental values. Hence, the challenge is to develop the waterfront in such a way that it enhances flood protection levels by applying measures that also improve environmental values. This study, therefore, recommends that those waterfront areas should be prioritized where coastal flood protection and nature preservation can be co-developed, and, hence, where local government and the state and federal environmental and coastal zone policies have mutual interests. Such an approach could be addressed through better integrating federal and state coastal zone protection into local waterfront revitalization programs. The support for environmentally based flood protection to anticipate climate change receives support from communities, as has been communicated during the borough workshops initiated for the City Council's *Vision 2020*.

The rationale for such an approach is that these multifunctional land use developments need new planning regulations and urban designs that allow for a less rigid boundary between land and water. This implies that, in some instances, to compensate for the loss of urban space, the land–water boundary should be moved landward and in some instances seaward. Moreover, most environmental values are found in creating (shallow) gradients between land and water. International examples show how the mechanism of "environmental compensation" is applied in cases where it is permitted to use open water for waterfront development or protection in exchange for creating (added) environmental values elsewhere through new wetlands or artificial reefs.

Recent research supports the notion that modifications in the open water zone and intertidal wetland area should be evaluated to determine whether waterfront activities can enhance the resilience to climate change. Many such modifications, however, require discretionary permits. Currently, the manner in which NYS environmental regulations have been administered has effectively prohibited any waterfront development into open water space.

Building codes

The NFIP determines minimum building code standards, but, in addition, NYC has designed its own building codes that can go beyond these minimum standards. The building codes apply to new structures and substantial improvements to existing structures. Building regulations apply only to residential properties, commercial properties, and sport stadiums, for example, but not to public infrastructure, such as the subway. The additional flood building code regulation for NYC consists of three main components: (1) building above the BFE level (freeboard) required by the NFIP, (2) dry as well as wet floodproofing, and (3) requirements per flood zone for four different types of buildings. These specific requirements apply to the 1/100 year flood zones, but differ between A and the coastal V flood zone. Moreover, building codes are stricter for certain categories of buildings (up to four categories exist) that have a higher hazard of human life in case of failure, such as hospitals.

In A zones, elevation is needed in low-lying areas except for storage, parking, the building access, or a crawlspace. The design flood elevation (DFE) equals the BFE level of the 1/100 year flood for building categories I and II, while it is, respectively, 1 ft and 2 ft higher for building categories III and IV. Below this DFE level, wet floodproofing is required for all building categories according to their specific DFE level. Instead of wet floodproofing, dry floodproofing is possible in certain cases for all building categories according to their specific DFE level, except for residential buildings for which dry floodproofing is not allowed. Building requirements are stricter in V flood zones because these are coastal areas that are subject to high-velocity wave action. The waves have to be able to flow underneath the buildings, which can be done by building on adequately anchored pilings or columns. The DFE is the same as the BFE of the 1/100 year flood for building categories I and II, while it is, respectively, 1 ft higher for building categories III and IV if the flood is located parallel to the direction of waves, and 2 ft higher if it is perpendicular. Only flood damage–resistant materials and finishes can be used below the DFE, and dry floodproofing is not allowed.

Current regulations could be made stricter on the basis of the existing flood hazard maps. For example, it would be useful to explore more strict foundation standards, especially in the current A flood zones. For example, some of the foundation standards that currently exist in the stricter regulated V zones could be made applicable to A zones. Moreover, all buildings in the 1/100 year A flood zones can be elevated, with the bottom of the lowest horizontal supporting structural member above the flood protection level, as currently applies to the V flood zones. Furthermore, in NYC it would be useful to add additional freeboard to the current elevation requirements. For example, currently no freeboard is required for category II buildings, while this is advised by the American Society of Civil Engineers' (ASCE) 24 standard (+1 ft) and NYS building codes (+2 ft). This would improve protection for many buildings against floods, since these category II building regulations cover most residential buildings. The city government could adopt the ASCE standard for category II buildings, which is more stringent than the federal regulations. For the evaluation of the NFIP, Jones *et al.* (2006) conducted cost–benefit analyses of adding freeboard up to 4 feet. The analyses have been performed for various discount rates, flood conditions, elevation methods, and damage functions. The results show that most of the time, the benefits of freeboard in terms of reduced flood vulnerability exceed its costs, especially for coastal V flood zones. This analysis has been conducted for single-family homes, and further research needs to determine whether similar results apply to other building types. Therefore, it is advisable that NYC adopt the freeboard requirement of NYS of at least 2 ft above BFE and also consider adding freeboard up to 4 feet. Adding freeboard to the building regulations of waterfront development could be a fruitful measure to make waterfronts more resilient to climate change. It should be further examined how ease of accessibility to these elevated buildings can be guaranteed for disabled persons, for example, by making ramps or elevating streets. Moreover, design and public realm considerations for adding freeboard need to be explored.

Cost of damage mitigation

Jones *et al.* (2006) conducted an extensive study for estimating the costs of flood damage mitigation measures. They concluded that for new residential buildings, the additional costs of adding freeboard to the at-BFE building cost are estimated to be between 0.8% and 1.5% per foot of freeboard in a masonry wall with an interior pier (crawlspace) foundation, between 0.8% and 3.0% per foot of freeboard in a fill foundation, and between 0.25% and 0.5% per foot of freeboard in a pile or masonry pier foundation.

Flood protection and architecture

Several examples exist where waterfront development has been combined with flood protection measures. For example, the city of Tokyo (Japan) has been experimenting with a fail-proof, low-maintenance levee for the protection of urban areas. These "super-levees" improve on the typical levee by widening its footprint and reducing the backslope to a low gradient. The stabilized and strengthened sides can be developed, extending the urban development area to the top of the levee and allowing easier visual and physical access to the water. In Japan, these developments are high rise and interwoven with parks, open spaces, and wetlands that are scarce throughout much of the city. There are problems with finding space to develop such wide levees and with the demand for large amounts of fill material. Some of the fill can be offset by including parking and service structures in the body of the levee. For the NYC area, this would imply a joint effort among local, state, and federal governments, especially the U.S. Army Corps of Engineers. However, the Japanese example shows that protecting cities from floods with super-levees is feasible and affordable. Waterfront developments on super-levees are technically feasible and this does not necessarily mean that they are shut off from the water, as is often perceived.

In the city of Hamburg (Germany), an old port facility has been rebuilt and an entire new waterfront has been elevated to a height of about 20 feet. Above this elevation, residential housing is permitted, and a service and emergency road system exist at 20 ft to maintain accessibility in case of a flood. The ground floors are occupied by parking lots and businesses that can be sealed off with steel doors in case of a flood. High-rise waterfront development can be promising for NYC in some locations, as visualized in the Museum of Modern Art (MoMA) exhibition on flood risk-only architectural innovations, such as evacuation routes, public access to the shore, and the combination of flood protection and housing, all of which can be illustrative for redeveloping old port facilities in NYC.

Toward an integrated flood management plan

The complexity of the issue and the inherent uncertainty associated with future projections, such as climate change, requires an integrated approach to flood management in NYC. Currently, only the CRS coordinated by the NFIP encourages communities to develop a community-based flood management plan for implementing mitigation measures in return for premium discounts. However, discussions with government experts in NYC have revealed that the CRS is not attractive for a highly densely populated area such as NYC.

A coordinated effort is needed between insurers and governmental planners to develop a more comprehensive flood management plan, which would outline the effects of climate change, alternative solutions, and costs and benefits of the different strategies. Internationally, examples can be found in the city of Paris, where an integrated flood management plan is being developed, showing how the vulnerability of properties and infrastructure can be reduced; the implementation of these measures is linked to the level of the deductibles for flood insurance. The city of London has conducted an extensive study (Thames 21) on climate change and flood risk that discusses different adaptation strategies and their costs and benefits.

The NYC Mayor's Office of Long-Term Planning and Sustainability, with its established relationships with multiple stakeholders, is well-positioned to coordinate, explore, and foster the implementation of such a plan.

Contents

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All errors or opinions remain ours.

1. Introduction

The recently published report of the New York City Panel on Climate Change (NPCC) indicates that climate change poses a challenge for waterfront development in NYC, given the uncertain risks of sea-level rise and more flooding (Rosenzweig and Solecki, 2010). The NPCC states that NYC is vulnerable to coastal storm surges, which are associated with either late summer/autumn hurricanes or extratropical cyclones in the winter period (nor'easters). Climate change and sea-level rise is projected to increase the frequency and intensity of flood events, and, although these events are relatively rare, it is relevant to address flood risks in current and planned urban development activities, such as waterfronts, because floods can cause considerable losses (Aerts *et al.*, 2009).

Human exposure to flood hazards is caused by settlement and other development in flood-prone areas, such as floodplains and coastal areas. Since the beginning of human civilization, people have realized the benefits of these areas, and urbanization near the waterfront continues today because of the attractiveness of locating near the water for recreational and economic activities (Rosenzweig *et al.*, 2010). The question that arises is how to develop these areas so that vulnerability to flooding is managed in a way that limits risks to human life and physical structures? In this respect, flood zoning policies and building codes are powerful tools for controlling changing future land use, and hence the potential vulnerability of land use to flood risks (Sussman and Major, 2010). The NYC waterfront plays a crucial role in this context as a first line of flood defense and in managing flood risk and protecting NYC for future challenges like climate change. Therefore, the way zoning policies are applied to waterfronts will directly determine future vulnerability to flood risks; hence, new (re-) zoning policies for waterfronts can be perceived as an option for climate adaptation in NYC.

The federally operated NFIP is an important program for zoning policies near the waterfront, as it sets the basic requirements for zoning and building codes in flood-prone areas. For example, the ground floor of new structures in flood zones has to comply with a certain flood elevation level, the BFE. Although the NYC zoning policies and building regulations incorporate information and regulations from the NFIP, there is scope for improved cooperation between the NFIP and zoning regulations in order to better anticipate the challenges of climate change (Burby, 2006; Sussman and Major, 2010).

Currently, parts of the waterfront in NYC are being assessed for rezoning procedures in order to increase the attractiveness of these areas for residents, to increase environmental values, and to stimulate economic activities. NYC is planning new development on these sites, given the increasing demand for attractive and spacious housing and economic activities near the water. In order to address climate change in waterfront development, NYC has embarked on a climate adaptation program (PlaNYC) outlining the policies needed to anticipate the impacts of climate change. As part of this policy, the Department of City Planning has recently prepared *Vision 2020: New York City Comprehensive Waterfront Plan* for the over 500 miles of NYC waterfront, defined as New York Harbor and its tributaries, creeks, and bays. *Vision 2020* sets long-term goals to guide waterfront development. An integral part of the vision is to improve resilience to climate change and sea-level rise. The plan articulates a general strategy for creating a more flood-resilient city, including studies of global best-management practices for coastal management, shoreline protection, flood-resistant building design, and other climate change adaptation strategies in dense urban areas.

This study seeks to provide guidance for NYC's *Vision 2020* by assessing how flood insurance, flood zoning, and building code policies can contribute to waterfront development that is more resilient to climate change. Botzen and van den Bergh (2009) propose that a resilient risk-management strategy comprise risk prevention, damage mitigation, and efficient risk-spreading mechanisms, such as insurance. Along these lines, this study reviews the current NFIP, and flood zoning and building code policies of NYC, by identifying future challenges and by giving recommendations to deal with a future change in the risk landscape. Several examples of international practice will be provided to give suggestions for resilient waterfront development in NYC, including policies in the UK, France, Germany, and the Netherlands. Information for this study has been gathered using interviews and discussions with experts in NYC and abroad (see Appendix A), which are complemented with an in-depth literature review and data analyses.

The remainder of this study is structured as follows. Section 2 provides information on flood risk and climate change in NYC. Section 3 provides flood damage estimations for NYC. Section 4 presents an assessment of the NFIP with a special focus on flood-resilient urban development. Section 5 examines flood zoning policies in NYC and provides suggestions for improving flood zoning to accommodate potential future increase in risks. Section 6 conducts a similar analysis for building code regulations. Section 7 discusses (other) international examples of waterfront development and environmental regulation of the use of waterfronts. Section 8 concludes.

2. Climate change and flood risk in New York City

Climate change projections indicate that by the end of the century, NYC may face an increase in mean annual temperature of 4–7.5° F, an increase in baseline rainfall of 5–10%, and a rise in sea level of at least 12–23 inches (Horton *et al.*, 2010). The rise in sea level is very uncertain and sea-level rise may be considerably higher if ice caps, such as the Greenland Ice Sheet, melt more rapidly than current model studies project.

The two types of storms that can strike NYC are hurricanes and nor'easters, and both of these storms can cause storm surges and flooding. It has been recorded that since 1815, 15 hurricanes have struck NYC with a maximum strength of Category 3 on the Saphir-Simpson scale. A direct hit of a Category 3 hurricane in New York may cause huge economic losses, but nor'easters can also have high wind speed and cause considerable damage (LeBlanc and Linkin, 2010). The storm surges and related coastal flooding are mainly caused by strong winds that pile up water along the shore and generate large waves. For example, the current 1/100 year coastal flood causes a surge of about 8.5 ft at the Battery in Lower Manhattan (Horton *et al.*, 2010). Sea-level rise is expected to increase the intensity, frequency, and duration of coastal flooding in NYC. Projections of the NPCC indicate that the 1/100 year flood event may occur approximately four times as often in 2080, while the 1/500 year flood event may occur on average once in 200 years (NPCC, 2009). The current flood height associated with the 1/100 and 1/500 flood zone is, respectively, 8.6 ft and 10.7 feet. This may increase to 9.4 ft and 11.5 ft for the 1/100 and 1/500 flood zones, respectively, in 2080 (NPCC, 2009; Horton *et al.*, 2010).

In addition to climate change, socioeconomic developments, such as population and economic growth in hazard-prone areas, are likely to have a major impact on future flood risks. An upward trend in worldwide natural disaster losses can be observed. This has been mainly caused by socioeconomic developments, such as increased urbanization in coastal zones, which are likely to continue in the future (Aerts *et al.*, 2009). NYC has been no exception to this global trend and has experienced a considerable increase in concentrations of population and economic activities over time that have heightened flood risk (Gornitz *et al.*, 2001). According to the NYC Department of City Planning (NYC-DCP, 2006), NYC's population is projected to continue to grow from over 8 million in 2000 to 9.1 million in 2030, which is an increase of 1.1 million or 13.9%.[a] These projections indicate a need to create new housing and public infrastructure, including a further concentration of economic values and recreation opportunities near waterfronts.

For the consequences of flooding, most flood-risk assessments are limited to the detrimental effects (damage). The term *flood damage* refers to all varieties of harm caused by flooding. Flood damage can be divided into several categories: usually it is divided into direct and indirect flood damage, both of which are often further divided into tangible and intangible damage (Smith and Ward, 1998; Penning-Roswell *et al.*, 2003). Direct damage can include damage to buildings and economic assets, loss of crops and livestock, immediate health impacts, loss of lives, and loss of ecological goods and objects (Smith and Ward, 1998; Merz *et al.*, 2004; Büchele *et al.*, 2006). Indirect damage is damage that is induced by the direct impact but that occurs outside of the space and/or time of the flood event. Examples of indirect damage include disruption of traffic, trade, and public services (Büchele *et al.*, 2006). Tangible damage refers to damage that can be relatively easily evaluated in monetary terms (e.g., damage to assets or loss of production). Intangible damage, such as social and environmental impacts of floods (Smith and Ward, 1998), is more difficult to evaluate in monetary terms (Lekuthai and Vongvisessomjai, 2001), as is loss of human lives.

To obtain some more insight into the role of waterfronts in flood-risk management and the value at risk, we focus here on two potential consequences of a flood in NYC: exposed assets (direct damage) and population at risk (number of people).

[a]In 2006, New York City's population had already grown to an estimated 8.2 million, according to the U.S. Census Bureau.

Exposed assets

Several studies exist that provide rough estimates of potential flood losses due to hurricanes and winter storms in New York. Nicholls *et al.* (2008) use a relatively simple method to estimate the population and assets at risk from floods in 135 port cities around the globe, including the NYC–Newark region. They estimate the current potential damage for the NYC–Newark region at US$320 billion. Using a scenario for population growth, this may increase to US$1,739 billion in the year 2070. They also combined a sea-level rise scenario of 50 cm in 2070 with the scenario for population growth, which yields potential damage of as much as US$2,147 billion in the year 2070.

LeBlanc and Linkin (2010) state that a direct hit of a Category 3 hurricane in New York may cause huge economic losses of more than US$200 billion (Table 2.1). In addition, nor'easters can have high wind speed and cause considerable damage, as demonstrated by, for example, the nor'easter in December 1992 with damage of over US$1 billion in NYC and the flooding of Lower Manhattan (LeBlanc and Linkin, 2010). Furthermore, a report on climate change and adaptation by NYS (NYS, 2010) provides some estimates on the potential damage of a 1/100 flood in the metropolitan area of NYC. They currently estimate the combined direct and indirect losses to be US$58 billion, of which, US$48 billion would be attributed to indirect losses. Indirect losses were calculated as the cost for recovering from a flood. This is expressed as a percentage from the daily gross metropolitan product, which currently is estimated at US$4 billion. Using two sea-level rise scenarios of 2 ft and 4 ft, respectively, these total losses could increase to US$70–84 billion, from which US$57 billion and US$68 billion would be attributed to indirect losses.

People at risk

The estimate by Nicholls *et al.* (2008) of the population at risk in the 1/100 flood zone in the NYC metropolitan area is 1.54 million people. This could increase to 2.37 million people in the year 2070 because of a population increase. When combining the latter scenario with a sea-level rise scenario of 50 cm, the number of exposed people could increase to 2.93 million. A newly developed mapping method (Cadastral-based Expert Dasymetric System, CEDS) was applied by Maantay and Maroko (2009) to

Table 2.1. Existing estimates of the potential storm surge damage (direct and indirect damage) for the metropolitan area of NYC in billion US$

	1992 Winter storm	1/100 Flood	1938 Hurricane	Category 3 hurricane	Maximum damage (current)	Maximum damage (2080)
Nicholls *et al.* (2008)[a]					320	2147
Pielke *et al.* (2008)			37–39			
LeBlanc and Linkin (2010)[b]	0.72			>200		
NYS (2010)[c]		58				

[a]NYC–Newark region.
[b]Based on other sources, such as ISO/PCS, AIR Worldwide, RMS, Eqecat, Insurance Information Institute.
[c]Based on calculations by K. Jacob and G. Deodatis, Columbia University.

estimate the population in NYC who are at risk from flooding (Fig. 2.1). Using the CEDS method, Maantay and Maroko (2009) estimated the number of people affected by the 1/100 flood in NYC to be approximately 400,000 people.

Uncertainties and need for improved risk estimates

The amount of potential damage and number of population at risk should be interpreted with care. Nicholls *et al.* (2008) state that they have only used flood depth as an indicator for the hazard using a digital elevation model (DEM) with a relatively coarse resolution. The impact of a flood hazard is obviously also dependent on many other factors, such as flood velocity and inundation propagation. Furthermore, the specific nature of NYC buildings and infrastructure is not explicitly considered in their study, and people and assets in skyscrapers are valued the same as people and assets in single story buildings.

Maantay and Maroko (2009) show the influence of uncertainties in data and geographical methods to estimate a population at risk in the 1/100 flood zone. They applied the aforementioned new mapping method of the CEDS and compared this with existing methods, such as the conventional areal weighting of census data and centroid-containment selection. The kernel of this method is to disaggregate spatial data to a finer unit of analysis, using additional (or ancillary) data to better locate population. The main advantage is that the analysis is not restricted to using the locations of, for instance, census tract boundaries, ZIP codes, postal zones, or any other administrative boundaries. These data are often much too aggregated to provide the necessary detail and assume the population to be “distributed evenly throughout the zone, when, in fact, population distribution is generally much more heterogeneous” (Maantay and Maroko, 2009).

Flood- and climate change–resilient development increased in importance on the research and policymakers’ agenda after the destructive Hurricane Katrina in 2005 that caused insured losses of more than US$71 billion, according to Swiss Re (2010). It has been argued that this unprecedented damage was largely caused by unsafe socioeconomic development during the decades before the disaster, which provides important lessons for future development in coastal zones. Burby (2006) has identified two main paradoxes that caused an increase in hurricane exposure: the “safe development paradox,” which means that the federal government substantially increased the potential for catastrophic damage by encouraging urban development in the floodplain, while it tried to make hazardous areas safer by funding the building of levees and providing flood insurance; and the “local government paradox,” which means that local governments gave insufficient attention to the flood hazard in urban development.

These are important lessons for future urban development in areas that can potentially be affected by hurricanes, such as waterfront development in NYC. Therefore, a main part of this study will assess how the federally run flood insurance program and the NYC building code and flood zoning policies

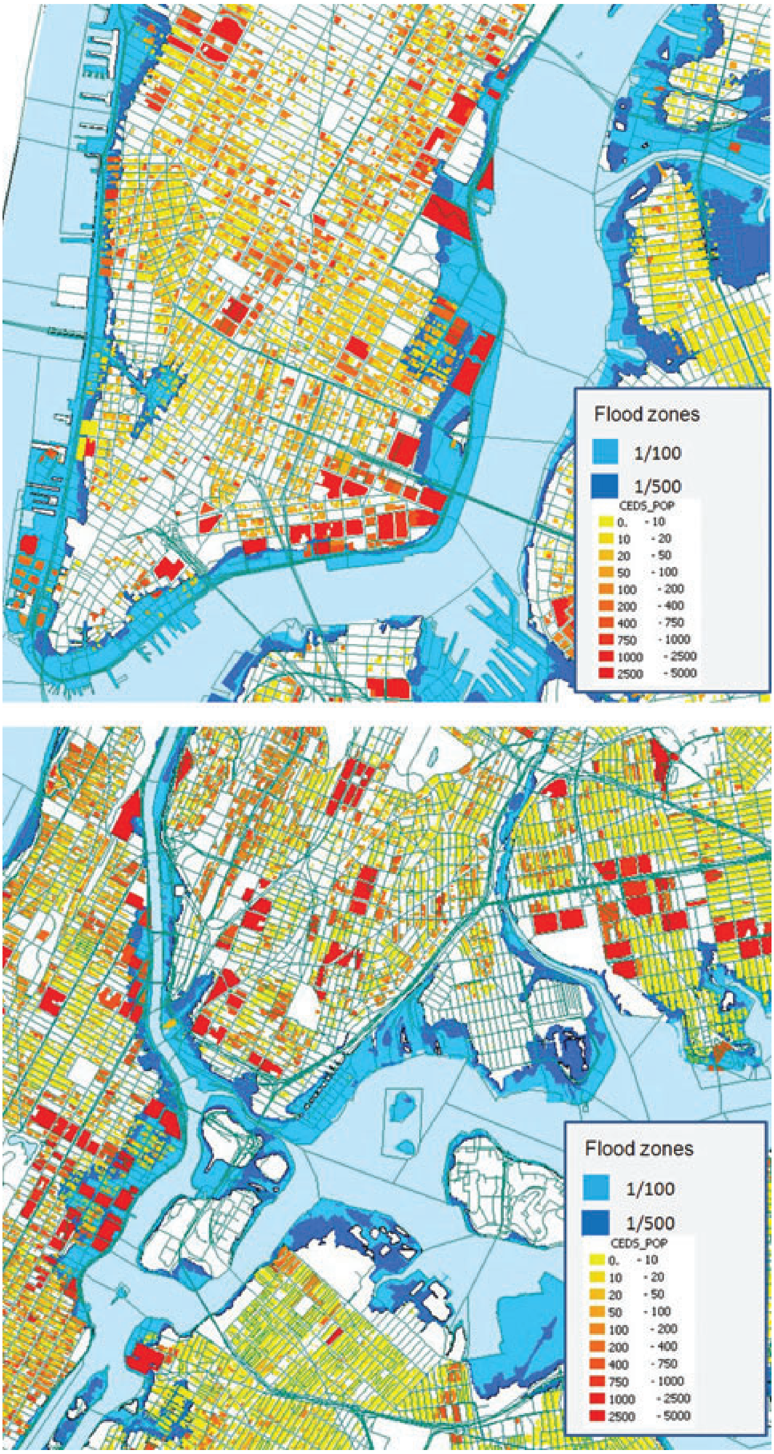

Figure 2.1. Population at risk (in number of people per tax lot) in the 1/100 and 1/500 flood zones in Lower Manhattan (top) and the Harlem River area (bottom) (after: Maantay and Maroko, 2009).

can be geared toward providing adequate protection against flooding and its consequences.

3. Flood damage estimations for New York City

Although some studies have made a global analysis of flood risk in NYC, little information exists on the potential flood damage for individual buildings, tax lot levels, or infrastructure (e.g., LeBlanc and Linkin, 2010). Therefore, we conducted several analyses using spatial information on, for example, zoning lots, individual buildings, infrastructure, and flood zoning. The purpose of these analyses is to derive more insight into the number and types of buildings that are currently located in the different flood zones. In addition, the value at risk of buildings in the 1/100, 1/500, and the other four hurricane flood zones has been estimated using different catastrophe-modeling approaches (e.g., Grossi and Kunreuther, 2005; De Moel *et al.*, 2009; De Moel and Aerts, 2010). The results of these analyses can be used to underpin some of the recommendations made in this study, and to identify possible hotspots on the NYC waterfront where new flood-resilient regulations should be implemented with priority. This detailed information on buildings and zoning lots at risk could, moreover, be useful for a follow-up study that estimates the costs and the benefits of flood management measures or regulations (e.g., Ward *et al.*, 2010). In addition, we also calculate the potential damage to the subway and tunnel systems in NYC in order to derive the total potential flood damage (buildings + infrastructure), and how flood damage to buildings compares with the damage to transport facilities.

The databases used in this study and their sources are listed in Appendix C. Section 3.1 describes the main features of the databases that were available for this study. The subsequent sections proceed with the analyses. The software programs ARCGIS 9.3, Grass 6.4.0RC6, Quantum GIS 1.5, a PostGIS backend, and MATLAB have been used to perform spatial and statistical analyses. Please note that most data on buildings in NYC, such as those used in this study, have generally been developed for tax, planning, inspection, and zoning purposes. Therefore, some approximations from the data are necessary for use in flood damage models, and these are identified throughout the section.

3.1. Available data and data preparation

The MapPLUTO database has been made available by the NYC DCP.[b] This database contains data by tax lot and information about the principal building and the number of structures on it. For example, MapPLUTO has information on the number of stories and the building class of the principal building on a lot, the estimated year of building, the year(s) in which the building was renovated, the building's assessed value, and the square footage for all structures on the lot. The data dictionary describes the variables and some of the limitations of the data.

The NYC Department of Information Technology and Telecommunications (DoITT) provides a database on building footprints.[c] These building perimeter outlines usually have a building identification number (BIN) that is associated with them. This database can be used with the property address directory (PAD) to link the building perimeter to the MapPLUTO database and assign MapPLUTO characteristics to individual buildings. Other databases include a DEM, which was kindly provided by the Organization for Emergency Management (OEM) (Fig. 3.1).

Information on flood hazard zones is shown on FIRMs, which can be downloaded from the map service part of the FEMA website.[d] A FIRM is a product of the flood insurance study conducted for a community and is available in both paper and digital form. FIRMs delineate special flood hazard areas (SFHAs), which are land areas subject to inundation by a flood that has a probability of 1/100 or lower. SFHAs are divided into different flood-hazard zones, depending on the nature and severity of the flood hazard (see Table 3.1). For this study, the 1/100 flood zone is divided in A and V zones, and the 1/500 flood zone is used as a rough approximation of the potential future flood zone.

The first step in the data preparation was to assign tax lot information with details on zoning characteristics from the MapPLUTO database to individual

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[b]It can be accessed via http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml

[c]This data can be downloaded from www.nyc.gov/datamine

[d]See http://msc.fema.gov

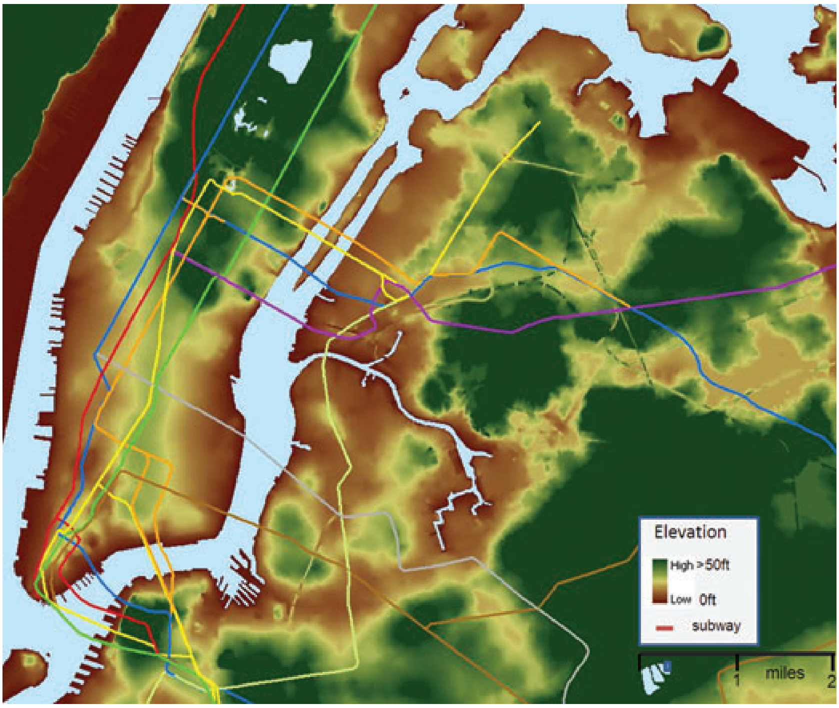

Figure 3.1. Elevation map for part of Manhattan, Brooklyn, and Queens and a projection of subway lines.

buildings. The number of unique building footprints in the building data is 1,049,871. Of those, only 950,921 have a proper BIN assigned to them. Of those proper BIN numbers, 950,919 appeared to be actually unique and only 945,669 matched with the PAD data. Conversely, 39,407 unique BIN numbers that are in the PAD data have no match in the footprint data. Of those with a match, 90,852 buildings are not clearly identified, in the sense that they have multiple entries in the PAD data, with the same BIN appearing in 2 up to 35 PAD records. Finally, only 854,817 buildings could be unambiguously assigned to lots. This implies that 195,054 buildings—roughly 19% of all buildings—cannot be assigned and need to be excluded from the analysis if the BIN is used to combine buildings' characteristics across the data sets.

Because the approach using the BIN number would result in a loss of 19% of our database, we decided to follow an alternative approach. For this, the DCP's own efforts are used to assign lots to a dominant land use. It is assumed that the buildings on a given lot are homogeneous in type and number of floors. All buildings on a lot were assigned to this dominant zoning type. If a lot contained mixed zoning classes, all buildings on a lot were assigned to the class that most likely used the ground floor. In this respect, it is assumed that industrial use takes first priority for the ground floor, then commercial use, and finally residential use. In addition to the categories residential (R), commercial (C), and manufacturing (M), we introduced a category other (O) for built-up structures that could not qualify as R, C, or M, such as public buildings, military sites, utilities, and large infrastructure (see Appendix F). A further distinction has been made within the O category in order to differentiate between lots that consist mostly of buildings (e.g., museums, schools, and churches) and those where buildings are only a small part (e.g., parking lots, airfields, and marinas).

3.2. Analysis of buildings in flood zones

Table 3.2 shows the number of buildings within the 1/100 and 1/500 flood zones in NYC. About 33,122 buildings are located in the 1/100 flood zone, and 66,249 buildings are located in the 1/500 flood zone. Note that those buildings listed in the 1/500 zone also include buildings in the 1/100 flood zone. Table 3.2, moreover, shows the number of vital

Table 3.1. **Information on flood zones based on FEMA Technical Fact Sheet 1.3 "Using a Flood Insurance Rate Map (FIRM)"**

FEMA classification of flood-hazard zones	
V zones	those areas closest to the shoreline and subject to wave action, high-velocity flow, and erosion during the 100-year flood
A zones	areas subject to flooding during the 100-year flood, but where flood conditions are less severe than those in V zones
AO zones	areas subject to shallow flooding or sheet flow during the 100-year flood; if they appear on a coastal FIRM, they will most likely occur on the landward slopes of coastal dunes. Flood depths, rather than BFEs, are shown for AO zones.
X zones	areas that are not expected to flood during the 100-year flood
VE zone	V zone with a determined BFE level
AE zone	A zone with a determined BFE level

Note: Old FIRMs label zones with a letter and number (e.g., A1, A10, V10). The classification in the Table applies to the letter, and in this case the number can be ignored. Moreover, old FIRMs label X zones as zone "B" or zone "C." Source: www.FEMA.org

facilities, which are defined here as both vital for public services (hospitals, fire stations, and military bases) and prone to suffer relatively large damage, such as gas stations (see Appendix D for details). In the current 1/100 V zone, 18 vital facilities are listed in the MapPLUTO database. In the 1/100 A zone, 252 vital facilities are known. The 1/500 flood zone includes 436 vital facilities.

The MapPLUTO database provides information on the year buildings have been altered, which indicates that renovation of the building has taken place (Table 3.2). In total, 2,146 buildings have been renovated over the period 1985–2009 in the 1/100 flood zone, which is about 6.5% of all buildings located in the 1/100 flood zone. This is a substantial increase compared with the 191 renovated buildings over the period 1970–1985. Further analysis reveals that most of the renovated buildings (1,165) were originally built in the years 1920–1950, which is 54% of the total number of renovated buildings in the period 1985–2009. Individual buildings can be renovated more than once, and we have counted only the most recent renovation per building.

Table 3.2 shows the number of vacant lots in the different flood zones. It appears that in the V and A zones, respectively, 11.8% and 16.3% of the lots are still vacant. Especially on Staten Island, many lots are vacant, which offers possibilities for applying adjusted zoning or building codes to floodproof new buildings. In addition, Table 3.2 shows the number of residential properties with a basement. This information is only available for two- or three-family structures but can be relevant for estimating the value at risk in flood zones, and to get an impression of whether more stringent building codes for basements can be effective in reducing risk. The table shows that the number of buildings with a basement is substantial, especially in the 1/500 flood zone. Therefore, flood risk may be decreased significantly if additional building codes were to be applied to floodproof these basements.

Figure 3.2 shows the number of buildings in the 1/100 flood zone (A and V zones) and the 1/500 flood zone, differentiated according to the number of stories per building. Most buildings in either the 1/100 or 1/500 flood zone have 2–3 stories, followed by the category of 3–9 stories. It is also clear that within the V flood zone, only a few building have multiple stories (>3). This information could be used in additional analyses to estimate evacuation risk and the potential for vertical evacuation.

Figure 3.3 shows a map with the building height (number of stories) of the dominant building on a tax lot. The figure shows that several areas in Brooklyn and Queens have properties with only two- or three-story buildings. The large yellow lot on the bottom map is LaGuardia Airport, which lies fully within the 1/100 flood zone.

3.3. Analysis of the value at risk of properties and population at risk

Different approaches have been used in order to estimate the value at risk in the different flood zones in NYC, namely, by using the total built-up value at risk, the total value of the ground floor at risk, and the value per ft^2. The results are summarized in Table 3.3 and further below in Figure 3.4. As an

Table 3.2. **Number of buildings, tax lots, and areas of lots in the 1/100, 1/500 flood zones, and flood zones of hurricane Categories 1, 2, 3, and 4 (for details on FEMA flood zones, see Table 3.1)**

	1/100 flood zone		1/500 flood zone	Hurricane 1	Hurricane 2	Hurricane 3	Hurricane 4
FEMA flood zone	VE	A, AE, AO	X500	NA	NA	NA	NA
No. of buildings	997	33,122	66,249	14,778	108,973	205,459	287,702
No. of residential buildings with a basement[a]	236	4,565	11,009	unknown	unknown	unknown	unknown
No. of vital facilities[c]	18	252	436	unknown	unknown	unknown	unknown
No. of renovated buildings[e] (1985–2009)	100	2146	4,093	1,342	6,450	12,047	17,015
No. of (tax) lots	1,612	33,442	56,415	18,883	92,421	155,398	199,395
No. of vacant lots[b]	355	5,694	7,034	2,974	2,974	10,371	12,512
Area of vacant lots (million ft^2)	0.98	12.86	16.37	9.92	9.92	21.94	24.08
Total area (million ft^2)	8.31	78.64	114.33	41.17	139.99	205.02	248.26
Percent vacant ft^2 [d]	11.8	16.3	14.3	24.1	7.09	10.7	9.7

[a]This information is only available for two- or three-family structures. However, MapPLUTO does not provide this information for all two- or three-family structures.
[b]As indicated by the land-use class in the MapPLUTO database.
[c]Hospitals, fire stations, police stations, and military bases. See Appendix D for detailed information.
[d]Percent of vacant lots in the flood zone relative to the total lots in the flood zone.
[e]If a building has been renovated more than once, then only the most recent renovation was counted.
NA, not applicable

illustration, Table 3.3 also shows the population at risk for each flood zone.

Estimating the total built-up value at risk. The total value comprises all buildings in the flood zones, including those on airfields, marine bases, and the value of parking lots and parks. The information per tax lot has been used for determining the total built-up value at risk. From the MapPLUTO database, the total value of both the land and buildings was available, as well as the value of only the land. We, therefore, subtracted the land value from the total value to obtain the value for buildings only (total value – land value = building value). The value at risk in the 1/100 V flood zone amounts to US$5.9 billion, whereas the properties in the A flood zone represent US$18.3 billion. The value at risk in the 1/500 is US$22.3 billion, which includes all property values in the 1/100 zone. Hence, the additional value at risk in the 1/500 flood zone compared with the value at risk in the 1/100 flood zone is US$4.0 billion.

Using the value of the ground floor. The aforementioned value at risk based on the total value of the buildings on a tax lot may not, however, be very accurate. It is unlikely that the whole building will

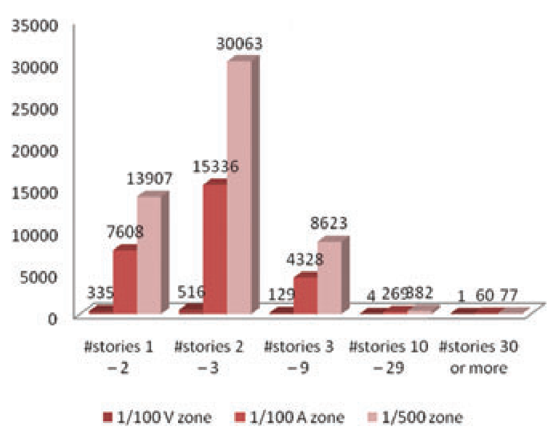

Figure 3.2. **The number of buildings in the 1/100 flood zone (A and V zones) and the 1/500 flood zone, differentiated according to the number of stories per building.**

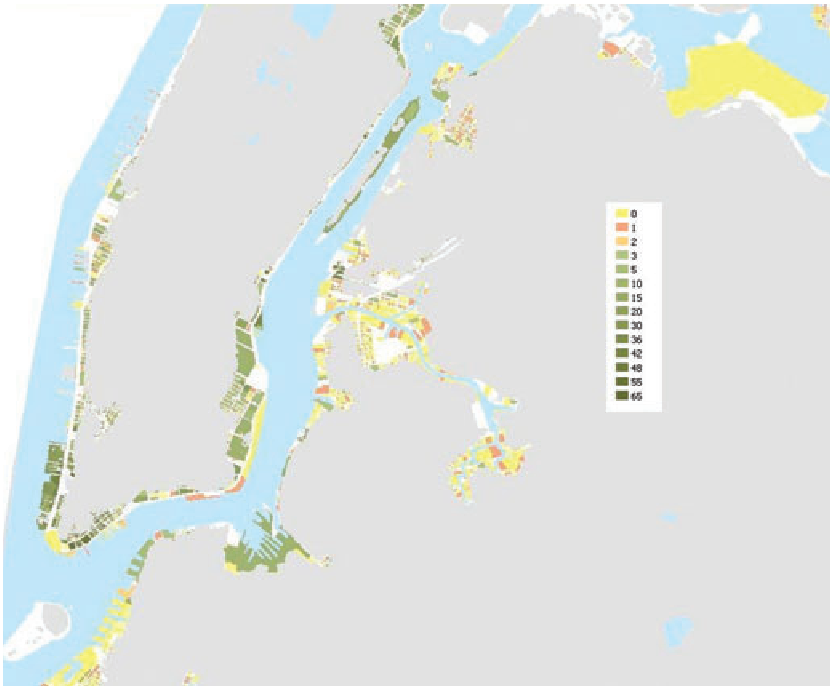

Figure 3.3. **Number of stories of the dominant building in a tax lot in the 1/100 flood zone.**

be damaged in the event of a flood, except perhaps in V flood zones where a high flood velocity may severely damage the structure of the building. The value of the ground floor is estimated by dividing the value of a specific building by its number of stories in order to obtain a better estimate of the value at risk of flooding. The total ground floor value in the flood zones is listed in Table 3.3, and is estimated at US$3.48, US$6.26, and US$7.44 billion for buildings in, respectively, the 1/100 V, 1/100 A, and 1/500 flood zones. Obviously, for tax lots with different building types[e] the result can be either an under- or overestimation of the value at risk, depending entirely on which building type is considered to be the dominant structure. Unfortunately, such cases cannot be identified in the data. Note that basements in the flood zones (see Table 3.2) are vulnerable to flood damage. We did not, however, estimate the damage to basements in this study since the MapPLUTO database only provides information on basements for a limited number of residential buildings. This means that the flood damage estimates are probably too low.

[e]For example, it can be that one building on a tax lot has several floors (a five-story office building), while another is a single-story building (factory hall).

Using the value per ft^2. In order to concentrate on the flood risk for buildings rather than on tax lots, the value at risk per ft^2 for each individual building footprint is estimated. For this, it is assumed that the value of the property in US$ per ft^2 is equal for all uses, and a homogeneous distribution of value over stories and floor area within a tax lot is assumed. With this method, the footprint areas of all buildings (in ft^2) within a lot have been summed. Next, the ground floor value of the tax lot (in US$) has been divided by the total ft^2 of the buildings' footprint to arrive at a price per ft^2 of that particular tax lot. In order to estimate the value at risk per building, the value per ft^2 of a tax lot can be multiplied with the footprints of each individual building to arrive at an estimate of the value at risk per building.

There are, however, some problems with applying this approach, especially for large and valuable lots, such as parks and airfields, with only a few buildings. For example, in tax lot 34699 (Central Park), the total assessed value is US$2.77 billion, while the

Table 3.3. **Property value at risk and the population at risk in the different flood zones in NYC**

	1/100 flood zone		1/500 flood zone	Hurricane 1	Hurricane 2	Hurricane 3	Hurricane 4
FEMA flood zone	VE	A, AE, AO	X500	NA	NA	NA	NA
Using the total value of the building[a]	5.99	18.32	22.31	15.58	27.14	34.42	45.91
Using the total value of the ground floor[b]	3.48	6.26	7.44	5.59	8.32	11.01	13.15
Population at risk[c]	2,932	214,978	462,971	119,208	701,674	1,352,683	1,973,577

[a]Calculated as the difference of total assessed value and assessed value of land (US$ billion, in 2009 values).
[b]Calculated by dividing building value by the number of stories (US$ billion, in 2009 values).
[c]Number of people, calculated using the database from Maantay and Maroko (2009).
NA, not applicable.

land value is assessed at US$2.67 billion. This would mean that the built-up value is US$0.1 billion. This value is distributed over only a few building footprints in Central Park, which may cause too high of a price per ft^2 for the building footprint. Another shortcoming is that quite a number of lots were left out in the analyses when calculating the values at risk per ft^2 on the basis of building footprints. In some instances, these were valuable lots within the flood zones, but they could not be included in the analysis because they lacked a single building footprint in the DoITT database. This means that, while the lot has value, it is not included in the value at risk estimate, which results in an underestimation of the value at risk per ft^2 for some tax lots. Nevertheless, despite these errors, the values at risk per ft^2 of residential and commercial buildings are reasonable, with values ranging between US$1 and over US$400 per ft^2 for buildings in Manhattan (see Fig. 3.4).

Value at risk over time. Figure 3.5 shows the cumulative value at risk of all properties (both total value and values of ground floors) over time between the years 1880 and 2009 (in US$ 2009 values). Four interesting observations can be made. First, both in the 1930s and the 1990s, there was a very large increase in the value at risk, which is probably due to an accelerated increase in urban development, in combination with the development of some expensive properties, such as airfields and naval bases. Second, in the 1990s, the figure shows that the increase in the value at risk in the 1/100 flood zone was similar to that in the 1/500 flood zone. This indicates that flood-risk management, such as that conducted by the NFIP, was not able to restrain development in the 1/100 floodplain, which has a higher risk than the 1/500 year floodplain. Third, the development of the value at risk based only on ground floors shows that the value at risk in the 1/100, 1/500, and hurricane 3 flood zones was much closer in terms of absolute numbers compared with the total built-up value at risk in the 1930s than other periods. This means that in the 1930s, relatively many low-rise properties were developed in the flood zones as compared with high-rise buildings. Note, however, that there is uncertainty related to these calculations as newer buildings could have replaced older buildings. Fourth, both figures indicate that development in the flood zones continues steadily over time. This trend, in combination with the fact that a substantial number of lots are still vacant, indicates the relevance of exploring how floodproofing through zoning, building codes, and protection can reduce the flood risk of newly built structures, as will be the focus of Sections 4 to 7. In addition, Figure 3.6 shows a map of the age of buildings within the 1/100 flood zone. Most buildings in the flood zone were built between 1930 and 1960.

Distribution of the value at risk. Figure 3.7 shows the distribution of the value at risk on the basis of the ground floor over the 1/100 and 1/500 flood zones. It appears that the value at risk in the "Other" non-building class (see Appendix F) is substantial. These values mainly reflect naval bases and main airfields that are located in the flood zones near the

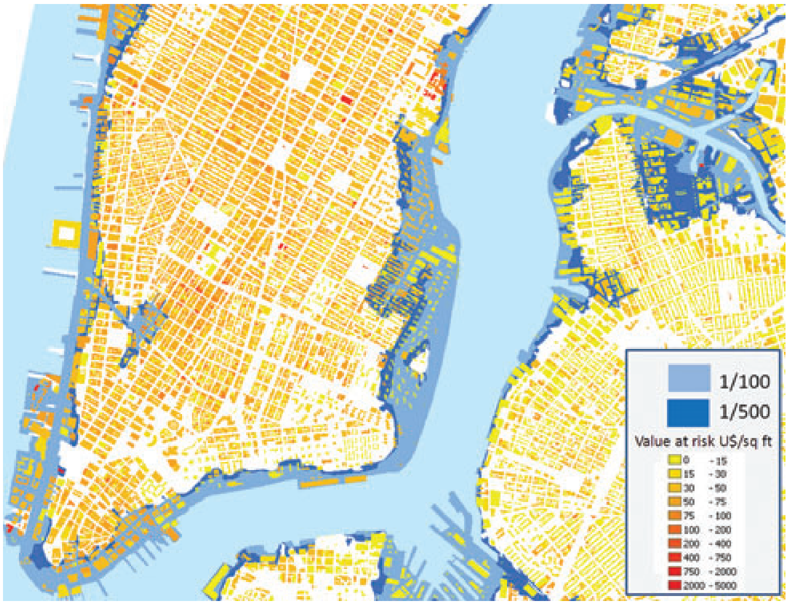

Figure 3.4. **Value at risk in US$ per ft² based on the ground floor of buildings in Manhattan and Brooklyn. Note: The map shows in light blue those areas that are expected to be flooded during a 1/100 storm surge, and in dark blue, those areas at risk of flood in the 1/500 flood zone.**

coastline. The share of the "Other" non-building values is smaller in the 1/500 flood zone because that zone includes more landward lots that mainly contain built-up residential and commercial uses. The figure shows, moreover, that residential use makes the smallest contribution to the ground floor value at risk.

Figure 3.8 shows the distribution of both the number of buildings and the value of the ground floor over the five NYC boroughs in the 1/100 and 1/500 flood zones and the hurricane Category 3 zone. In terms of the number of buildings at risk, it appears that most buildings are located in Queens compared with the other boroughs: 12,310 and 24,862 buildings in Queens are in, respectively, the 1/100 and 1/500 flood zones. Brooklyn has most buildings in the hurricane Category 3 zone: specifically, 104,500. Queens has the largest share of the ground flood value at risk in all three zones, which is consistent with the large number of buildings at risk in Queens. Manhattan has a larger share in the ground floor value at risk compared with the other boroughs (except Queens), because the average value of the buildings is much higher in Manhattan. Nevertheless, the share in the ground floor value at risk of Manhattan may be lower than might be expected at first sight, which probably is because many buildings in Manhattan are high-rise buildings with multiple stories, which lowers the value of the ground floor at risk relative to the total value of a building.

Population at risk. Table 3.3 also shows the population at risk for each flood zone using the database that was provided by Maantay and Maroko (2009). The numbers for the 1/100 flood zone are much lower than those provided by existing literature (see Section 2), which can be explained by the rather coarse GIS classification system we applied to the population data. Maantay and Maroko (2009) estimated the population at risk at 400,000 people, whereas our estimate is 214,978. Furthermore, Appendix H shows the distribution of the population at risk across the different boroughs. It appears that Brooklyn, Manhattan, and Queens form the top three, respectively, in terms of population at risk.

3.4. Potential damage to the NYC transport system

Most existing studies that provide estimates of flood damage in NYC include both damage to buildings and damage to infrastructure (see Section 2). We now focus on potential flood damage to the NYC transport system (subway and rail) in order to

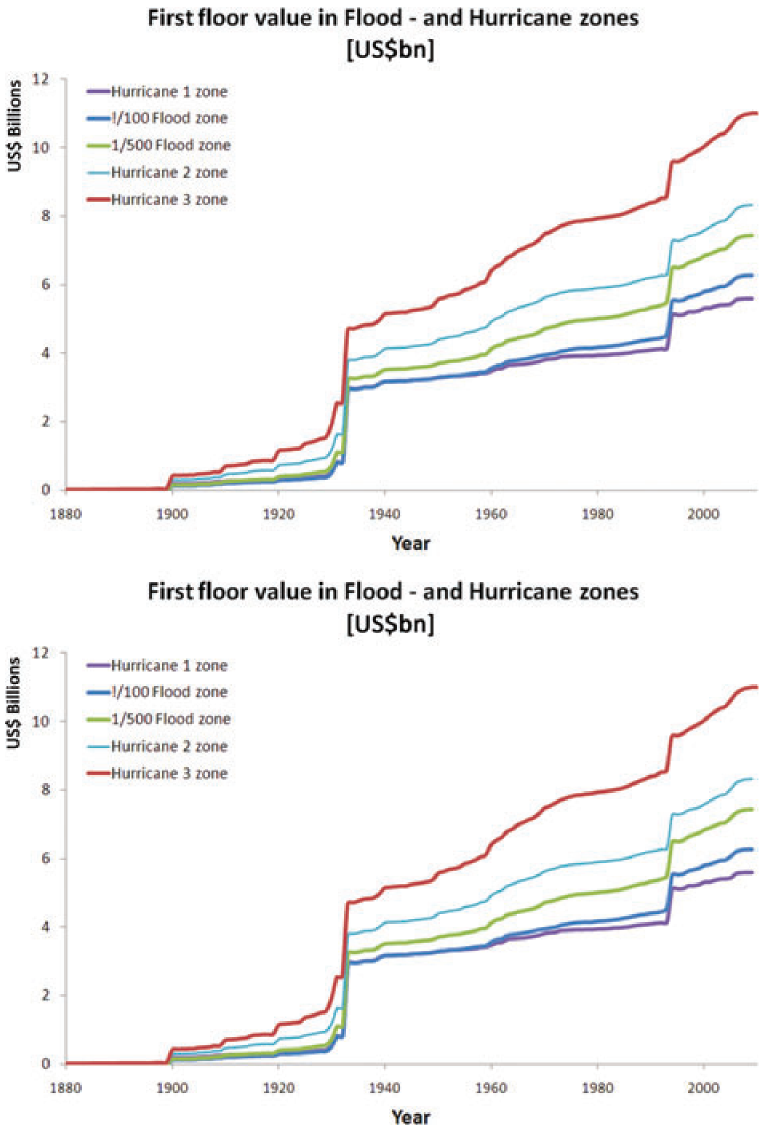

Figure 3.5. **Cumulative values of the properties at risk in the 1/100, 1/500, and Hurricane 1 and 3 flood zones over time (period 1880–2010). Note: The top figure shows total built-up values, and the bottom figure the cumulative values for the ground floor (all in net present 2009 values, in US$bn).**

compare this with damage to buildings. Currently, the Metropolitan Transportation Authority (MTA) has about 44,000 ft (>8.3 miles) of underwater subway tunnels that need to be protected (Fig. 3.9). Several studies stress the high potential flood damage to the NYC subway rail and subway systems in case of an extreme flood event. Table 3.4, for example, in the middle column shows the number of some individual infrastructure objects located just below the 1/100 flood levels.

Historic flood events showed that NYC rail systems are indeed very vulnerable. For example, the PATH rail system between NYC and New Jersey flooded during a coastal flood in the winter of 1992 causing considerable damage (USACE, 1995). In the USACE (1995) study, several scenarios of flooding are discussed and how these could affect the road-tunnel and subway-tunnel systems. In case of a Category 1 hurricane, which is approximately the equivalent of a 1/100 year flood, water "...would fill

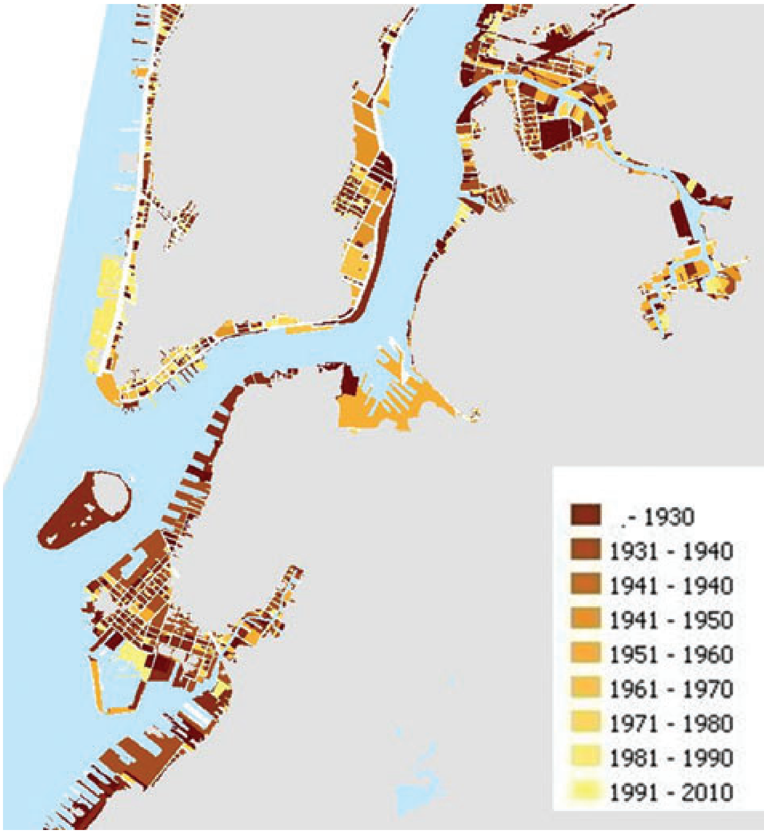

Figure 3.6. Age of the buildings in the 1/100 flood zone.

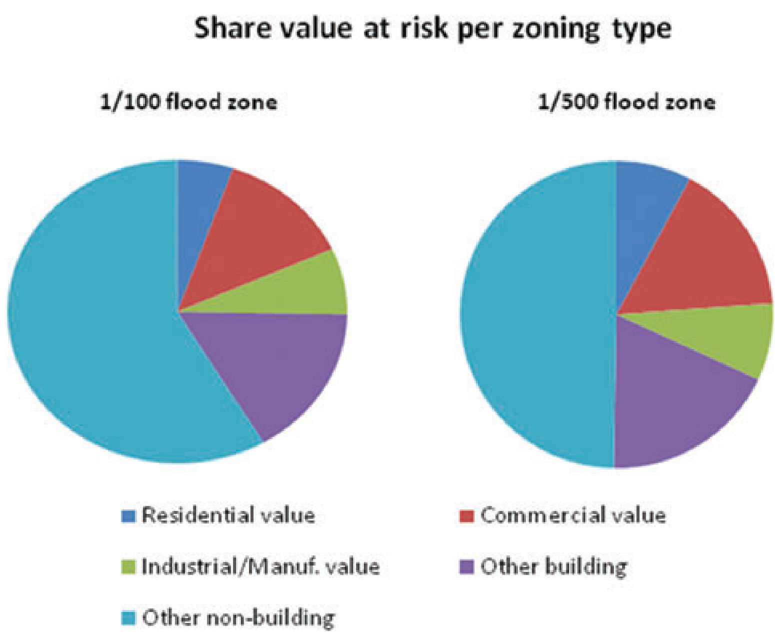

Figure 3.7. The distribution of the ground floor value at risk per building type in the 1/100 and 1/500 flood zones.

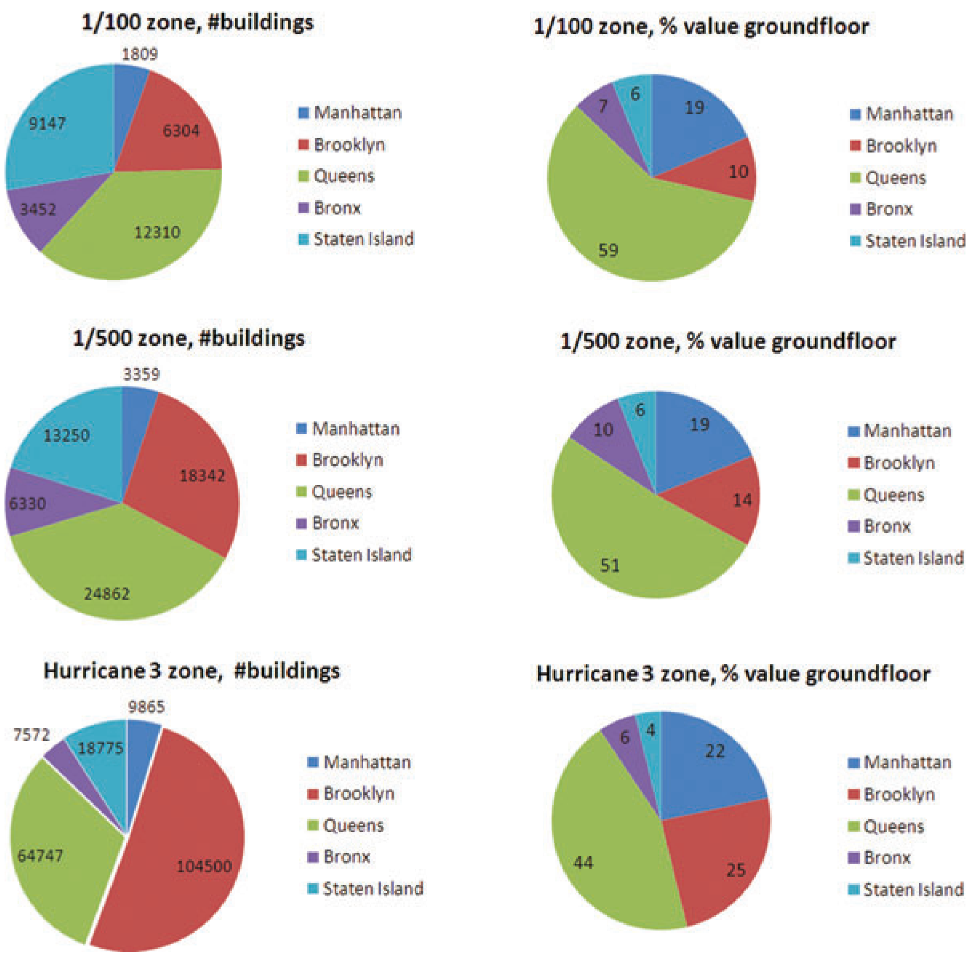

Figure 3.8. The distribution of the number of buildings (left) and the ground floor value at risk (right) per borough in the 1/100 and 1/500 flood zones, and the hurricane Category 3 zone.

Amtrak tunnels and the lower levels of Penn Station and Grand Central stations, the Manhattan subway system from the Battery to 14th Street including the East River tunnels" (USACE, 1995). Of particular importance is the rate at which flood waters will rise as these determine the time available to evacuate the tunnels (NYS, 2010).

Extreme precipitation may also damage the subway system. For example, severe thunderstorms in August 2007 caused severe flooding conditions in the NYC subway systems and a disruption of services during most of that day (MTA, 2007). During such a flood event, railroads can directly inundate when they are situated at lower elevations at grade. Or as the streets get flooded and water levels continue to rise above the sidewalks, flood water can directly enter vent gratings or subway entrances (MTA, 2007). Flood management measures are already implemented and flood water is directed to troughs between the tracks and to drains leading to sewers or a pumping station. However, high velocity and large volumes of flood waters beyond the draining and pumping capacity of the subway system can lead to a flood. This is sometimes exacerbated by floating debris in draining channels that hinders draining to sewers and pumping stations. In such cases, the service will be suspended as water levels rise above the running rail (MTA, 2007).

Direct damage to subways systems involves costs for inspection, repairing tracks, and replacement of equipment (e.g., track relays, transformers, electric motors, signal equipment, etc) (MTA, 2007).

Figure 3.9. Subway lines (colors) and railroad tracks (black) in Manhattan and Brooklyn overlaid with the 1/100 and 1/500 flood zones. Ventilation shafts, subway, and tunnel entrances are depicted in small black rectangles. Source: NYC-DoITT, see Appendix C.

This is confirmed by Compton *et al.* (2009) who write that most losses in subways during historical events were caused by damage to power supply systems, signaling equipment, and escalators that were out of operation for weeks to months after a flood event. Furthermore, cleaning costs are involved for removing debris and mud from tracks and stations.

Flood damage was calculated for different rail systems in NYC: Metro-North Railroad (MNRR), Long Island Rail Road (LIRR), New Jersey Transit (NJT), and New York City Transit (NYCT). We, moreover, calculated direct damage to road tunnels (see Table 3.5) by applying the approach described by Compton *et al.* (2009) who studied the effects of flooding in the subway system of Vienna (Austria) (See Appendix G). In their study, empirical data were obtained from historical flood events in subway systems, such as in Boston, Seoul, Taipei, and Prague. These empirical data were compared to a flood loss modeling study of the subway system of Vienna. A table of available historical flood losses to subways systems is listed in Appendix G. Compton *et al.* (2009) assumed an empirical relationship "α" between direct damage and the length of the flooded track (see Appendix G). Following this

Table 3.4. Summary of the extent of transportation infrastructure potentially affected by sea-level rise in the New York region

Type of transportation infrastructure	Facilities 10 ft. or fewer above sea level	Facilities 10–12 ft. above sea level
Transit: Railroad stations	10	4
Subways: PATH stations	17	3
Surface transport: roads, bridges, tunnels	21	9

Source: Adapted from Zimmerman and Faris (2010) and originally compiled from Zimmerman and Cusker (2001).

Table 3.5. **Direct flood damage to tunnel facilities (subway, Amtrak, and road) in NYC using damage factors from Compton *et al.* (2009) (see Appendix G)**

Name *East River tunnels (south to north)*	Year	Length [m]	Length [ft]	MTA Lines #	Critical elevation [ft] 1)	Min damage [US$ mln][a]	Max damage [US$ mln][b]	Comments	Maintenance
Brooklyn–Battery Tunnel	1950	2779	9117		8.6	8.9	55.6	I-478	NYC/TBTA
Joralemon Street Tunnel	1908	1641	5385	4,5	9.8	5.3	32.8	IRT Lexington Avenue Line (4, 5 subway services)	NYCT / MTA
Montague Street Tunnel	1920	1191	3908	M,R	7.5	3.8	23.8	BMT Broadway Line (N, R subway services)	NYCT / MTA
Clark Street Tunnel	1919	1800	5900	2,3	9.1	5.8	36.0	IRT Broadway – 7th Avenue Line (2, 3 subway services)	NYCT / MTA
Cranberry Street Tunnel	1933	933	3060	A,C	7	3.0	18.7	IND 8th Avenue Line (A, C subway services)	NYCT / MTA
Rutgers Street Tunnel	1936	838	2750	F	10.6	2.7	16.8	IND 6th Avenue Line (F subway service)	NYCT / MTA
14th Street Tunnel	1924	1018	3341	L	7.2	3.3	20.4	BMT Canarsie Line (L subway service)	NYCT / MTA
East River tunnels	1910	1204	3949	LIRR	9	3.9	24.1	Amtrak and Long Island Rail Road	Amtrak/LIRR
Queens–Midtown Tunnel	1940	1955	6414		10.6	6.3	39.1	I-495	NYC/TBTA
Steinway Tunnel	1915	1067	3500	7	11	3.4	21.3	IRT Flushing Line (7, ⟨7⟩ subway services)	NYCT / MTA
53rd Street Tunnel	1933	1006	3300	E,V	10	3.2	20.1	IND Queens Boulevard Line (E, M subway services)	NYCT / MTA
60th Street Tunnel	1920	1673	5489	N,R,W		5.4	33.5	BMT Broadway Line (N, Q, R subway services)	NYCT / MTA
63rd Street Tunnel	1989	960	3140	F	12.7	3.1	19.2	upper level: IND 63rd Street Line (F subway services) (lower level: future LIRR to Grand Central Terminal)	NYCT / MTA
Harlem River (south to north)									
Lexington Avenue Tunnel	1918	335	1100	4,5,6	9.9	1.1	6.7	IRT Lexington Avenue Line (4, 5, 6, ⟨6⟩ subway services)	NYCT / MTA
149th Street Tunnel	1905	195	641	2		0.6	3.9	IRT White Plains Road Line (2 subway service)	NYCT / MTA
Concourse Tunnel (161 St)	1933	552	1810	B,D		1.8	11.0	IND Concourse Line (B, D subway services)	NYCT / MTA
Hudson River (South to North)									
Downtown Hudson tubes	1909	1720	5976	PATH	7	5.5	34.4	Montgomery-Cortlandt Tunnels / PATH	PAUTHNYNJ
Holland Tunnel	1927	2600	8400		7.6	8.3	52.0	I-78	PAUTHNYNJ
Uptown Hudson tubes	1908	1700	5500	PATH	7.4	5.4	34.0	Hoboken-Morton Tunnels / PATH	PAUTHNYNJ
North River tunnels	1910	1900	6100	NJT		6.1	38.0	Amtrak / New Jersey transit	Amtrak/NJT
Lincoln Tunnel	1937–1957	2300	7900		10.6	7.4	46.0	NJ 495/I-495	PAUTHNYNJ
Total damage						**94.0**	**587.3**		

[a]Critical elevations are determined using elevations from ventilation shafts, tunnel entrances or station entrances (see USACE, 1995).
[b]Direct Damage calculation following Compton et al. (2009) using alpha 3.2 and 20 for minimum and maximum damage, respectively. See also Appendix G.

calculation, direct damage of a flood to tunnel facilities is estimated between US$94 and US$587 million.

Furthermore, indirect damage to transport authorities has been calculated using different scenarios for rail disruption (1 and 30 days of disruption) and different valuation methods. We used estimates by Compton *et al.* (2009), who used an average price per flooded mile of track of US$1.66 million per mile (2010 values). This number uses an average ride cost of €2 per ride, which is comparable to the average ride in NYC (~US$2.25). On the basis of these assumptions, the indirect losses are estimated at US$740–900 million, depending on the length of the flooded tracks (see Appendix G). In another approach, indirect losses due to the disruption of the subway system are based on estimating the number of passengers that are either delayed or cancel their ride. Using different scenarios for the number of passengers and different ride price (see Appendix G) estimates of indirect losses vary between US$140–312 million.

In summary, the sum of direct and indirect losses to the subway and rail system caused by a 1/100 year flood varies between US$0.23 billion (US$140 million + US$94 million) and US$1.49 billion (US$900 million + US$587 million) on the basis of calculations in this section. This is considerably lower than the direct damage to buildings and other infrastructure such as airports for the same flood event.

Indirect damage. Note that these numbers do not include losses due to business interruption in other businesses and address a range of losses for only rail infrastructure. The total of indirect flood damages are damages caused by disruption of the economy, the extra costs of emergency, and other actions taken to prevent flood damage and other losses. "This includes, for example, the loss of production of companies affected by the flooding, induced production losses of their suppliers and customers, the costs of traffic disruption or the costs of emergency services" (FHRC, 2008). So far, we have focused on direct flood damage to buildings and infrastructure and briefly touched upon indirect damage due to a flood in the NYC subway system. Research, however, shows that a flood may have a considerable effect on indirect economic damage (Bockarjova, 2007; Hallegate, 2008).

Hallegate (2008) published a study on the relationship between direct and indirect damage from flooding using an input–output model. The model is used to simulate the response of the economy of Louisiana to the landfall of Hurricane Katrina. The simulation results showed that disturbed economic processes may exacerbate direct losses. For example, whereas the direct losses of Hurricane Katrina are estimated at US$107 billion, indirect effects are estimated at an additional US$42 billion—hence 28% of the total costs. Furthermore, Hallegate (2008) found a nonlinear relationship between total losses due to a flood disaster with respect to direct losses when the latter exceed US$50 billion: "When direct losses exceed US$200 billion, for instance, total losses are twice as large as direct losses." These findings could be used in new research into the total potential flood damage for NYC.

3.5. Lessons for flood-risk management

This section has analyzed the number and type of buildings that are located in the different flood zones in NYC, has provided estimates of the value at risk of flooding and has provided some analyses of the value at risk of the NYC transportation system. More detailed estimates of the flood risk in NYC and the costs and benefits of flood management measures should be made in follow-up studies using flood damage models. Nevertheless, the relatively simple analyses in this section deliver some relevant insights for flood-risk management. The number of buildings in the flood zones in NYC is substantial, and is about twice as large in the 1/500 year flood zone as in the 1/100 year flood zone. If the 1/500 year flood zone is a rough approximation of the future 1/100 year flood zone in the face of climate change, then climate change may considerably increase the number of buildings exposed to flooding.

The data show that many buildings have been renovated over time. This suggests that there may be scope to reduce flood risk by imposing on existing buildings strict building codes that take effect when they are renovated. Moreover, the number of buildings with a basement is substantial, especially in the 1/500 flood zone. This suggests that flood risk may be decreased significantly if additional building codes were to be applied to floodproof these basements. Relatively many low-rise properties were developed in the 1930s, which are vulnerable to flooding. It is important that flood-risk management takes into account how these existing buildings can be protected against flooding.

Our different estimates indicate that the value at risk of flooding is substantial in NYC. Especially Queens appears to be very vulnerable to flood damage, as was shown by the values at risk per borough. In general, flood-risk management has been ineffective in steering development away from the high-risk 1/100 flood zones. A steady increase in the value at risk in the different flood zones can be observed over time, which is likely to continue in the future. This trend, in combination with the fact that a substantial number of lots are still vacant, indicates the relevance of exploring how floodproofing through zoning, building codes, and protection can reduce the flood risk of newly built structures. Estimates of the different components of the value at risk indicate that flood-risk management should not solely focus on protecting buildings from flooding, since the largest value at risk is actually presented by "non-building values" such as infrastructure. Finally, our calculations show that direct damages to both buildings and the NYC transport system can be very high. However, indirect damage can have a large share in the total damage from flood risk in the City but this has not been assessed in detail in this study.

4. The National Flood Insurance Program and New York City

4.1. Description of the current NFIP and federal mitigation policies

The federal government provides flood insurance through the NFIP in the United States, which insures a value of about US$31.6 billion in NYS and US$8 billion in NYC. The program was initiated by the U.S. Congress in 1968, and several amendments took place in 1969, 1973, 1994, and 2004 in order to improve its performance. The program was established in the 1960s to ensure that local government planning and land-use management decisions give adequate recognition to flood hazards and meet insurance needs in flood-prone areas (U.S. Congress, 1966 a and b, cited in Burby, 2001). A well-designed flood insurance program with risk-based premiums can, in theory, be beneficial for societal welfare by giving a price signal of risk that prevents the uneconomical use of floodplains, and by incentivizing the undertaking of cost-effective risk reducing or "mitigation" measures, while providing compensation for flood damage to inhabitants of flood-prone areas (Burby, 2001; Botzen and van den Bergh, 2008). The NFIP enables homeowners to purchase insurance coverage against flood damage under certain conditions that most commercial insurance companies refuse to cover in standard insurance policies.

The standard flood insurance policy of the NFIP covers direct material damage caused by floods, flood-related erosion as a result of waves or currents of water, and mudslides. The general coverage limits are US$250,000 for residential buildings[f] and US$500,000 for nonresidential buildings, such as shops and businesses. Risks to infrastructure, life, and agriculture are outside the scope of the NFIP. Also, wind damage, for example, caused by hurricanes is not covered through the NFIP, but this coverage can be purchased from private insurance companies, although flood losses caused by hurricanes fall under the NFIP coverage. In 2007, the total value of this private insurance coverage (thus excluding NFIP, but including wind damage) in NYC and Long Island was more than US$2.3 trillion, which illustrates the large size of the value at risk (LeBlanc and Linkin, 2010). This value is an estimate of the cost to replace structures and their contents for all insured residential and commercial property, and includes business interruption coverage.

The NFIP operates like a public–private partnership. Table 4.1 lists the main stakeholders of the NFIP and their responsibilities. FEMA administers the program and sets flood insurance premiums, identifies flood-hazard areas, makes flood-risk maps, and provides design standards for constructions in floodplains. The state governments authorize and assist building regulations in flood-prone areas of local governments. In principle, communities can decide on a voluntary basis whether they want to join the NFIP. Insurers are the agents that sell the policies and underwrite the risk for which they are compensated, but the NFIP has the final financial responsibility and bears the risks. The NFIP operates like a national type of risk pool, and has never been reinsured by private insurance. The government operates like a reinsurer of last resort and Congress can

[f] The standard residential policy covers, for example, structural damage to furnaces, water heaters, and air conditioners; the clean-up of flood debris; and floor surfaces, such as carpeting and tiles.

Table 4.1. **The stakeholders of the NFIP and their main responsibilities**

Federal Emergency Management Agency (FEMA)	
	Set flood insurance premiums
	Identify flood-hazard areas
	Make flood-risk maps
	Design and review of construction criteria and floodplain management by communities
	Fund mitigation projects
	Provide flood insurance
State governments	
	Authorize and assist building regulation of local governments
Local governments	
	Regulate building in floodplains
Private insurers	
	Market insurance policies
	Handle the process of paying out claims

lend money to the NFIP if it experiences deficits, and, in principle, this borrowed money should be repaid in the future. Reserves are built up by premiums. Most of the time premiums match losses, but not during times of catastrophes, such as hurricane Katrina. Reinsurers, such as Swiss Re, have no stake in the NFIP. In addition to the NFIP, private flood insurance is available that is especially attractive for industry and large commercial entities, for which the coverage limit of US$500,000 of the NFIP is too low. For example, Swiss Re reinsures clients who sell such insurance and also provides direct insurance to businesses for large risks. Apart from the NFIP, the federal government may provide federal disaster assistance to areas that have experienced a severe natural disaster, such as a hurricane or earthquake, but this ad hoc relief is not directly tied to the flood insurance program.

Amendments made to the NFIP over time. The NFIP has been a dynamically adjusted program, and has been revised several times since it was established in 1968. Insights into the main amendments and the problems they aimed to overcome are useful to comprehend the characteristics of the program that is currently in place. The main amendments made to the program are listed later in Table 4.2. In 1969 an amendment was needed because it became clear that the NFIP did not have the capacity to conduct all the detailed flood studies and flood-risk mapping in a reasonable time span. These studies were required in order to allow communities to enter the program. To solve this problem, it was decided that communities could enter the NFIP in what is called "an emergency phase," in which preliminary flood-risk studies are sufficient to enter the program. In addition, the local government needs to agree to make best efforts to control building to reduce flood risk. In principle, this amendment took away a major regulatory burden in order to facilitate more widespread participation of communities in the NFIP in the early stage of the program.

The second amendment occurred with the passing of the Flood Disaster Protection Act in 1973 (U.S. Congress, 1973). This amendment was enacted because few communities entered the NFIP, and because the market penetration of flood insurance was low until that time. Also, the incentives of the insurance program to encourage the adoption of required floodplain building regulations were insufficient. The amendment aimed to increase communities' participation by declining grants in aid for construction in flood-hazard areas to local governments which were not in the NFIP, and refusing them federal disaster assistance. Moreover, the amendment required homeowners in the 1/100 year floodplain to have flood insurance if they had federally backed mortgages in order to stimulate market penetration. These amendments to the NFIP proved to be effective in stimulating the participation of communities in the program, and increased the market penetration rate in the 1/100 year flood zones, although concerns about the monitoring and enforcement of the purchase requirement remained (Burby, 2001).

The National Flood Insurance Reform Act in 1994 aimed to further increase the market penetration of flood insurance and limit the experience of high losses by promoting risk reduction (U.S. Congress, 1994). Market penetration was stimulated by strengthening the monitoring and enforcement of the requirements to purchase flood insurance, limiting disaster assistance for households without flood insurance, and by requiring that households in the 1/100 year flood zones who received disaster assistance to purchase and maintain flood insurance. Indeed, it has been empirically verified that the purchase requirements did increase flood insurance demand (Kriesel and Landry, 2004). Moreover, the

Community Rating System (CRS) was established, which is a voluntary program that rewards communities who invest in risk reduction with premium discounts for the policyholders in their community. The majority of NFIP policyholders participate in the CRS (Burby, 2001), and it has been found that the CRS participation reduces flood claims of communities (Michel-Kerjan and Kousky, 2010).

The 1994 Act, moreover, established the Flood Mitigation Assistance Program (see Table 4.3 later for more details) that provides mitigation grants to states and local governments. In addition, the "increased costs of compliance" coverage was established that aims to help homeowners to pay the costs of making their property comply with the NFIP floodplain standards and regulations. This grant, given in the form of additional coverage, will pay the homeowner who has NFIP flood insurance a maximum of US$30,000 to comply with state or local floodplain management laws and ordinances (that include NFIP regulations) that affect the repair or reconstruction of a structure that has been damaged by flooding. Mitigation activities that are financed by this fund include elevation, floodproofing, relocation, or demolition of the building. The fund has only been applied to a limited extent, with total expenditures of US$59 million for 3,209 "increased costs of compliance" claims until 2006 (Wetmore *et al.*, 2006). This is mainly caused by strict eligibility requirements so that only specific expensive mitigation measures can be funded.

A recurrent problem for the NFIP is that certain existing buildings in a floodplain suffer flood damage repeatedly over time, because they were built in very high risk areas. About 1% of the properties insured by the NFIP are defined as repetitive loss properties and these have suffered about 38% of all flood claims since 1978 (Bingham *et al.*, 2006). The 2004 reform started a pilot program to mitigate the flood damage of properties that have suffered repetitive losses. For this purpose, the Repetitive Flood Claims Grant Program and the Severe Repetitive Loss Program were established (see Table 4.3 for more details). Nevertheless, the number of insured severe repetitive loss properties continues to grow despite NFIP mitigation efforts (U.S. Department of Homeland Security, 2009).

In summary, the discussion in this subsection shows that the current NFIP consists of a collection of various acts. The program has been subject to several major amendments over time that have aimed to solve and respond to practical problems that were mainly related to community participation, market penetration, and flood-risk reduction. While some of these amendments have been quite successful, the program faces considerable challenges, and there are a number of opportunities to improve its performance as Sections 4.2 and 4.3 will show. The remainder of this section will examine the main components of the NFIP in more detail.

Requirements for purchasing NFIP insurance. Individuals and businesses in the 1/100 year floodplain in NFIP communities are required to have NFIP flood insurance as a prerequisite for receiving any type of federal financial assistance including federal disaster assistance, and federally backed mortgages (including those provided by Fannie Mae and Freddie Mac). The objective of this requirement is to stimulate the market penetration of flood insurance. The amount of insurance coverage that needs to be purchased equals the amount of the outstanding mortgage loan, but obviously cannot exceed the maximum NFIP coverage. There are no obligations for contents coverage, unless contents serve as collateral for a loan. The regulation is enforced by eight agencies that regulate the banking and mortgage lending industry. These include the Comptroller of the Currency, the Federal Reserve Board, the Federal Deposit Insurance Corporation, the Office of Thrift Supervision, the Farm Credit Administration, and the National Credit Union Administration. Property owners are obliged to retain flood insurance for the entire duration of their mortgage loans. The federal lending regulators can impose monetary penalties on lenders that have a "pattern of practice" of violating the regulations. Lenders should assess whether a loan is secured by real estate subject to the mandatory insurance purchase requirement and, if so, notify the borrower that NFIP flood insurance is required, and ensure that flood insurance is maintained throughout the loan duration. If people "forget" to renew their policy, then the bank notices this and obtains private flood insurance for the property ("force-placed flood insurance") for a much higher rate than the NFIP flood insurance (Tobin and Calfee, 2006). The premium of the force-placed flood insurance is charged to the homeowner again. In this way the homeowner gets an incentive to apply for flood insurance through

Table 4.2. **Amendments to the NFIP**

Amendment	Problems to be solved	Main changes	Result
Insurance legislation 1969	Limited capacity for detailed flood risk studies and maps	Establish an “emergency phase” in which the NFIP makes preliminary flood studies and maps of the floodplain Flood insurance is available if the local government agrees to make its best efforts to control building to reduce flood risk	Communities could enter the NFIP without detailed flood risk studies
Flood Disaster Protection Act 1973	Low participation of communities in the NFIP	Governments not in the NFIP are ineligible for grants to aid construction in flood-hazard areas	Participating communities increased from <3,000 to >18,000 in 5 years
	Low market penetration	Homeowners of communities not in the NFIP cannot obtain federal disaster assistance	
	Insurance incentive for building regulation was inadequate	Homeowners in floodplains of communities not in the NFIP cannot obtain federally backed mortgages Homeowners in the 1/100 year floodplain with federally backed mortgages are required to purchase flood insurance	
National Flood Insurance Reform Act 1994	Low market penetration	Strengthen oversight of mandatory flood insurance purchases for homes in the 1/100 zone with federal mortgages	Flood insurance demand is observed to be higher for individuals who are subject to the mandatory purchase requirement
	High losses due to inadequate incentives for mitigation	Limit disaster assistance for households that have suffered flood losses but do not have flood insurance	More than 60% of the NFIP policyholders participated in the CRS in 2000
		Require that households in the 1/100 zone who have received disaster relief should purchase and maintain flood insurance	Empirical evidence shows that the CRS has lowered claims in a sample of communities in Florida
		Set up of the Community Rating System (CRS) that rewards communities who invest in risk reduction with premium discounts	About $20 million a year is authorized for mitigation grants
		Provision of grants to states and local governments for actions to reduce flood hazards	
		Extend coverage up to $20,000 to cover costs of building substantially damaged buildings in compliance with NFIP rules	
Flood Insurance Reform Act 2004	Repetitive losses	Program for mitigation of flood damage to properties affected by severe repetitive loss	Severe repetitive losses continue outpacing FEMA mitigation efforts

Sources: Burby and French (1985); Pasterick (1998); Burby (2001); Kriesel and Landry (2004); U.S. Department of Homeland Security (2009); Michel-Kerjan and Kousky (2010).

NFIP. This is an attractive market for private insurers, such as Lloyds, because they can charge high premiums.

Flood hazard maps and insurance premiums. An important task of FEMA is to produce flood hazard studies and maps. This task consists of delineating flood hazard areas, mapping floodways, flood elevations, and flood velocity. FEMA defines the floodway as "the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation to more than a designated height." Floodplains or flood zones are defined as areas that can be inundated by a specific flood event, and are often expressed as having a certain flood probability, such as the 1/100 year floodplain. These flood hazard studies form the basis of the creation of FIRMs. FEMA determines the insurance premiums on the basis of historical losses averaged for the entire United States. The insurance rates are divided into a few groups and depend on a flood-zone classification system. It should be noted that similar standard premiums are charged per flood zone across the United States, regardless of whether a community has suffered repeatedly from very high flood losses, or at the other extreme, has never experienced major flooding. The NFIP classifies flood zones according to their flood return period. An important flood zone is the area that is flooded 1 in 100 years on average, which is defined as the special flood hazard area (SFHA). The following differentiation has been made to reflect different levels of flood risk: namely, moderate to low risk (zones B, C, and X), which is outside the 1/100 year floodplain; high risk (zone A) which is in the 1/100 year floodplain; and the high-risk 1/100 year floodplain in coastal areas (zone V) (Table 4.3).

Table 4.3 shows the standard premium levels in the different zones for residential insurance policies that cover damage to buildings and contents, only buildings, or only contents. This table gives an indication of the degree of premium differentiation across the distinctive flood zones. Actual rates depend on, among other factors, the type of building, number of floors, the level of coverage, and the deductible.[g] The table only gives the rates for the maximum coverage, which are US$250,000 for residential buildings and US$100,000 for contents.[h] Two types of policies are available in moderate to low risk zones: the preferred risk policy and the standard policy. The premiums of a preferred risk policy are considerably lower and are only applicable to households that meet specific eligibility criteria that depend on the buildings' entire flood loss history.[i] Only standard policies are available in the A and coastal V zones that are at higher risk, and have consecutively higher premiums of up to US$5,700 in the latter zone. Average flood insurance premiums in NYC are US$776 per year for an average coverage per policy of US$218,563, which is relatively high compared with average coverage in other states mainly because of the higher average values of the properties in the former (Michel-Kerjan and Kousky, 2010).

Existing buildings in floodplains that were erected before the creation of the NFIP flood-risk maps pay lower premiums. Premiums paid for insurance coverage for such buildings are in between 35% and 40% of the true risk premium (Bingham *et al.*, 2006). This subsidy is granted because it was considered unfair for these homeowners to pay high rates, since they may have lacked the knowledge that their building was in a floodplain. Moreover, these subsidies were meant to encourage homeowners to purchase flood insurance, and stimulate communities to join the NFIP (Burby, 2001). The premiums in Table 4.3 are standard premiums, and individual policyholders may obtain reductions in their premium if the lowest floor of their house is located above the BFE level of the 1/100 year flood. These reductions in premiums can be obtained for both new and existing buildings. New buildings have to be elevated at least to the BFE level according to the NFIP regulations, and only buildings that are further elevated can obtain a premium discount. In order to be eligible for the premium reduction, the policyholders

[g]Policyholders can choose among six deductible levels: US$500, US$1,000, US$2,000, US$3,000, US$4,000, and US$5,000. The lower the deductible, the higher the insurance premium charged by the NFIP.

[h]The coverage limit for the contents of nonresidential buildings is US$500,000.

[i]Homeowners are ineligible for a preferred risk policy if they have had two previous claims or have received flood disaster relief payments of US$1,000 or more, or three losses of any amount.

Table 4.3. Standard annual flood insurance premiums for residential properties in 2010

Risk level of the area	Zone	Policy	Building and contents	Only building	Only contents
Moderate to low risk	B, C, X	Preferred risk	$395[a]	NA	$228[b]
Moderate to low risk	B, C, X	Standard	$1,489	$911	$618
High risk	A	Standard	$2,633	$1,620	$1,053
Coastal high risk	V	Standard	$5,700	$3,487	$2,253

[a]This premium is for buildings with a basement or enclosure and is higher than for buildings without a basement or enclosure.
[b]This premium is lower if only the contents above the ground floor are insured.
Source: FEMA (2010).

have to submit an elevation certificate to an insurance agent that is made by licensed engineers and surveyors. This elevation certificate shows the BFE level, the elevation of the structure, and the location of the building in the floodplain.

Policyholders can, moreover, obtain premium discounts through the CRS that reward communities who invest in risk reduction with premium discounts of up to 45% of the full rates defined by FEMA. These credits benefit all of the NFIP policyholders in a community because they get a percentage reduction in premiums. The CRS assigns a ranking of 10 classes, where a "1" indicates that the community has taken the most significant collective flood mitigation measures, while a "10" is given to communities who have done nothing in this respect. Table 4.4 shows the premium discount that can be obtained per class. Communities can improve their ranking by implementing a range of mitigation strategies, improve flood awareness, or facilitate accurate insurance ratings. The CRS discount is not applicable to preferred risk policies.

NFIP requirements and mitigation of flood damage. In principle, communities decide themselves whether they want to join the NFIP, although a few state governments require that their communities participate in the program (Burby, 2001). The NFIP has established the eligibility requirements related to flood-risk reduction that communities have to meet in order to be covered by the flood insurance. For example:

- Local governments have to restrict development in floodways, but they are not required to apply zoning regulations in the remainder of the floodplain;
- The ground floor of new constructions in the 1/100 year flood zone needs to be elevated to the estimated BFE;
- Existing structures should meet this elevation criterion if improvements are made to the structure that exceed 50% or more of its market value;
- Mobile homes need to be anchored and are no longer allowed to be built in the floodway; and
- Subdivisional proposals, which are areas of real estate that are composed of subdivided lots, are to be reviewed to limit flood risk. For example, the works should be consistent with minimizing flood damage in the flood-prone area; public utilities and facilities should be located and constructed while simultaneously minimizing or eliminating flood damage; and an adequate drainage system should be provided.

The elevation requirements in the 1/100 year floodplain and prohibitions to build in floodways remain in force after the community has entered the program. The NFIP enforces local compliance with the flood insurance legislation and can conduct site visits to local governments, and state governments can report violations to the NFIP. Moreover, enforcement is checked through the "rate applications" that are made in a specific community. If a homeowner applies for flood insurance then a special assessment of the building is required for estimating premiums if the building does not meet the general standards. For example, such a special assessment is needed if the elevation is further below the BFE than can be indicated on the standard application forms for flood insurance. These rate applications are submitted to FEMA, and together

Table 4.4. **Community Rating System (CRS) premium discounts per class**

Class	Discount	Class	Discount
1	45%	6	20%
2	40%	7	15%
3	35%	8	10%
4	30%	9	5%
5	25%	10	0%

Source: FEMA (2006).

form a database that FEMA can use to evaluate the level of compliance of structures with the NFIP standards.

Mitigation grant programs. Table 4.5 provides the main characteristics of the five most important currently available mitigation grant programs of the NFIP. The Hazard Mitigation Grant Program can provide mitigation funds to state and local governments and to some private non-governmental organizations after a disaster has occurred, as indicated by a presidential disaster declaration (FEMA, 2009). The main aim of this fund is to promote more hazard-resilient rebuilding after a disaster. The fund is not limited just to financing only flood mitigation, but also provides funds to mitigate other hazards, such as earthquakes and wildfires. The Flood Mitigation Assistance Program is specifically geared towards mitigating flood damage and provides grants to state and local governments for developing FEMA applications, assessing risk and developing mitigation plans, and implementing projects that "flood-proof" buildings. The Pre-Disaster Mitigation Program was authorized in 2000. The main objective was to allow the funding of mitigation measures under the Hazard Mitigation Grant Program before disasters occur, which was regarded as being more effective than only providing mitigation funds to areas that have actually suffered from a disaster.

The Repetitive Flood Claims Grant Program funds 100% of those mitigation measures for structures that have one or more NFIP loss claims (see Table 4.5), and is paid out of NFIP premium revenues. Funding will be prioritized for those applications that can result in the largest cost-savings for the NFIP. In addition, the Severe Repetitive Loss Program provides financial resources to state and local governments for mitigation activities, such as elevation, relocation, demolition, rebuilding, floodproofing, and purchasing the property (see Table 4.5). These state and local governments have to match 25% of the funding provided, which may be reduced to 10% if the state has an approved mitigation plan, and if FEMA has determined that it has taken action to reduce the number of severe repetitive loss properties. The FEMA grant is paid out of NFIP premium revenues. If a homeowner with a severe repetitive loss refuses to agree with a reasonable mitigation offer, then the flood insurance premium will be increased to 150% of the chargeable rate of the property at the time of the flood loss. At the maximum, this chargeable rate is the estimated risk premium of the area. The mitigation fund consisted of US$40 million in 2006 and 2007, US$80 million in 2008 and 2009, and US$70 million in 2010. In NYS and the state of New Jersey, respectively, 206 and 509 buildings have been validated as a severe repetitive loss property, and about US$4 million and US$11 million of grants have been provided out of the mitigation funds to "flood-proof" these buildings in NYS and the state of New Jersey, respectively (U.S. Department of Homeland Security, 2009).

4.2. Strengths and weaknesses of the NFIP

Several studies have critically reviewed the performance of the NFIP, and recommended major revisions to improve the program, which mostly focused on more effective incentives and policies for flood-risk mitigation (Burby, 2001, 2006; Wetmore *et al.*, 2006; Kunreuther *et al.*, 2009). These studies do not provide an explicit or in-depth assessment of how the NFIP needs to be geared towards dealing with a potential increase in future flood risk as a result of climate change, as is the focal point of this study. Nevertheless, the recommendations of existing studies about how the NFIP can be geared toward achieving risk reduction are especially relevant in the context of the future increase in flood risk due to climate change that is projected for some regions in the United States. Our study provides a novel contribution by especially focusing on how the NFIP can accommodate, and contribute to, flood resilient waterfront development in NYC, although many of the issues addressed are more broadly applicable.

Requirements for purchasing insurance through the NFIP. Although the NFIP has been successful in providing many homeowners with flood insurance that would otherwise not be available, the market penetration of flood insurance is rather low.

Table 4.5. Mitigation grant programs from FEMA

Mitigation grant	Requirements	Eligible recipients	Main measures funded	Yearly financial capacity
Hazard Mitigation Grant Program	Presidential disaster declaration	State and local governments Some private non-governmental organizations	Elevation of homes and businesses Demolition or relocation of homes Retrofitting buildings Flood control projects for critical facilities Construction of safe rooms for tornado protection	Sliding scale funding of 3 portions: (1) 15% of first US$2 billion of disaster assistance (2) 10% of disaster assistance between US$2 and US$10 billion (3) 7.5% of disaster assistance between US$10 and US$35.333 billion
Flood Mitigation Assistance Program	Flood mitigation plan for project grants	States and communities	Planning grants for assessing risk and developing flood mitigation plans Project grants for elevating, acquiring, demolishing, or relocating NFIP insured buildings Technical assistance grants for developing FEMA applications and implement projects	US$32.3 million in 2010
Pre-Disaster Mitigation Program	Flood mitigation plan	States and communities	Elevation and relocation of existing public or private structures Flood control projects for critical facilities Protective measures for utilities Stormwater management projects Vegetation management for natural dune restoration, wildfire, or snow avalanche Structural and nonstructural retrofitting Construction of safe rooms for public and private structures Voluntary acquisition of real property	US$90 million in 2009
Repetitive Flood Claims Grant Program	One or more claim payments from NFIP Ineligible for flood mitigation assistance program State hazard mitigation	States and communities	Acquisition, structure demolition, or structure relocation, with the property deed restricted for open space uses in perpetuity	US$10 million per year
Severe Repetitive Loss Program	Only for residential properties Flood losses that resulted in either within a 10-year period (1) four or more flood insurance claims payments each > $5,000 with at least two of the payments made, or (2) two or more flood insurance claims payments that cumulatively exceeded the property value	States and communities	Elevation, relocation, or demolition of existing residential properties Flood-proofing measures for historic properties Minor physical localized flood control projects Demolition and rebuilding of properties to at least the base flood elevation (BFE) or greater if required by any local ordinance	US$70 million in 2010

Sources: Burby (2001); FEMA (2008); FEMA (2009); www.fema.gov

The exact market penetration of the NFIP is difficult to assess, but a study has been made by Dixon *et al.* (2006). According to these authors, only about 49% of single family homes in the 1/100 year flood zone carry NFIP flood insurance, which is similar to estimates by Kriesel and Landry (2004) for coastal areas in the United States. Market penetration is very low (about 1%) in the flood zones without the mandatory insurance purchase requirement. Large regional differences exist in market penetration rates. As an illustration, market penetration is estimated to be only 28% in the northeast of the United States, while it is the highest at 60% in the south. This sample excludes NYC and to our knowledge, there is no specific study about market penetration of flood insurance in NYC. Total NFIP policies in force in NYC were about 37,000 in 2010, which suggests that market penetration is also low in NYC. The market penetration of commercial flood insurance is even more uncertain than that of the NFIP, because it is not monitored and reported. Kriesel and Landry (2004) estimate that the market penetration of commercial flood insurance is only about 4% in coastal areas (across all flood zones). Large industrial risks are likely to carry flood insurance coverage.

There are several explanations for the low market penetration of flood insurance. The mandatory purchase requirement of flood insurance only applies to federally backed mortgages of homeowners in the 1/100 year flood zone, while there are no obligations for tenants to purchase flood insurance. This severely limits the scope of the obligation, and only an estimated 50% to 60% of the single-family homes in the 1/100 year zones are subject to the mandatory insurance purchase requirement (Dixon *et al.*, 2006). There are no obligations to purchase flood insurance outside the 1/100 year flood zone. Many homeowners drop the coverage once their loans have been paid off, because they are only required to purchase insurance coverage for the portion of the mortgage that is outstanding (Tobin and Calfee, 2006). Compliance with the requirement is estimated at approximately 75% to 80% (Dixon *et al.*, 2006). Enforcement may be complicated because FEMA has no authority over the eight financial institutions that are responsible for checking compliance with the requirements (Wetmore *et al.*, 2006). Several behavioral explanations have been put forward to explain the low voluntary purchase of flood insurance, such as low risk perceptions and awareness by individuals (Browne and Hoyt, 2000).

The low market penetration is an impediment for stimulating flood-risk reduction through insurance. The aforementioned empirical studies of NFIP market penetration indicate that many households are not insured, which implies that insurance does not impose market discipline by promoting risk reduction or prevent uneconomic use of the floodplain. The low market penetration has, moreover, the adverse effect that the ability to spread risk is impaired, which generally results in higher premiums for the remaining pool of insured. The NFIP insurance may suffer from adverse selection that causes the observed shortfall of premium revenue compared with claims, because flood insurance does not generate enough revenue if homeowners with lower risk do not purchase it. Adverse selection in insurance markets occurs if mostly individuals with a high-risk choose to purchase insurance, while insurers are insufficiently capable of distinguishing low- from high-risk policyholders and charging the latter a higher premium. Especially in the face of a projected rise in flood risk due to climate change, it is desirable to stimulate the take-out of flood insurance and increase the market penetration in order to improve risk sharing and make better use of the tools that insurance offers to encourage households to invest in risk reduction. If climate change increases flood risks, then this would imply that more uninsured households would suffer flood damage, which would either increase the need for federal disaster assistance or leave many households uncompensated and in financial distress. A higher market penetration of flood insurance could, therefore, be a way to alleviate the impacts of, and promote adaptation to, climate change.

FIRMs and insurance premiums. An important strength of the NFIP program is that it provides a platform for studying flood risk and creating flood hazard maps for the communities in the United States, which is a tremendous task given the large geographical area of the country. Indeed, the NFIP delineates flood-hazard areas for most of the United States, and updates their FIRMs, which are publicly available on the Internet. An accurate and detailed assessment of the regional flood risk is essential for a well-functioning insurance program, because it is the input needed to set actuarially based premiums that reflect risks. Moreover, such maps provide important information for local floodplain management policies.

According to Burby (2001), the quality of the flood-risk studies falls short of achieving an accurate risk assessment for four reasons, which have nationwide implications and do not only apply to NYC. First, there is a lack of funding to keep flood insurance maps up to date by revising them frequently enough so that they reflect changes in local conditions. Second, no maps are created for areas subject to localized stormwater drainage flooding and areas that are vulnerable to the failure of dams and flood control infrastructure. If areas are protected by levees that are high enough to withstand the 1/100 year flood level, then these areas are mapped out of the 1/100 year zone. However, it has been asserted that maintenance of levees is often inadequate, and a variety of failure mechanisms exist that cause the flood probability to exceed the 1/100 level, which would provide a rationale for taking a more prudent approach and mapping these areas more carefully (Bingham *et al.*, 2006). Third, neither maps have been created nor are regulations in place for probable future hazards and changes in risk that could, for example, arise because of watershed development, land subsidence, erosion, and sea-level rise caused by climate change. Fourth, the maps are often not detailed enough for incorporating flood hazards in land-use planning and management. For example, our discussions with local planners in NYC revealed that, in practice, a single property can lie partly within, and partly outside, the 1/100 year flood zone demarcation line. In that case, inspectors need to determine whether the property needs to comply with the flood building codes.

The consequences of the resulting inaccuracy of FIRMs are three-fold. First, although premiums partly depend on the flood-zone classifications, premiums do not completely reflect actual risk if the maps are inaccurate. This impairs incentives for homeowners to limit risk (Kunreuther, 2008). Second, the decision not to map certain risks, such as the failure of flood protection, results in an underestimation of flood risk and premiums that are too low, which contributes to the operating losses incurred by the NFIP, and distorts incentives for mitigation (Burby, 2001). In the past, the NFIP has experienced considerable shortfalls of premium revenues compared with payouts of claims: in particular operating losses occurred in the 18 years between 1972 and 2005 (Pasterick, 1998; Burby, 2006). Third, Burby (2001) recognizes that, in general, the spatial (in)accuracy of flood-risk maps, the lack of detailed geo-references, and the lack of property lines indicating the location of structures are problematic for local governments if they desire to implement stricter building codes than the NFIP requires and regulate land use in floodplains.

The inaccuracy of the current flood hazard maps is especially problematic in the face of the projected rise in flood risk as a result of climate change. If current hazard information is insufficient to steer effective risk reduction by individuals and governments, then the resulting suboptimal flood protection and preparedness may turn out to be very costly when flood risk increases in the future. Moreover, a continuous process of updating maps may be especially important if risk changes over time not only because of socioeconomic developments in the floodplains, as has been the case in the past, but also because of changes in the frequency and intensity of the flood hazard due to changes in precipitation, storms, and sea-level rise. Accurate and up-to-date FEMA flood hazard maps are important in steering appropriate waterfront development in NYC. For example, the delineation of the 1/100 year flood zone determines the minimum standards to which new constructions are subject, and whether it is mandatory for new construction financed with federally backed mortgages to carry flood insurance. Moreover, the flood hazard maps are an input for the insurance rates, which can provide an important price signal that may steer new development and provide homeowners and contractors with incentives to implement mitigation measures.

In general, the premiums of the NFIP do not completely reflect risks (LeBlanc and Linkin, 2010). There are four main reasons for this. First, the premiums of buildings in the 1/100 year floodplain that were constructed before the NFIP was enforced are subsidized. Although, the percentage of subsidized policies declined from 83% of total policies in 1985 to approximately 25% in 2004, the number of such policies remains high (Bingham *et al.*, 2006). In principle, premiums are actuarially based for new constructions. Second, the existing premium levels are high enough to ensure that the NFIP can pay its claims in an "average historical loss year," but not a catastrophic year. This implies that, in general, premiums are too low. The average premium shortfall before Katrina was about US$800 million per year, which needs to be borrowed from the federal government (Bingham *et al.*, 2006). In some years, shortfalls of premium revenue of the NFIP were considerable. For instance, FEMA paid US$19.28 billion of claims in the destructive hurricane season in 2005 compared with an annual US$2.2 billion in premium revenues, which required a large expansion of the borrowing capacity of the NFIP (Michel-Kerjan and Kousky, 2010). Third, the premiums and deductibles remain the same, even after repetitive losses have been suffered (unlike the case with car insurance after many accidents). It is noted here that most repetitive losses occur in the Gulf States. Fourth, the current premium differentiation is based on relatively few risk zones that are the same for the whole nation with no distinctions made for different states or counties (GAO, 2008). For example, the areas of 1/100 and 1/500 years are very large in certain cases, and there is no differentiation of premiums within the zones.

Incentives for homeowners to implement risk reduction measures are distorted if premiums do not accurately reflect risk, which can be especially troublesome if more investments in mitigation are needed in the future due to risk increases. A useful characteristic of the program is that homeowners get an incentive to invest in an elevation above the BFE level because this can lower their premiums. Nevertheless, it has been argued that the NFIP should re-evaluate flood insurance premium discounts for buildings in A zones, because A zone discounts effectively cease at 1 to 2 ft above the BFE, even though a higher elevation would be desirable (Jones *et al.*, 2006). A future challenge is that the BFE is projected to increase in many places, as the estimates made for future flood zones for NYC show (Rosenzweig and Solecki, 2010). Another problem with increasing flood risk due to climate change is that updates of FIRMs over time will imply a shift in the zone classification for many properties. The current regulation for such properties is that property owners who are remapped to a more costly zone classification are charged the lower insurance premium of the former flood zone through grandfathering (Bingham *et al.*, 2006). If this policy continues then it may be expected that the number of properties that pay such subsidized rates would increase considerably in the future.

The CRS gives communities incentives to implement mitigation measures in return for premium discounts. Although, in principle, this may be a good incentive for communities to increase mitigation investments, concerns have been raised that the CRS contributes to the too low levels of premiums in some communities (Burby, 2001). Our discussion with government experts in the New York area revealed that the CRS is not attractive for NYC. It is unclear for policymakers how the credits relate to specific measures and policies, and what the resulting premium reductions are. This has been examined for NYC but turned out to be administratively very complex and not worthwhile. It could be useful for FEMA to change this credit system so that its eligibility requirements are better suited to the needs of a densely populated city like NYC.

NFIP requirements and mitigation of flood damage. The NFIP aims to link flood insurance to improved risk prevention and damage mitigation at both the community and individual level. At least the NFIP forced the local governments to pay attention to managing urban development in a way that reduced flood risk in order to be eligible for flood insurance. It has been estimated that the NFIP standards and mitigation programs have saved in total over US$1 billion of flood losses per year (Sarmiento and Miller, 2006). However, it has been recognized that more can be done in this respect (Burby, 2001). The program has been rather effective in limiting the vulnerability of new constructions to flood hazards. Pasterick (1998) showed that buildings that were constructed before the enforcement of the NFIP standards suffered approximately six times more flood damage than buildings that were constructed in compliance with the NFIP standards.

Even though the NFIP requirements are quite successful in floodproofing new buildings, the program is generally evaluated as being ineffective in limiting new developments in high-risk areas. As an illustration, during the first 30 years of the NFIP the number of buildings in such areas has increased by 53% (Burby, 2001). These trends are likely to continue in the future, as is apparent from Figure 4.1 which shows the past and projected increase in the number of buildings in SFHAs, which is the 1/100 flood zone. Although the number of old buildings

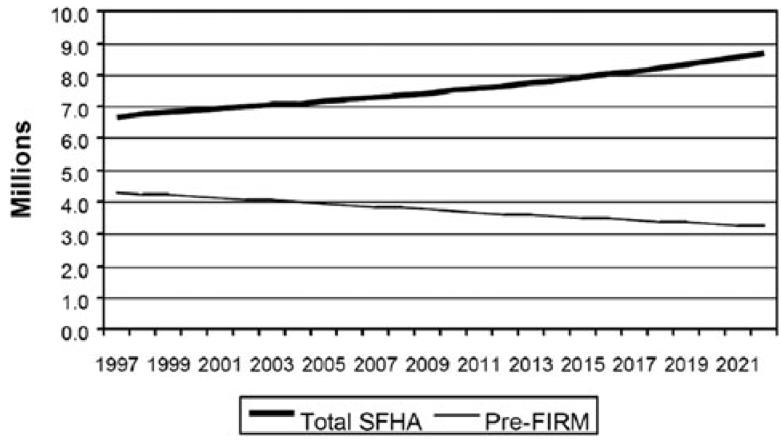

Figure 4.1. **Total historical and projected future number of buildings in SFHAs in the United States, and Pre-FIRM buildings. Source: Wetmore *et al.* (2006).**

constructed before the NFIP (Pre-FIRM) is expected to decrease, the total number of buildings in SFHA is increasing due to rapid urbanization in flood-prone areas. It should be recognized that large regional differences exist in the success of steering development away from high flood-risk zones. Fast-growing coastal communities appear to have been least successful in shifting development to non-vulnerable areas (Burby and French, 1985; Burby 2001), which is probably because of the high opportunity costs of building further inland.

In contrast to the success of floodproofing new constructions, the program did very little to reduce the vulnerability of existing buildings to flood hazards. Very few homeowners in the United States have taken measures to limit flood risk in existing buildings (Kunreuther and Roth, 1998). The NFIP can purchase insured properties that have flood damage representing more than 50% of their value, or have been repeatedly damaged. These houses can then be relocated or demolished. Approximately 1,400 properties were purchased at a total cost of US$51.9 million between 1968 and 1994 (Pasterick, 1998). Although this seems like a good strategy to deal with old buildings located in very high risk areas, the program continues to suffer from the problem of repetitive flood losses affecting existing buildings. For instance, properties suffering from repetitive loss were estimated in 2004 to cost the NFIP about US$200 million annually. NYS ranks in the sixth place of states with the most insured repetitive losses in the United States. It has 7,141 repetitive loss properties and suffered in total 100.4 million of insured repetitive losses between 1978 and 2002 (King, 2005). A factor that contributes to the problem of severe repetitive losses is that the premiums charged for these properties are not actuarially-fair and often too low, which impairs incentives to floodproof these buildings (U.S. Department of Homeland Security, 2009).

Another problem is that violations of the NFIP mitigation standards by local governments and homeowners are not uncommon and have resulted in considerably more losses in the past than would have occurred if regulations were adhered to (Burby, 2001). Moreover, many buildings that are exposed to flooding are currently unregulated by the NFIP because they are located outside the 1/100 year flood zone. The decision to regulate only the 1/100 year flood zone has been criticized, and seems to have been based on political criteria instead of efficiency grounds guided by cost-benefit analyses. This has been acknowledged by FEMA (2006) in its evaluation of the NFIP. Most flood losses in the United States are caused by less-frequent flood events (Burby, 2001). The program could increase its effectiveness by regulating flood zones affected by lower probability floods, such as the 1/500 year floodplain (Association of State Floodplain Managers, 2000).

Mitigation grant programs. FEMA has been actively involved with funding flood prevention by state and local governments and their efforts to mitigate potential flood damage to structures. The availability of the grant programs can be a motivation for communities to join the NFIP, while it reduces the costs of flood hazards to the NFIP and society in general. However, there could be scope to expand the grant programs for mitigation. The budgets of, respectively, the Flood Mitigation Assistance Program and the Pre-Disaster Mitigation Program are, in total, US$32 and US$90 million, which is not very large when it is considered that this applies to the entire United States, while the latter program also funds non-flood-related mitigation measures. Indeed, more investments in mitigation seem to have a high benefit compared with costs. The National Institute of Building Sciences (2005) has estimated that effective flood hazard mitigation has an overall benefit–cost ratio of 5 to 1.

The Repetitive Flood Claims Grant Program and the Severe Repetitive Loss Program seem promising initiatives to tackle the problems that the NFIP has experienced with repetitive losses. However, the budgets of these programs are, respectively, US$10 million and US$70 million per year, which appears to be too small for solving the problem with repetitive losses in a short time span. The costs to acquire the current properties defined as severe repetitive losses are estimated to be US$1.8 billion (U.S. Department of Homeland Security, 2009). This is considerably higher than the current funding available for the mitigation program for severe repetitive losses, which had, in total, US$160 million available in 2009. Although this may be enough to gradually reduce severe repetitive loss claims, it should be noted that the number of severe repetitive loss properties tends to increase over time, which may be accelerated by the projected increase in flood risk due to climate change. Another limitation is that many of the grant programs, such as the Severe Repetitive Loss Program, have a cost-sharing condition for local governments of about 25% before FEMA provides the flood damage mitigation grant. Local governments often lack these financial resources, which results in a limited applicability of the grants (U.S. Department of Homeland Security, 2009).

It seems unlikely, therefore, that the current grant programs will free up sufficient financial resources to finance the required adaptation policies and measures that will be needed to accommodate rising flood risk due to climate change. Examples of adaptation measures that could prevent the projected rise in flood frequency are beach nourishment, building dikes, sea walls, and storm surge barriers. Moreover, sea-level rise may increase the areas that will be inundated during floods, such as the 1/100 year flood-zone, which requires additional mitigation measures for buildings, such as elevating new constructions. There is much uncertainty about the costs of adaptation, which is obviously dependent on the uncertain impacts of climate change on flood risk. As an illustration of the possible size of these costs, Nicholls (2003) states in a study for the OECD that costs to adapt to a one meter sea-level rise could be in the order of US$257 billion (2010 values)[j] for the United States, considering only direct protection, and assuming no changes in storm conditions. This estimate may be considered an underestimation, because many cost categories are excluded, such as the costs for floodproofing buildings. Adaptation costs would be considerably more expensive in some places than in others, partly because current protection levels are already suboptimal, which has been defined as an "adaptation deficit." For example, Nicholls (2009) mentions NYC as an example of a city with a large "adaptation deficit" because parts of NYC are currently insufficiently protected against storm surge and flooding with hard infrastructure, such as coastal protection by dikes, high sea walls, or barriers. The current grant programs are, moreover, too limited in scope to provide a meaningful financial contribution towards building new waterfront development in NYC in a floodproof and climate-change resilient manner, because the grants mainly focus on protecting existing buildings from flood damage.

4.3. Suggestions for improving the NFIP and international examples

The Section 4.2 identified several weaknesses of the NFIP with respect to dealing with the impacts from climate change and ongoing socioeconomic developments in flood-prone areas. This section provides several suggestions for improvements, in particular concerning:

- enhancing the NFIP's market penetration;
- improving flood hazards maps;

[j] Nicholls (2003) reports that these costs are US$156 billion in 1990 values, which has been transformed to the 2010 price level using the consumer price index.

- charging insurance premiums that reflect risk;
- extending the duration of insurance contracts;
- addressing climate change in the NFIP requirements; and
- broadening mitigation grant programs.

Enhancing the NFIP's market penetration. The currently low market penetration of the NFIP flood insurance could be increased so that more households would have their flood losses covered by insurance after a flood event, and more buildings would be subject to the NFIP mitigation requirements. There seems to be some scope to improve the enforcement of the mandatory purchase requirement for homeowners with federally backed mortgages who live in the 1/100 year flood zone. Nevertheless, there would still remain a very low market penetration outside the 1/100 year zone. Raising risk awareness in areas with lower probability floods could bring about a higher demand for flood insurance. Given that the 1/100 year flood zone is expected to increase in the future, consideration should be given to making insurance compulsory in the expected future 1/100 year zone or in a current flood zone with a larger flood return interval, such as the 1/500 year zone. Expanding the mandatory purchase requirements brings the benefit that more constructions that are expected to be at future risk of flooding would be subject to the NFIP mitigation requirements. Alternatively, coverage against flooding could be made compulsory on all existing building and home contents insurance policies that, for example, cover fire risks, which could result in a very large risk pool and high market penetration. This is the practice in France where flood insurance is covered via a natural disaster insurance coverage called CatNat, which is compulsorily included with property insurance. This requirement has resulted in an almost universal market penetration among both tenants and homeowners (Poussin *et al.*, 2010). If such a requirement were to be introduced in the United States, then it would be important to set premiums according to risk in order to provide adequate incentives for mitigation. Furthermore, the French property insurance provides coverage against a variety of natural hazards via the CatNat system, and it could be useful to explore the application of this system in the United States. Broad natural hazards coverage could prevent the problems that homeowners in the United States have experienced about whether hurricane damage should be covered by the NFIP flood insurance or private windstorm damage insurance, which resulted in long and expensive lawsuits after Hurricane Katrina (Kunreuther and Michel-Kerjan, 2009).

Improving flood hazard maps. The discussion in Section 4.2 highlighted that there is scope to improve the accuracy of existing flood hazard maps produced by FEMA. More detailed maps would be useful to guide local land-use planning. Moreover, it could be useful to map residual risk more extensively, such as areas protected by levees, in order to improve the information about potential flood zones, and ensure that adequate building code regulations are in place in such areas. Also, a mechanism could be put in place that allows for regular updates of flood hazard maps, so that changing local conditions such as developments in flood-prone areas are adequately accounted for in estimating the flood zones. At this moment, FEMA is updating its flood maps in its "Flood Hazard Map Modernization Initiative," which has been work in progress since 1997 (Morrissey, 2006). The plan is to update all flood hazard maps and create digital maps that can be used by computer applications. Even though the creation of digital flood maps could lower the costs of updates, concerns have been raised about whether FEMA has the capacity to regularly update maps that reflect the continuously changing conditions in risk in the future (Morrissey, 2006).

To implement measures to limit the expected future increase in flood risk due to climate change, it would be useful to make maps that indicate the expected future change in the floodplain or change in risk. For example, it could be useful to know where the future 1/100 year flood zone will be (e.g., in the year 2050). Knowing the future 1/100 flood zone offers the possibility to impose the same requirements that apply to the current 1/100 year zone, such as elevating new buildings, to the future 1/100 year zone. Such a policy could ensure that adequate mitigation measures are undertaken in what is expected to be the future floodplain. Given the long lifetime of new constructions, such regulation would anticipate the current problems with floodproofing existing properties.

It can be questioned whether FEMA currently has the financial and human resource capacity to produce future-looking flood hazard maps. A more

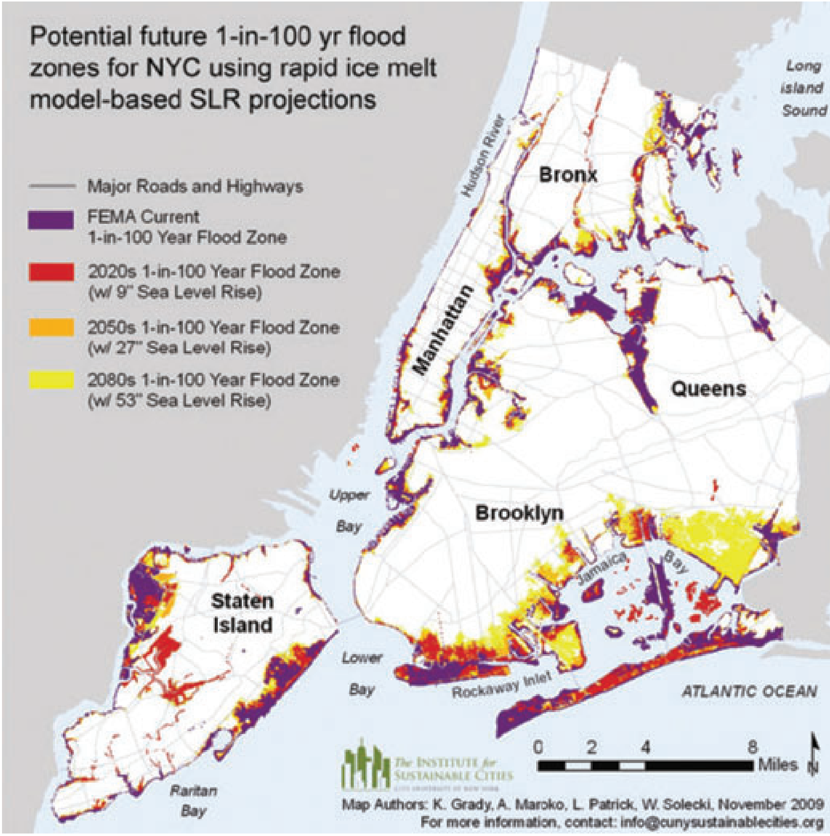

Figure 4.2. Current 1/100 year flood zone for NYC and potential future 1/100 year flood zones under various scenarios of climate change. Source: Rosenzweig and Solecki (2010).

active role for the insurance industry may be needed to create flood hazard maps, as is, for example, the case in the UK and Germany (De Moel *et al.*, 2009). Alternatively, local governments with a large exposure to flood risk and a strong adaptation policy agenda, such as NYC, may take the lead in this and produce their own future flood hazard and risk maps. Rosenzweig and Solecki (2010) made an initial estimate of the future 1/100 year flood zone for NYC, which is shown in Figure 4.2. This map does not show the exact boundaries of the 1/100 year flood, but is a rough indication of how the current 1/100 year zone may change in the future. There is a high degree of uncertainty about the extent of future flood zones, and more research is needed if future flood maps are to be used as an input in insurance, flood zoning, or building regulations. To effectively guide adaptation, a more accurate and detailed analysis is in order, while an estimation of the geographical distribution of flood risk is needed in order to indicate those locations that are especially vulnerable to flood damage. Current and future flood risk in NYC can be estimated more precisely with catastrophe models and the expertise of insurance companies and academics (LeBlanc and Linkin, 2010). The knowledge to create such maps has already been developed in other countries: for example, the modeling of current and future flood risk is already common practice in the Netherlands (e.g., Bouwer *et al.*, 2010).

Charging insurance premiums that reflect risk. Section 4.2 indicated that the NFIP insurance premiums do not accurately reflect the actual risk faced by policyholders. It has been well recognized that risk-based premiums can facilitate risk reduction by providing a price signal of risk of settlement in risk-prone areas, and by providing incentives to policyholders for risk reduction (Kunreuther, 1996; Botzen *et al.*, 2009). Kunreuther *et al.* (2009)

propose that premiums that reflect risks are a fundamental guiding principle to develop efficient insurance protection against natural disaster risks. The application of this principle would provide a signal of relative flood damage to those currently residing in flood-prone areas and those who are considering moving to those locations, such as constructions near the waterfront. Indeed, such homeowners are charged higher rates if they move into, for example, a coastal flood zone (see zone V in Table 4.3), but the current crude relationship between premiums and actual risk provides an inaccurate or "noisy" signal of risk, at best. Adequate incentives to policyholders, such as premium discounts, to invest in cost-effective flood-risk reduction cannot be provided through insurance, unless premiums reflect the risk of exposure to floods.

The NFIP could set actuarially fair premiums that better reflect risk in order to make more effective use of the insurance mechanism to steer risk reduction by individuals. This could be implemented in the current program by charging premiums that are high enough to not only cover losses in an average loss year but are also on average capable of covering losses of catastrophic floods, and by better differentiating premiums according to the actual flood risk faced by policyholders. Moreover, the current subsidies given to premiums of pre-FIRM buildings could be phased out over time (Bingham *et al.*, 2006), and the grandfathering of lower premiums for structures that are rezoned to a higher risk area after a map update could be abolished.

Alternatively, a greater role may be given to private insurance companies in the pricing and underwriting of risk, which could result in more actuarially sound rates. This is, for example, current practice in the UK where flood insurance is provided by the private sector without government support (Crichton, 2008). In the UK, premiums are differentiated according to risks and insurers obviously have an incentive to set premium levels high enough to recoup flood losses. With a higher spatial accuracy of mapping risk, the NFIP could improve pricing the risk into actuarially fair premiums.

Changing the premium structure of the NFIP by charging homeowners premiums that fully reflect risk brings about important equity and affordability issues. While the premiums of policyholders with a very low risk would decrease, premiums would increase for policyholders in flood-prone areas with a very high flood risk. This rate of increase for households currently residing in hazard-prone areas may be regarded as inequitable, and low-income households may not be able to afford higher risk based premiums. Therefore, some form of income support or compensation could be given to these individuals to overcome this issue of equity. However, any treatment should come from public funding and not from subsidies on insurance premiums in order to provide incentives for risk reduction. For instance, tax reductions could be provided to partly compensate for the drop in households' disposable income due to higher insurance premiums. Along the lines of the current food stamp program in the United States, Kunreuther *et al.* (2009) propose the introduction of "insurance vouchers" provided by the state or federal government that would enable low-income residents to purchase insurance. Nevertheless, it should be noted that such special treatments are only needed in the short term, since they should not apply to new residents that locate in flood-prone areas, as otherwise there would be an incentive to settle in hazard-prone areas in order to be eligible for these benefits.

Extending the duration of insurance contracts. The short-term nature of the current flood insurance policies of only one year may restrain active collaboration between insurers and policyholders in reducing exposure to flooding. Several scientific experts have suggested introducing long-term flood insurance contracts that are tied to properties instead of to individuals with a duration of, for example, 5, 10, or 20 years (Kunreuther, 2008; Kunreuther *et al.*, 2009). Such long-term contracts would establish a long-term relationship between insurers and policyholders, which gives both incentives to implement cost-effective risk-reducing measures. For example, insurers have an interest in rewarding the undertaking of such measures with premium discounts that the policyholders can receive for a long time horizon; namely, for the duration of the insurance policy. Problems with short-term contracts are that policyholders are not sure that premium reductions that would be provided as a reward for mitigation would continue long into the future, while insurers may be reluctant to stimulate risk reduction of policyholders who are able to cancel their contract each year after it expires. A long-term policy would prevent homeowners from canceling their flood insurance after a few years if they had not experienced any flood damage, which often occurs in practice (Michel-Kerjan and Kousky, 2010). A long-term insurance contract could overcome such problems and increase the effectiveness of the insurance instrument in encouraging risk reduction. However, a challenge with long-term policies is how to price the future risk if the risk landscape changes due to climate change. The question is whether climate change projections are currently sufficiently reliable to price future flood risk and further research in this area is required.

Addressing climate change in the NFIP requirements. It could be useful to adjust mitigation requirements in the current 1/100 year zone so that they reflect the future change in water levels that are expected due to sea-level rise. For example, elevation requirements could be based on the likely future BFE level instead of the current level. Moreover, the geographical extent of the 1/100 year zone is likely to increase. The NFIP regulations could be made applicable to the future 1/100 year flood area to promote adaptation in that area. Failing to do this now, means that many existing buildings without mitigation measures would exist in the future 1/100 flood zones. Delineating the future flood zones and the potential water level is a complicated and probably expensive task. If this task is considered to be infeasible, then an alternative policy is to regulate not only the current 1/100 flood zone, but also other flood zones, like the current 1/500 year flood zone. This would be an effective adaptation policy if it is expected that the current 1/500 flood zone is approximately the future 1/100 zone. Moreover, regulating the current 1/500 year flood zone may be justified by the high amount of flood losses that already occur in that zone, and the arbitrary nature of the decision of the NFIP to regulate only the 1/100 year flood zone.

Broadening mitigation grant programs. The current grant programs are unlikely to provide sufficient financial resources to keep mitigation efforts in line with the expected change in risk in the future. Sea-level rise requires additional beach nourishment and, in some places with considerable capital at risk, additional protection against storm surge may be cost-effective, such as sea walls and storm surge barriers. The limited financial capacity of state and local governments may result in a suboptimal level of investments in prevention, while ad hoc funding through Congress may be difficult to obtain. An expansion of the current NFIP grant programs, for example, by establishing a specific “Flood Risk Adaptation Grant Program,” could be effective in ensuring a continuous funding source for investments in flood-risk adaptation. This fund could finance adaptation measures aimed at flood prevention, as well as damage mitigation. In addition, mitigation grant programs should be better integrated with ongoing and new coastal zone management programs that are funded by both the federal government and the state.

Detailed cost–benefit studies of such adaptation measures are in order to prioritize the most effective measures and projects that need funding. Moreover, new and existing grant programs could be better geared towards financing low- and high-cost mitigation measures that can be implemented by homeowners or contractors of new waterfront development projects. Further research could examine how much money is needed for investments in flood-risk adaptation in the United States, and assess the financial capacity required for grant programs that stimulate these investments.

5. Flood zoning policies in New York City

5.1. Introduction

New York City has a long history of developing and implementing zoning regulations since it enacted the first comprehensive zoning resolution in 1916 (Marcus, 1992). Zoning can be defined as legislation that determines the size and use of buildings, where they are located, and in large measure, the densities of NYC’s diverse neighborhoods (NYC-DCP, 2010b). Zoning is a dynamic policy instrument, and in the past ten years the NY Department of City Planning has taken a more flexible approach to the historically stricter segregation of uses. It increasingly encourages a mix of uses, and has expanded and refined what are called “contextual” zoning tools to better preserve the character of the City’s established neighborhoods (NYC-DCP, 2010a). For example, new lower density growth management techniques have been developed for outlying areas that are faced with rapid growth and are distant from (public) transportation systems.

Zoning policies in NYC pertain to three basic zoning districts. A zoning district is a mapped residential (R), commercial (C), or manufacturing (M) district with structures of similar use, bulk, and building density. The three basic districts are further divided into a variety of lower-, medium-, and higher-density residential, commercial, and manufacturing districts. Furthermore, just for residential uses, each district regulates the number of dwelling units permitted, the amount of open space required on the zoning lot, and the maximum amount of the lot that can be covered by a building (lot coverage). Each zoning district has dedicated regulations for each of the 18 use groups. Use Groups include uses that have similar functional characteristics and/or nuisance impacts and are ranked from residential uses (Use Groups 1–2), community facility uses (Use Groups 3–4), retail and service uses (Use Groups 5–9), regional commercial centers and amusement uses (Use Groups 10–12), waterfront and recreation uses (Use Groups 13–15), heavy automotive uses (Use Group 16) to manufacturing uses (Use Groups 17–18).

Contextual zoning policies regulate the height and bulk of new buildings, their setback from the street line, and their width along the street frontage, to produce buildings that are consistent with the existing character of the neighborhood. Bulk regulations are the combination of controls (e.g., lot size, floor area ratio, lot coverage, open space, yards, height, and setback) that determine the maximum size and placement of a building on a zoning lot. An important regulatory control function is the floor area ratio or FAR that determines the size of the building in relationship to the size of the zoning lot. The floor area ratio can be defined as the total covered area on all floors of all buildings on a certain plot divided by the area of the plot (see Appendix B for an extended zoning glossary).

The boundaries of the zoning districts are fixed in 126 NYC zoning maps and are an official part of the city's zoning resolution. Any amendment of a zoning map is subject to what is called a "Uniform Land Use Review Procedure" (ULURP). ULURP is the public review process, mandated by the City Charter, for all proposed zoning map amendments, special permits and other actions, such as site selections and acquisitions for city capital projects, and disposition of city property. Zoning regulations and plans are developed by the DCP and enforced by the Department of Buildings (DOB). Moreover, the DOB has inspectors in the field who check whether the regulations are adhered to. If the DOB is satisfied that the structure meets all relevant provisions of the zoning resolution and the building code, a building permit is issued and construction may start. Hence, the NYC Department of Buildings has primary responsibility for enforcing the zoning resolution, and for interpreting its provisions.

5.2. Zoning policies for waterfronts

Special zoning regulations to guide waterfront development in New York started in 1992 through the comprehensive waterfront plan (CWP) (NYC-DCP, 1992). Before 1992, waterfront lots were not treated differently from inland lots for zoning purposes. The 1992 CWP proposed by the Department of City Planning was developed on the basis of the federal Coastal Zone Management (CZM) Act of 1972 and the creation of the NYC Waterfront Revitalization Program (WRP). It was the first framework to guide land use along the City's entire 578-mile shoreline in a way that recognized its value as a natural resource. The plan presented a long-range vision that balanced the needs of environmentally sensitive areas and the working port with opportunities for waterside public access, open space, housing, and commercial activity (NYC-DCP, 1992; Salkin, 2005).

In 1993, the waterfront zoning regulations were adopted, and what was new about these regulations was the public's right to have access to the waterfront. In retrospect, however, while the requirement for public access was welcomed in high-density urban areas in New York, it was less welcomed in low-density suburban areas. For example, it was popular in Manhattan and the more urban areas of Brooklyn, Queens, and the Bronx, but was less popular in Staten Island and the more suburban areas of Brooklyn, Queens, and the Bronx. The principal reason for opposition to waterfront public access in low density areas of NYC was unease with allowing the public onto private property. Some of these public access areas became hangout areas for teenagers who made the nearby residents uncomfortable. Hence, the requirement to have public access throughout NYC was dropped in these low-density areas because of opposition in suburban areas.

Currently, the special waterfront zoning regulations apply only for residential and commercial use and not for industrial and manufacturing use. After the first CWP in 1992, the waterfront zoning regulations were changed in 2009. In particular, the design components of the public areas were refined during that time. These new designs, for example, finally dropped the requirement for guardrails near the water and allowed for a more natural shoreline with the railing no longer necessary.

5.3. How are flood risks addressed in NYC zoning policies?

Waterfronts play an important role in flood management. However, it appears that flood protection was only briefly mentioned in the 1992 CWP. The plan addresses the significant natural values of the waterfront and the need to restore or maintain wetlands and other natural buffer areas (NYC-DCP, 1992). Hence, the CWP perceived flood protection predominantly as a series of policies aiming at maintaining or revitalizing natural shorelines, such as wetlands and beaches (Salkin, 2005). For example, the CWP specifically addressed coastal erosion as a problem for sandy coasts such as the Rockaways, and the plan recommended a variety of nonstructural erosion control measures including beach nourishment and dune field creation. The plan also recommended new development inland of the NYS Department of Environmental Conservation (DEC) Coastal Erosion Hazard Line.

Furthermore, in terms of management responsibilities, flood protection starts at the federal level with the federal CZM Act (1990). This Act calls for state implementation of coastal zone management plans and provides the backbone for state and local planning and regulatory action in coastal areas. The Act addresses potential sea-level rise as a factor that should be "anticipated and addressed" in the preparation of state plans. In NYS, the Department of State oversees the plan and implements it by means of the Local Waterfront Revitalization Program, whereby NYC has authority to prepare its own plan. In NYC, the DCP is responsible for this effort. DCP, along with other agencies, is addressing climate change, for example, through *Vision 2020.*

The levels of responsibility are an important factor and influence the different responsibilities for land use. While the City is in control of land use issues within its borders, the State has authority to regulate land use within the tidal wetlands and their adjacent areas. The NYS Department of Environmental Conservation has authority over modifications to land or structures in this area, which can extend as much as 150 ft inward from the mean high water levels (Sussman and Major, 2010). This illustrates that the interlinkage between state and federal legislation and NYC zoning policies is often a complex issue, especially when it comes to climate change and flood protection issues that need to be addressed at all three levels. In 1992, it was estimated that—at the federal and state levels alone—about 50 separate laws guide development in the coastal zone: for example, the federal Flood Disaster Protection Act, the Endangered Species Act, and the state's Environmental Conservation Law and Navigation Law. As of today, all NYC zoning amendments and actions must be assessed for potential environmental impacts in accordance with the State Environmental Quality Review Act (SEQRA) and the City Environmental Quality Review (CEQR) procedures (NYC-DCP, 2010b). However, resilience to climate change is not specifically mentioned as an issue in the current zoning policies for waterfronts.

Relationship between the NFIP and NYC zoning policies. The idea in the 1992 CWP that flood protection and climate change are perhaps more of a federal responsibility, and hence, not really an issue in current waterfront policies, is further supported by the fact that there is no explicit linkage between the NFIP managed by FEMA and NYC's zoning regulation. As explained in the previous section, the NFIP requires minimum demands for providing flood insurance, whereas NYC's zoning policies are superimposed on these minimum requirements.

The current zoning policies, however, are not fine-tuned to the NFIP regulations and nor are they developed in collaboration with FEMA. An important gap in the fine-tuning between the NFIP and zoning policies is that the NFIP is designed for covering losses mainly to *residential* properties, while only limited coverage is available to non-residential properties (see Section 4), and the NFIP does not require that the development of critical infrastructure is limited or prevented in floodplains. Zoning policies, however, apply to all uses, including infrastructure. The NFIP only encourages local authorities and zoning policies to prohibit the construction of critical infrastructure in the floodplain through the CRS, but this is not mandatory (Galloway *et al.*, 2006).

Zoning control: "height penalty." It appears that, in some instances, NYC zoning controls are counterproductive with regard to existing NFIP regulations in terms of reducing flood risk. An illustrative example is the issue related to the "zoning building height penalty." The NFIP requires the ground floor of new buildings to be elevated to at least the height of the BFE level, which is related to the water level of the 1/100 flood event. The elevation of an individual building relative to the 1/100 year flood level partly determines the credits that serve as a discount on the level of the insurance premiums that households or businesses have to pay, in the sense that buildings that are raised even higher than the flood level are eligible for reduced insurance rates.

NYC zoning regulations measure building height from either the ground level or the elevation of the 1/100 year flood level determined by FEMA, whichever is the highest. However, new buildings that are voluntarily raised higher than the flood level are penalized in their total height. For instance, if zoning allows a 60 ft high building on a waterfront lot, and the 100-year flood level is 10 ft above grade, zoning allows the building to be 70 ft above grade. But the building might be eligible for reduced insurance rates if it raises itself another 10 ft above the 100-year flood level. If it does so, it is still limited to a height of 70 ft above grade, i.e., zoning penalizes it by 10 ft of height or one story (e.g., Sussman and Major, 2010). In addition, the penalty does not only affect building height, but affects FAR as well, since floor area is measured from the BFE (at least in the waterfront zoning, lower-density, and contextual zoning districts).

Zoning control: restrictions. Another issue is the restriction control in zoning policies, which could be used to prohibit the development of (certain) land uses in (vulnerable) flood zones. Such flood hazard restrictions do not exist in current NYC zoning policies. The NFIP has various policies to minimize or restrict the development of new properties in vulnerable flood-risk areas: (1) no new construction is allowed seaward of mean high tide, and (2) local authorities must prohibit any encroachment within the floodways that results in any increase in flood heights. In this respect, the difference between floodways and floodplains should be noted: "Floodplains are low-lying lands next to rivers and streams. When left in a natural state, floodplain systems store and dissipate floods without adverse impacts on humans, buildings, roads, and other infrastructure" (DEC, 2010). The SFHA are part of the floodplain and can be used for urban development, but when the floodplain is designated as a SFHA, development is subject to FEMA floodplain development regulations. Floodways are the channels of a river and adjacent land areas, which must be reserved to discharge the 100-year flood without causing a rise in flood elevations (DEC, 2010). For floodways, more stringent development controls exist than elsewhere in the SFHA, and no development is allowed unless the developer has first proved that the development will not increase flood elevations at any location during the 100-year flood. Research shows, however, that in the United States these restrictions have not stopped development in floodways, for the following reasons: (a) many floodplain maps in rural areas do not show floodways; (b) the floodway can be rearranged (e.g., through channelizing) to free up flood-prone land for development (Wetmore *et al.*, 2006).

Preserve open space. The percentage of open space in floodplains, such as the 1/100 SFHA, is an important factor in determining the potential damage of a flood: the greater the area of building footprints, the more flood damage can be expected. NYC zoning regulations define open space as "the part of a residential zoning lot (which may include courts or yards) that is open and unobstructed from its lowest level to the sky, except for specific permitted obstructions, and accessible to and usable by all persons occupying dwelling units on the zoning lot. Depending upon the district, the amount of required open space is determined by the OSR, minimum yard regulations, or by maximum lot coverage" (Appendix A).

It is widely recognized that the total number of buildings in the 1/100 year floodplain has

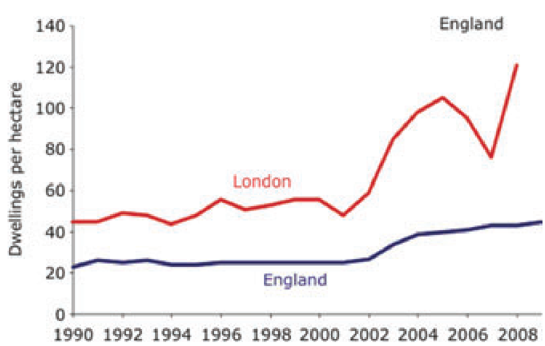

Figure 5.1. Number of urban dwellings per hectare in the UK over the period 1990–2008. Source: DEFRA (2010).

increased over time in the United States, although exact growth rates cannot easily be determined (Wetmore *et al.*, 2006). This is not an issue particular to the United States or New York City. In other global cities such as London (UK) similar trends can also be observed (Fig. 5.1). In London, the density of new dwellings rose from 45 per hectare in 1990 to 59 per hectare in 2002. Density then rose to 105 new dwellings per hectare in 2005, and increased sharply to 121 in 2008 (DEFRA, 2010). Similar trends can be observed in Tokyo, where there has been strong demand for allowing higher density than the official FAR allowed in the building code and zoning regulations (Hori, 2004). In the Netherlands, potential flood damage has also increased by a factor of 6 or 7 within the last 50 years as a result of new developments in areas vulnerable to flooding (Klijn *et al.*, 2007).

There are a number of zoning regulations that control the percentage of open space on a lot, and hence the potential damage during a flood. The most important bulk regulation is the OSR. The OSR is the amount of open space (in ft^2) required on a residential zoning lot in non-contextual districts, expressed as a percentage of the total floor area of the zoning lot. For example, if a building with 20,000 ft^2 of floor area has an OSR of 20, 4,000 ft^2 of open space would be required on the zoning lot ($0.20 \times 20{,}000$). In some zoning districts, open space is preserved by the maximum lot coverage, which is that portion of a zoning lot which, when viewed directly from above, is or would be covered by a building or any part of a building.

Density controls are regulations to control the intensity of development and allow the City to plan in an orderly way for new schools, utilities and transit expansion. Population density is controlled by the requirement (which varies by district) that a specified number of ft^2 of lot area be provided per dwelling unit or room. Another important control in this context is the FAR, which is currently applied to the 18 different uses in NYC (see Section 5.1) to determine the building coverage per acre of lot area. For residential districts, a dwelling unit factor is applied to determine the maximum number of dwelling units permitted on a lot. The maximum number of units is calculated by dividing the maximum residential floor area permitted on a zoning lot by the applicable factor for each zoning district. The higher the factor, the lower the number of units permitted on a lot.

Wetlands and open water. When analyzing international waterfront developments, it is clearly shown that environmental values are increasingly addressed in new waterfronts (e.g., Hill, 2009). Not only wetlands, but, in general, environmental values such as green zones or open spaces are considered to (1) have an added natural value for waterfronts; and (2) provide buffer capacity for protecting waterfronts and the City against (future) flood risk. These environmental zones are under increased pressure through urban development, and Gornitz *et al.* (2001) show that about 50% of the land surface of salt marsh islands have already disappeared in Jamaica Bay since 1900, and that there is an urgent need to maintain these natural buffer areas as flood protection. While losses that occurred prior to stricter environmental protection starting in 1972 can largely be attributed to anthropogenic activities, such as landfilling, dredging, and urbanization, sea-level rise and increased coastal erosion could create serious problems with flood management.

Waterfront development, which addresses environmental values through enhanced regulations can restore the environmental functions of the waterfront. Hence, the greening of waterfronts and other uses is now commonly applied in NYC through different zoning regulations. For example, policies are in place to promote the greening of parking lots in order to reduce the water runoff and limit the risks posed by local extreme precipitation. Other policies promote the greening of front yards, especially in lower density districts, and, in some areas, about 50% needs to be planted. In addition, subsidies are available for green roofs.

However, some coastal management plans include the restoration of wetlands or greens zones that also claim parts of the current open water area. The idea of building into open water to create additional natural values is, however, a complicated issue in NYC. Currently, the manner in which NY State environmental regulations have been administered has effectively prohibited any waterfront development into open water space. This complicates and restrains waterfront development and environmental compensation. This regulation may impede both the

Figure 5.2. **MTA commissioned these elevated ventilation units to stay above flooding, Jamaica, Queens. Source: Photo courtesy MTA.**

development of attractive waterfronts and the creation of new environmental areas that can accompany this development.

Creating waterfronts that act as a super-levee. The idea of building a waterfront that serves as a levee system, as in Tokyo, has never been applied to NYC. Our discussions with different specialists revealed that it is generally perceived that such a system would imply large scale interventions that are hugely expensive and impractical. Furthermore, an elevated waterfront in combination with a levee could possibly hinder access to the waterfront for the general public or may form an obstacle to other uses and needs of the waterfront. The impracticality of designing waterfronts as a super-levee, for example, by elevating whole waterfront blocks, can be illustrated by a redevelopment project in Coney Island. Recently, many blocks are currently vacant and planned for large-scale redevelopment. This area is vulnerable to flooding today because large areas lie below the 1/100 year flood level. The area subject to redevelopment is situated right by the beach and is currently lower than the boardwalk and vulnerable to flooding. These areas have recently been rezoned in order to create more shops, commercial activities, and housing. As part of the redevelopment, the existing streets and underground utilities will be completely rebuilt. When they are rebuilt they will be raised up above the flood level, and all new buildings on these blocks will, therefore, be above the flood level. Problems exist when connecting new (elevated) streets to lower-lying streets in the adjacent blocks, and the new street area will gradually ramp down to connect with existing streets and buildings in neighborhoods on either side of the new development. This creates problems since properties on the inclined connecting streets are partly behind the street level—hindering the entrances of the houses. A solution would be to elevate existing adjacent blocks but this would be very expensive and very disruptive because it would displace thousands of people.

5.4. Suggestions for improvements

Relationship between the NFIP and NYC zoning policies. Waterfronts are already subject to many more codes than inland areas, and waterfronts with a mixed use are more complex to design (see Section 6). Hence, it is important to first seek policies that better link or integrate existing legislation rather than developing additional zoning regulations for the waterfront. A promising step is to assess how to improve the cooperation between FEMA, the NYC Department of Buildings, and the NYC Department of City Planning in order to ensure that all regulations are complied with. As such it could be interesting for NYC to explore applying the French zoning

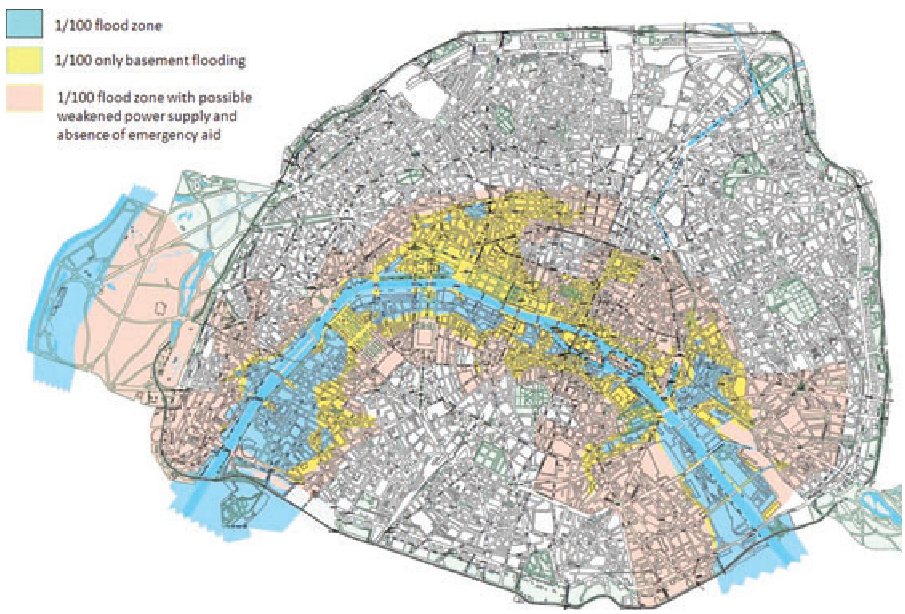

Figure 5.3. **Flood zones in Paris. Paris uses the flood of the year 1910 as a basis for the 1/100 year flood map. Source: Ville de Paris, EDF-GDF Services (2010).**

system, which is closely tied to the flood insurance system (Poussin *et al.*, 2010). In France, the credit system for lowering flood insurance deductibles is directly coupled to zoning policies and mitigation measures. Such integration could be beneficial for NYC. Furthermore, an improved integrated exchange of information between the NFIP and the NYC zoning and building database could enhance the effectiveness of flood risk–reducing measures.

FIRMs in zoning policies. An important step for improved cooperation between FEMA and the NYC zoning departments is to address future flood-risk maps (e.g., the change in the 1/100 year floodplain) in flood zoning policies. FEMA could produce such maps and so could the DCP and embed those future 1/100 flood maps in their current databases. Each new development or revitalization program could then be overlaid on the future 1/100 flood zone maps, and current NFIP regulation with BFE requirements could be applied to these future flood zones. Including the data in current zoning processes and policies is not expected to result in major practical complications for the DCP. However, enforcing new regulations in future flood zones needs a political process and a change in zoning regulations. Moreover, the creation of future flood-risk maps, such as suggested in Section 4.3, could be a challenging task for FEMA.

Infrastructure. The relationship of infrastructure and flood risk in NYC is a complex issue, and much of the city's vital infrastructure such as tunnels, rail roads, ventilation shafts, and subways are within the flood hazard area mapped by FEMA (see Section 3). However, infrastructure damage is not addressed through the NFIP, whereas potential flood damage is for a large part determined by the infrastructure at risk (Jacob *et al.*, 2000; Jacob *et al.*, 2001; Zimmerman and Faris, 2010).

Zoning policies and especially the building code should, therefore, better address flood risk for (at least critical) infrastructure projects. Zimmerman and Faris (2010) argue this is a difficult issue because infrastructure planning often does not involve a formal role of any governmental agency. However, there is scope for the improved fine-tuning and cooperation between agencies involved in developing zoning policies, NFIP policies, and transportation authorities in order to ensure tunnel entrances and ventilation grates can be, for example, protected and or elevated (e.g., NYS, 2010) (Fig. 5.2). Furthermore, NFIP restrictions for the development of critical infrastructure are only encouraged through

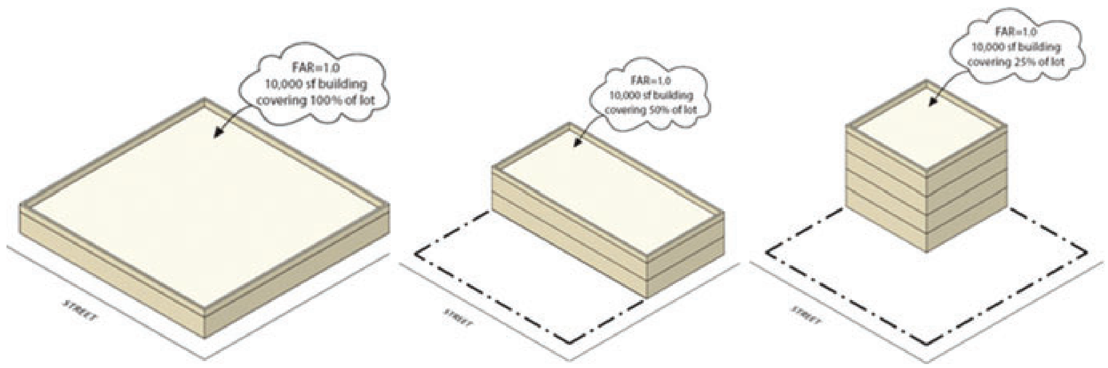

Figure 5.4. Example of a lot where a building of 10,000 sq ft covers 100, 50, or 25% of the lot, while the floor-to-area ratio remains the same. Source: NYC-DCP (2010a).

the CRS, but are not strictly enforced. A common policy could aim at describing what infrastructure can be assigned as "critical."

The MTA has identified some key climate adaptation challenges that address flood risk, and that more specifically address the vulnerability of subway system stations and tunnels below expected flood levels (MTA, 2009). In a study, they suggest an improved integration of MTA's emergency evacuation plans with those of NYC. Other adaptation steps "include inspection of existing or planned facilities within the expanded flood areas and reevaluation of the MTA's internal 'captive' insurance programs" (MTA, 2009). Furthermore, a study evaluating the impacts of an extreme precipitation event in 2007 on MTA's facilities outlined some adaptation options for some specific locations (Mott Yard, Corona/Shea Yards, Hillside Avenue). Options include elevation of facilities, additional pumping systems, and levee systems (MTA, 2007).

An example of cooperation between insurers and governmental planners is France, where the city of Paris is working on an integral flood management plan (PPRI, Flood Prevention Plan) (Direction de L'Urbanisme, 2003). Apart from flood damage mitigation measures that are required for flood insurance, this plan also addresses transport networks (air, water, electricity, gas, telecommunication) and vulnerable objects, such as hospitals and museums. The plan describes how the vulnerability of those objects can be reduced. For these vital facilities, more stringent elevation measures are required, or the plan prescribes floodproofing measures to seal the objects from potential flood damage when they are below the BFE of the 1/100 flood level.

Eliminating the zoning building height penalty. The zoning resolution could provide additional flexibility for buildings in flood-risk areas to allow for freeboard, which means additional elevation of the BFL above the FEMA BFE in order to earn a discount on insurance premiums. However, these elevated buildings are also subject to zoning height limits just like buildings that do not increase their elevation (Sussman and Major, 2010). A logical next step would be to eliminate this zoning penalty. To eliminate it requires a zoning text amendment, which must go through a public review process. The public might be concerned about allowing taller buildings on the waterfront. It would ultimately be up to the City Planning Commission and then the City Council to approve the text amendment.

Existing buildings. Set back, relocation, or elevation of existing properties in very dangerous areas is an option, but would, in practice, be infeasible (Sussman, and Major, 2010). However, historical analysis shows that radical rezoning policies can be implemented. For example, in 1961 NYC was rezoned drastically, and, during that time, many low-lying areas along the waterfront were designated as manufacturing areas, even though people may have lived in these areas. According to the 1961 zoning policies, residential buildings in manufacturing zones were not allowed to be expanded or improved further, but the residents were allowed to stay there. However, as a result of the 1961 zoning policy, many people eventually left these areas. Therefore, one solution to limit development in certain high-risk areas would be to no longer allow the enlargement of homes or start new businesses and invest in businesses in these areas. Obviously, such policies would be controversial,[k] and regulations that prohibit the enlargement of new homes or the establishment of new businesses could raise both legal and planning issues. Moreover, regulations that impose an outright prohibition on development would likely be illegal, as the U.S. Supreme Court has held that regulators cannot deprive owners of all economically-beneficial use of their property without compensation (Supreme Court of the United States, 1992, No. 91–453). Regulations that did not prohibit investment outright but discouraged investment could have blighting effects on communities, and would contradict goals to increase the resilience of existing buildings.

In Paris, rather strict regulations are applied for existing buildings and these regulations are summarized in a Flood Prevention Plan (PPRI, Direction de L'Urbanisme, 2003). Such a plan uses flood zone maps in a similar way to the FEMA flood maps. Paris uses the 1/100 year flood map, which for Paris refers to the devastating flood of 1910 (Fig. 5.3). A green zone has been assigned for areas in the flood zone that should be maintained as open spaces for recreational activities, such as parks and sporting facilities. These areas are potentially important for temporarily storing flood water. Red zones are the areas in or near the flood channel, and only uses related to water, e.g., navigation facilities, are allowed under strict regulations. A further differentiation has been made between light blue flood zones where the maximum inundation is smaller than 3 ft, and dark blue flood zones where the maximum inundation exceeds 3 feet. In both zones, new properties have to be built above the 1/100 flood level. Hatched zones are areas within the blue zones where the ground level is supposedly already above the PHEC (Plus Hautes Eaux Connues—the highest known water levels, the 1/100 flood level from 1910). For existing buildings, it is required that homeowners implement measures that floodproof telephone, electricity switchboards, and heating and gas installations above the PHEC. Additional regulation for the storage of hazardous materials exists. If these damage mitigation measures are not implemented five years after the PPRI has been approved by the regional government, all responsibility for flood damage during and after a flood lies with the homeowner.

Wet-proofing policies for existing buildings such as provided in the example from Paris could be a worthwhile adaptation strategy for NYC. Although it is difficult to require elevation measures for existing buildings, it is possible to require floodproofing measures that can reduce damage to electricity, heating and gas installations. These requirements could apply if an existing building is subject to renovation activities (see also Section 6).

Lowering building footprints through controlling open space. New or revitalized waterfronts are increasingly seen as a source for developing environmental "green" values, and for providing the City's façade with a greener character. Such a perspective also provides an incentive for exploring whether the required percentage of open space on a waterfront lot could be increased. Sussman and Major (2010) note that such spaces are often used for stimulating more parks in NYC, but, in addition, new regulation could provide incentives to lower flood risks in the area. The OSR, for example, expresses the percentage of the total floor area of a building that must be provided as open space on a development parcel. For example, in a district with an OSR of 19, the amount of open space required on the lot would be 19% of the total floor area of the building. In other residential districts, open space is determined by yard regulations or by limiting development to a maximum lot coverage.

Density controls and open space regulations are powerful controls to regulate both the number of people on a lot and the buildings' footprint per lot. When reviewing the potential of zoning controls for managing flood risk, altering FAR has an effect on the population density, and hence on the population at risk in the flood zone, whereas OSR and lot coverage have a direct effect on the potential direct damage to a building. Figure 5.4 shows how a combination of OSR and FAR control works to preserve open space on a lot.

Lowering FAR, however, is difficult, since much of the 1/100 flood area is composed of one- and two-family homes. Difficulties may arise when existing buildings that currently comply with a FAR are damaged by a flood, and are subject to new FAR regulations when rebuilding the property. The city would also have to address new provisions in the zoning regulations that allow homeowners to

[k]For a review on the 1961 zoning regulations, see, for example, Marcus (1992) and Angotti and Hanhardt (2001).

rebuild these buildings in the event of damage or destruction; amending that would have significant implications for property values, mortgages, and insurance. Furthermore, reducing densities would indeed reduce the number of people who are subject to flood risks in the future, but only if such areas are largely undeveloped today, which is not the case in NYC. Reducing permitted densities in such as areas could tend to discourage, rather than encourage, the type of investment needed for adaptation, such elevation or dry or wet floodproofing. Replacing a two-story flood-vulnerable building with a floodproofed six-story apartment building, for instance, may also serve adaptation goals.

Lowering urban density through TFA and a FAR bonus. Zoning is not the only solution for preserving natural areas and open space, and a growing number of communities in Japan, for example, in Tokyo, are using market-based preservation techniques called transfer of development rights, or TDRs (e.g., Masahiko and Nohiriro, 2003). Local authorities undertake TDR programs to use the market to implement and pay for development density and location decisions. In Tokyo, the owners of land that communities want to preserve with lower densities, referred to as "sending areas," are compensated for voluntarily restricting their development potential by allowing additional development in other—neighboring—areas (referred as "receiving areas"), but only when they participate in the preservation of the sending areas. Tokyo legislation allows potential floor area to be transferred from sending sites to receiving sites, thus allowing more intensive land use in these receiving sites. Floor area can be easily transferred between property owners. Originally, this transfer mechanism was only available to developments consisting entirely of new buildings. However, an amendment of the building codes in 1999 made it possible to include existing buildings in these merged lot developments.

TDR programs are not always successful. If TDRs are not affordable, developers will not buy them because TDR costs will make the TDR option less profitable than the baseline option. Although TDR programs appear to be a potentially powerful land use tool, few communities have had success in using these programs because of the associated challenges. Furthermore, TDR programs do not reduce the need for zoning and can actually be more complex to administer. Communities may not support TDR programs, and local authorities may have to invest in community education programs to explain them to the public. Finally, although the permanency of TDR programs could be an advantage, it may also be a liability, since a community's land use needs change over time.

In NYC, density can be traded between high-risk waterfront properties and lower risk properties further inland if the properties are adjacent to one another. There are no mechanisms in place to allow density to be traded on lots that are not adjacent to one another. The problem with such an approach is that no one can be certain which properties will accept the increased density, and, as a rule, no neighborhood wants increased density. The courts in New York have already determined that the development rights cannot just float freely (Fred F. French case, NY Court of Appeals; Fred F. French Investing Co. v. City of New York, 39 N.Y.2d 587, 350 N.E.2d 381, 385 N.Y.S.2d 5 (1976), appeal dismissed, 429 U.S. 990 (1976)).

A nice example of how TDRs were applied is the development of a high building above the Grand Central Station in NYC (Fig. 5.5) (Hanly-Forde *et al.*, 2010). Grand Central Terminal, constructed in 1913, is one of the City's architectural landmarks. In the late 1960s, the Penn Central Transportation Company wanted to construct a 53-story "addition" over the protected landmark. The city decided the tower would destroy the character of the terminal, so NYC allowed Penn Central to transfer the development rights of the high-rise building to adjacent properties to preserve the railway station. A number of buildings have received approval to develop above landmarks (e.g., the Palace Hotel). It does, however, require a Certificate of Appropriateness, which is not very easy to get.

Waterfront development and open water restrictions. As stated in Section 5.3, the manner in which NY State environmental regulations have been administered has effectively prohibited any waterfront development into open water space. Clearly, such policies have been developed in the past because the environmental values of, for example, wetlands and fish habitat were threatened, and many acres of environmental values have been lost in the past through both urban development and natural processes such as coastal erosion. On the other hand, local

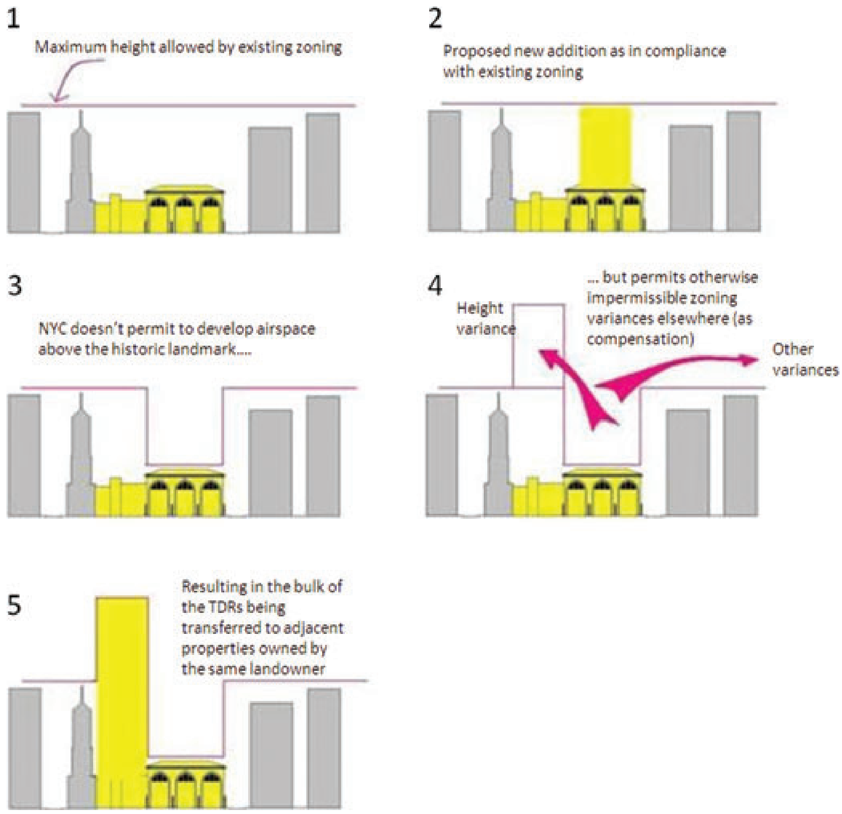

Figure 5.5. An example of how TDRs were applied on the development of a high building above the Grand Central Station in New York City. Source: Hanly-Forde *et al.* (2010).

authorities have an interest in maintaining and enhancing economic activities of waterfronts, and, therefore, increase the attractiveness of waterfronts as residential and manufacturing areas. In the past, these two objectives of protecting environmental values and increasing economic activities were often in conflict.

There is, however, an opportunity for waterfront development that enhances both environmental values, increases flood protection levels, and preserves the economically-sound development of the area. Induced by the 1992 CWP, both the state government and the local authority are currently aiming to enhance the environmental values of the waterfront, for example through softer edges and developing gradients (e.g., Nordenson *et al.*, 2010). In this respect, there is a mutual interest in greening the waterfront such as outlined in the Hudson Raritan Estuary Study (USACE, 2009), and some of these policies are already in place in current zoning regulations. However, the issue of climate change and sea-level rise puts an additional burden on waterfront developments and policies, and the challenge is to create a greener waterfront that is more resilient to climate change. Here, it is possible to think of creating wetland areas that can act as buffer zones or more open space areas on waterfronts.

Such multifunctional land use developments, however, need new planning regulations and urban designs that allow for a less rigid boundary between land and water. For example, most environmental values are found by creating (shallow) gradients between land and water. This implies that in some instances, the land–water boundary should be moved inland and in some instances seaward to compensate for the loss of urban space. One option for dealing with this issue is to compensate the loss of open water in other areas by creating new nature protection areas, such as has been done in the seaward extension of the Rotterdam harbor (see Section 7). By creating environmental buffer zones (wetlands, beaches) the city's waterfront can be better

Figure 5.6. **Artist's impression of southwest Brooklyn with Amsterdam style residential areas (*top*). Source: NArchitects (2010). Amsterdam, Java Island: a revitalized old port facility now converted into a residential area (Amsterdam, the Netherlands) (*bottom*).**

used as a protection against climate change and sea-level rise, while preserving (or even increasing) the environmental values. Hence, this implies using open water for environmental buffer zones and hence trading one environmental value (open water) against another value (wetlands). Obviously, it is a difficult process to determine how much compensation is needed when open water is claimed, and such a process needs multi-stakeholder involvement from the local to the federal levels (Pahl-Wostl *et al.*, 2007). In the Netherlands, it is ultimately a political decision whether environmental compensation measures are sufficient, and whether the use of open water is of "national importance with major social and economic benefits."

A less rigid boundary between land and open water to stimulate both environmental values (e.g., Bain *et al.*, 2007) and to enhance flood protection levels makes demands on current jurisdictions in the management of land and open water. An example is provided in Figure 5.6 where an artist impression is provided for Brooklyn's waterfront

Figure 5.7. **(Top) Futuristic view of Manhattan, where ecological buffer zones protect Manhattan from flooding. Source: dlandstudio, LLC and Architecture Research Office; MOMA (2010). (Bottom) Reflections of the Tin Shui Wai residential skyscrapers, seen from Hong Kong Wetland Park. Source: www.hypsos.com.**

and a similar real world waterfront in Amsterdam where an old port facility was converted in a residential area. Sussman and Major (2010) write that modifications in the open water zone and intertidal wetland area should be evaluated to determine whether such activities enhance the resilience to climate change. Many such modifications require discretionary permits, and the anticipated effects of climate change, including adaptation measures to address the vulnerability of infrastructure, which will likely affect the volume and type of such permit applications. An alternative futuristic view of environmentally based flood protection was developed in the program "Rising Currents" coordinated by the MOMA (Fig. 5.7; for more information see http://www.moma.org/risingcurrents; MOMA, 2010).

In summary, the idea of using open water for waterfront development should first focus on areas where coastal flood protection and nature preservation can be co-developed and, hence, where local government and the state and federal policies have a mutual interest. This is supported by Salkin (2005) who argues that coastal zone protection programs should be better integrated into local waterfront revitalization programs. The support from communities for the preservation of natural waterfronts to anticipate climate change is further supported by the Borough workshops initiated through *Vision 2020*. During these workshops, stakeholders have identified primary issues and key priorities for different reaches of the waterfront. In Queens, suggestions were made to increase resilience to climate change and evaluate evacuation strategies (for example, for the Jamaica Bay area). On Staten Island, preventing coastal erosion and the negative effects from climate change have been raised, and solutions could include improved bulkheads and the creation or improvement of wetlands (e.g., the Kill van Kull area). Similar issues were raised for the South Shore of Staten Island, and it was advised to better inform homeowners about the permission process and its effects on coastal erosion, and provide financial incentives to limit coastal erosion (South Shore). Further recommendations for waterfront development are to preserve open space, such as soccer fields and baseball fields, and to keep the natural shoreline intact so that it can serve as a buffer against flooding. These developments mean that zoning policies need to be modified to encourage new technologies, like green roofs.

6. Flood-resistant building codes for New York City

6.1. Introduction

In order to manage natural disaster risks, state governments in the United States have formulated state building codes and planning policies. The states mandated their local governments to enforce these codes and design comprehensive plans of urban development that are consistent with natural hazard management policies. Burby (2006) examined state requirements regarding local enforcement of building codes and local planning for urban development in the Atlantic, Gulf, and Pacific states in the United States, and related this to claims paid by the NFIP in these states between 1978 and 2002. The results of this study are shown here because they indicate that the more stringent building code regulations that exist in certain states can result in considerable reductions in damage. The results of this study are presented in Table 6.1, which indicates that the state governments have addressed these issues very differently across the country. Six states do not require either building codes or comprehensive plans of urban development that consider natural disaster risks, while three states, including New York, require their local governments to enforce building codes but not comprehensive plans. The majority of the states examined by Burby (2006) require comprehensive plans, but no building codes (five states), or both comprehensive plans and building codes (ten states). The last column in the table shows that total NFIP claim payments between 1978 and 2002 averaged per capita were considerably higher (US$299) in the states without local government building code enforcement and without comprehensive plan requirements than in states where one or both of such policies were in place.

Another example of the effectiveness of building codes is shown by Kunreuther *et al.* (2009) who examined how much damage may be reduced by mitigation through building codes in NYS for hurricanes with different return periods. This study estimates with a catastrophe model how much money would be saved if all houses and buildings conformed to the most recent building code standards. Evidently, this is not a practical or realistic scenario, because it would be very costly, or maybe even impossible, to subject all older buildings to these standards. Nevertheless, this exercise gives an indication of the potential maximum gains of mitigation through current building code standards. The analysis of Kunreuther *et al.* (2009) shows that in NYS, 39% of damage could be saved by mitigation for a 100-year hurricane, while this is, respectively, 37% and 35% for a 250-year and a 500-year hurricane. This analysis shows that the potential gains of hurricane-proofing existing buildings can be substantial.

While Table 6.1 suggests that building code requirements in NYS have been relatively successful in limiting damage in the past compared with other states, the analysis of Kunreuther *et al.* (2009) shows that considerable savings in hurricane damage could be reached if the current building code standards were more widely adopted. More stringent building code policies may be needed to accommodate future risks in the face of new development near the NYC waterfront and the projected increase in future flood

Table 6.1. Differences in state requirements for local government building code enforcement and comprehensive plans of urban development that consider natural disaster risks in the Atlantic, Gulf, and Pacific states and mean per capita NFIP claim payments between 1978 and 2002

State requirements	States	Mean per capita claim payments
No state local government building code enforcement or comprehensive plan requirements	Alabama, Louisiana, Mississippi, New Hampshire, Pennsylvania, Texas	US$299
State local government building code enforcement requirement but not comprehensive plan requirements	Connecticut, New Jersey, New York	US$79
State local government comprehensive plan requirements but not building code requirements	Delaware, Georgia, Hawaii, Maine, South Carolina	US$137
Both state and local government building code and comprehensive plan requirements	Alaska, California, Florida, Maryland, Massachusetts, North Carolina, Oregon, Rhode Island, Virginia, Washington	US$99

Source: Adapted from Burby (2006).

risks as a result of climate change. This is analyzed by first assessing the current flood-related building code policies in NYC (Section 6.2), subsequently addressing future challenges (Section 6.3), and making policy recommendations (Section 6.4).

6.2. Existing flood-related building code policies in New York City

The NYC Department of Buildings advises and proposes building codes that need to be officially adopted by the City Council. The Department of Buildings receives applications for compliance with building and zoning regulations, which they check and approve with an official certificate. Moreover, it checks on the enforcement of zoning and building regulations, for which purpose inspectors can be sent in the field. The minimum building code standards in NYC are determined by FEMA (see Section 4) because NYC has participated in the NFIP since 1983.

The NFIP rules are rather static, because they have hardly been updated during the recent decades. International Building Codes in the United States (although it has been adopted almost exclusively in the United States) are updated every three years, which is the result of a review by experts.[l] These building codes include by reference "Flood Resistant Design and Construction ASCE 24 Standard" (ASCE, 2005). ASCE 24 was largely adopted by NYC-DOB (2008), with certain amendments (see NYC Building Code's Appendix G: "Flood-Resistant Construction"). These amendments have been reviewed by FEMA to check whether they comply with the FEMA flood regulations,[m] and these amendments have been designed to (NYC-DOB, 2008):

- Prevent the unnecessary disruption of commerce, access, and public service during times of flooding;
- Manage the alteration of natural floodplains, streams and shorelines;
- Manage filling, grading, dredging, and other development which may increase flood damage or erosion potential;
- Prevent or regulate the construction of flood barriers, which will divert floodwaters or which can increase flood hazards;

[l] For more information, see www.iccsafe.org.

[m] In constructing a building you need to comply with ASCE 24 and ASCE 7. In addition, the FEMA flood insurance rate maps and a guidebook by FEMA "How to Construct Manufactured Homes" (e.g., trailers) can be consulted.

- Contribute to improved construction techniques in the floodplain; and
- Comply with and exceed the minimum standards of the NFIP as administered by FEMA.

The building codes apply to new structures and substantial improvements of the structure. Substantial improvements are construction works on a building, the cost of which equals or exceeds 50% of the market value of the building before the work started. This also applies to buildings that suffer flood damage and need to be repaired at this level of cost. These building regulations apply only to, for example, residential properties, commercial properties, and sport stadiums but not to public infrastructure, such as the New York City Subway.

The FEMA FIRMs are an important input for building code policy. The main 1/100 year flood zones are the A and V zones depicted on the FIRMs. V zones are coastal areas where flood velocity and waves need to be considered in building regulations, which is not the case in A zones. Buildings in both of these zones need to be elevated according to the DFE, as is required by FEMA. The additional flood building code regulation for NYC consist of three main components: (1) building above BFE level (freeboard); (2) dry as well as wet floodproofing; and (3) requirements per flood zone for four different types of buildings. Wet floodproofing entails the use of construction methods that minimize damage when floodwater enters the building, while dry floodproofing aims to prevent floodwater from entering the building. These specific requirements differ per A and V flood zone. Table 6.2 describes the classification of structures on the basis of which different building code regulations are applied. Category I buildings present a low hazard to human life in the event of failure; category II buildings include primarily residential buildings; category III buildings represent a substantial hazard to human life in the event of failure; and category IV buildings are designed as essential facilities. Next, the main building code regulations for these categories are discussed for the A and V flood zones.

Requirements for building in the A flood zone. Structures in A zones must be designed and anchored to prevent flotation, collapse, or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy. In A zones, elevation is needed in low-lying areas except for storage, parking, building access, or crawlspace. Table 6.3 shows the minimum elevation requirements of the top of the lowest floor relative to the design elevation per building category. The DFE equals the BFE of the 1/100 year flood for building categories I and II, while it is respectively 1 ft and 2 ft higher for building categories III and IV. Below this DFE level, wet floodproofing is required for all building categories up to their specific DFE level shown in Table 6.3. This entails that it is only allowable to build with flood damage-resistant materials and construction techniques, such as concrete and tile walls, having no electrical components that are not waterproof, and no wooden materials. Utilities and attendant equipment need to be located at or above the DFE, or designed, constructed, and installed to prevent flood waters from entering and accumulating within the components. Water should be allowed to flow inside the building (in the lower level) to equalize hydrostatic pressures, and hence prevent the collapse of the structure. This allows the water to withdraw easily from the building after the surge via the open access.

Instead of wet floodproofing, dry floodproofing is possible in certain cases for all building categories according to their specific DFE level shown in Table 6.3, except for residential buildings for which dry floodproofing is not allowed.[n] Dry floodproofing encompasses a combination of design modifications that results in the buildings or structures being watertight up to the DFE level. Walls should be impermeable to the passage of water. Utilities and attendant equipment must be located within the dry floodproofed structure, or outside it, provided that they are located at least as high as the BFE, or are constructed so as to prevent water from entering or accumulating within their components during a flood. Flood shields can be used for dry floodproofing during flood events, which can be advantageous for keeping the building accessible, for example, for handicapped persons. Dry floodproofing also serves to keep lower floors usable for commercial use. If a

[n]If dwelling units are located in the building, then these units are required to lie at or above the DFE level. Moreover, no more than one toilet and one sink shall be located below the design flood elevation and no kitchen or kitchenettes can be located below the DFE.

Table 6.2. **Classification of structures for flood building codes, NYC**

Nature of occupancy	Structural Occupancy Categories (SOC)
Buildings and other structures that represent a low hazard to human life in the event of failure, including, but not limited to: - Agricultural facilities - Certain temporary facilities - Minor storage facilities	I
Buildings and other structures except those listed in SOC I, III, and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: - Buildings and other structures where more than 300 people congregate in one area - Buildings and other structures with elementary school, secondary school or day-care facilities with an occupant load >250 - Buildings and other structures with an occupant load of >500 for colleges or adult education facilities - Health care facilities with an occupant load of >50 resident patients, but not having surgery or emergency treatment facilities - Jails and detention facilities - Power-generating stations, water treatment for potable water, waste water treatment facilities, and other public utility facilities not included in SOC IV - Buildings and other structures not included in SOC IV that contain sufficient quantities of toxic or explosive substances deemed to be dangerous to the public if released	III
Buildings and other structures designed as essential facilities including, but not limited to: - Hospitals and other health care facilities having surgery or emergency treatment facilities - Fire, rescue and police stations and emergency vehicle garages - Designated earthquake, hurricane or other emergency shelters - Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response - Power-generating stations and other public utility facilities required as emergency backup facilities for SOC IV structures - Structures containing highly toxic materials, as defined by Section 307 where the quantity of the material exceeds the maximum allowable quantities shown in Table 307.7(2) of the New York City Building Code - Aviation control towers, air traffic control centers, and emergency aircraft hangars - Buildings and other structures that have critical national defense functions - Water treatment facilities required to maintain water pressure for fire suppression	IV

Source: Adapted from NYC-DOB (2008).

building is dry floodproofed then it is allowed to use building space below the BFE. Our discussions with the NYC Department of Buildings revealed that in NYC these manual shields are in use, especially in high-rise and highly valuable commercial buildings. These measures can be expensive and are only taken if it is economically viable.

Requirements for building in the V flood zone. Building requirements are stricter in V flood zones, because these are coastal areas that are subject to high velocity wave action. Buildings and their foundation must resist flotation, collapse, and lateral displacement due to the simultaneous actions of wind and water loads. The waves have to be able

Table 6.3. **Minimum elevation of the top of the lowest floor relative to DFE in A flood zones**

Structural occupancy category	Minimum elevation of the lowest floor
I	DFE = BFE
II	DFE = BFE
III	DFE = BFE + 1ft
IV	DFE = BFE + 2ft

Source: NYC-DOB (2008).

to flow underneath the buildings, which can be achieved by building on adequately anchored pilings or columns. The lowest portion of the lowest horizontal structural member of the lowest floor (excluding the pilings or columns) is required to be elevated at or above the DFE specified in Table 6.4 below. The DFE equals the BFE of the 1/100 year flood for building categories I and II, while it is respectively 1 ft higher for building categories III and IV in case the floor is located parallel to the direction of the waves, and this is 2 ft higher if this location is perpendicular. Spaces below this elevation that can be used for parking, storage, building access or crawl space should be free of obstruction or enclosed with a breakaway wall. Such a breakaway wall is designed to collapse under certain flood conditions, and is intended to reduce damage from waves to the building. Only flood-damage resistant materials and finishes can be used below the DFE indicated in Table 6.4. The DFE, below which wet floodproofing is required, is 1 ft higher than the BFE for building categories III and IV than the elevation requirements. Utilities and attendant equipment should be located at or above the design DFE shown in Table 6.5, or should be constructed to resist the wave action and prevent water from entering the equipment. Dry floodproofing is not allowed in V flood zones.

The ASCE standard (ASCE, 2005) for flood resistant design and construction has not been adopted for category II buildings in NYC. During the process of making the amendments, it was decided that the regulation for category II buildings should remain the same, although there has been some debate about this issue. The ASCE standard advises elevating category II buildings with 1 ft above the BFE level, while the NYC code requires that these buildings should be elevated only to the BFE level, and higher elevation is optional but not required. With regards to one- and two-family houses the NYS regulation for category II buildings is even more stringent than the ASCE standard and advises building at least 2 ft above the BFE level. However, NYS building codes are not applicable to NYC, because the City has its own regulations.

6.3. Strengths and weaknesses: challenges for the future

Accuracy of FIRMS. The effectiveness of the building code regulations is heavily dependent on the accuracy of the FEMA flood maps. There are several problems with these maps, as was explained in Section 4 and the inaccuracy of the maps can have the result that a suboptimal type of building codes are applied to a structure. For example, whether elevation requirements apply to a new structure depends on if it is located in the 1/100 year floodplain on the FEMA maps, but the delineation of floodplains on these maps is often based on outdated information (Burby, 2001). Moreover, the maps' lack of details complicates building code policy. In practice, a single property can lie partly within, and partly outside, the 1/100 year flood zone demarcation line. In that case, inspectors need to determine whether the property needs to comply with the flood building codes, which is obviously an expensive task for the city. FEMA uses historical data to determine the 1/100 year flood zone, and the FIRMs do not account for increasing flood hazards in the future. If flood risks were to increase owing to climate change, and the BFE level and geographical area of the 1/100 year zone increase, then the effect will be that elevation requirements imposed on existing buildings will turn out to be insufficient. Moreover, existing buildings that then come into the 1/100 year flood zone would have been built according to building codes that did not account for the flood hazard. This is likely to augment flood losses in NYC in the future, given the projected widening of flood zones and increase in flood levels.

Current New York City building regulations and floodproofing of new structures. NYC's building regulations have been successful in achieving that flood risks are now considered in new buildings constructed in the 1/100 year floodplain. In general, elevation requirements have been shown to protect

Table 6.4. Minimum elevation of bottom of lowest supporting horizontal structural member of the lowest floor relative to the DFE in V flood zones

Structural occupancy category	Member orientation relative to the direction of wave approach	
	Orientation parallel	Orientation perpendicular
I	DFE = BFE	DFE = BFE
II	DFE = BFE	DFE = BFE
III	DFE = BFE+1ft	DFE = BFE+2ft
IV	DFE = BFE+1ft	DFE = BFE+2ft

Source: NYC-DOB (2008).

buildings against the 1/100 year flood event, which has ameliorated flood losses (Jones *et al.*, 2006). Apart from having adequate building codes, it is evident that building code compliance is important to implement effective flood-risk reduction. Overall, building code compliance in the United States seems to be reasonably high, although there is scope for improvement. Mathis and Nicholson (2006) estimated that 63% of the buildings that are subject to the NFIP regulations comply with all of the NFIP's building standards. Of the 1,253 buildings surveyed, 89% have their lowest floor at or above the BFE, or within 6 inches of that elevation. These authors examined both community record keeping of constructions in the 1/100 year flood zone and field inspections of buildings. We are not aware of an extensive study that has estimated building code compliance in NYC. Nevertheless, given that Mathis and Nicholson (2006) find little variation in compliance across communities, we expect that compliance in NYC does not diverge much from their findings.

There seems to be scope to further improve the effectiveness of building codes to cope with wave impacts, especially by strengthening or elevating foundations (Wetmore *et al.*, 2006). This is especially relevant given the future expected increase in flood risk as a result of climate change. The current NYC building regulations do not, however, account for future increases in flood hazards. The building code standards are based on the current and the anticipated BFE, which may be problematic given the long lifetime of certain structures, and the difficulty of elevating existing structures. In this respect, NYC already lags behind building code policy in other regions, since it does not require any freeboard for category II properties that include residential buildings, while this is advised in the ASCE standard (BFE+1 ft) and current policy of NYS (BFE+2 ft).

Floodproofing of existing buildings and critical infrastructure. A major challenge is how to make existing buildings more resilient to flooding and how to encourage homeowners of existing buildings to adopt cost-effective mitigation measures. This is especially important, given the projected increase in flood risk, which would imply that many existing structures that were built without flood building codes will be subject to flooding in the future. According to the current regulations, existing buildings are only subject to the flood-related building codes if they are severely damaged after a flood (see the rules of the NFIP in Section 4), or if they are substantially renovated. This regulation is relevant, for example, for the Red Hook Port Facility in NYC, which has certain old buildings that need to be renovated. A general rule is that if the costs of new construction are at least 50% of the market value of the property then the existing structure must be in full compliance with building code requirements, as if it were a new building. In practice these regulations are side-stepped by doing small cost renovations several times, so that each single renovation costs less than 50% of the value of the building, and the strict building codes are not applicable. As a result, many existing buildings remain very vulnerable to the flood hazard. A practical problem with existing buildings is that elevation is considerably more expensive (but not impossible) compared with new structures, even though other floodproofing is possible, such as placing utilities on higher floors and adapting interior fittings to flooding.

A specific challenge for NYC is how to protect its critical infrastructure against climate change. NYC has one of the densest infrastructures of the world. Old infrastructure in particular is likely to be insufficiently capable of withstanding climate change impacts, such as more coastal and river flooding. Zimmerman and Faris (2010) provide a general assessment of infrastructure in NYC that is vulnerable to climate change impacts, which discusses, among other things, impacts on the energy and transportation sector and water supply, wastewater, waste, and

Table 6.5. Minimum elevation relative to DFE below which flood damage–resistant materials must be used and minimum elevation of utilities and attendant equipment in V flood zones

Structural occupancy category	Member orientation relative to the direction of wave approach	
	Orientation parallel	Orientation perpendicular
I	DFE = BFE	DFE = BFE
II	DFE = BFE	DFE = BFE
III	DFE = BFE+2ft	DFE = BFE+3ft
IV	DFE = BFE+2ft	DFE = BFE+3ft

Source: NYC-DOB (2008).

communications. As shown in Table 6.2, some of these critical infrastructures fall under category IV buildings that have stricter building code requirements, in particular higher elevation requirements. However, these requirements do not apply to existing infrastructure, which may be problematic given their long life time. The building code requirements of NYC do not apply to the NY subway. Many subway stations are built in areas that are vulnerable to flooding and are located in low-lying areas (Jacob *et al.*, 2001). The public is very dependent on the subway system for transportation, and its possible shutdown during a flood event has considerably broader social and economic consequences. Therefore, there appears to be an interest for NYC to floodproof the subway system and ensure that it is more resilient to climate change.

6.4. Suggestions for improvements

Apply building codes using future FIRMs. A first way forward is to update the current flood-risk maps, and examine whether flood regulations are needed in other currently unregulated areas. More detailed and accurate maps can be an important input for building code policy. In addition, it could be useful to explore the creation of forward-looking flood hazards maps (see also Sections 4.3 and 5.3). Future flood maps can indicate how the current base flood level is expected to change in, for example, the year 2050, because of sea-level rise. This can be useful information for designing forward-looking building regulations that account for the expected rise in flood levels. Moreover, forward-looking flood hazard maps can indicate how the current flood zones, such as the 1/100 year flood zone, are expected to increase because of sea-level rise (e.g., in 2050). The existing elevation requirements and the current requirements can be applied to the future 1/100 year flood zone, instead of only the current 1/100 year zone. Given the long lifetime of structures, it would be useful to anticipate these trends and design building code regulations for the future flood zones. It is challenging for the City to forecast how the future flood zone would be expected to change in the future. Our discussions showed that it is unlikely that FEMA will make future flood-risk maps. NYC could, therefore, explore how such maps can be created in collaboration with experts in the insurance sector and academics.

Update New York City building regulations and floodproofing of new structures. Two main strategies can be adopted to accommodate the projected rise in flood risk in building code regulations. First, the projected increase in flood hazards could be included in current policies by using future flood hazard maps, as described above. Second, current regulations could be made stricter, on the basis of the existing flood hazard maps. For example, according to Wetmore *et al.* (2006) it would be useful to explore more strict foundation standards, especially in the current A flood zones. For example, some of the foundation standards that currently exist in the more strictly regulated V zones could be made applicable to A zones. Moreover, all buildings in the 1/100-year A flood zones can be elevated in line with the bottom of the lowest horizontal supporting structural member above the flood protection level, as currently applies to the V flood zones (Wetmore *et al.*, 2006). In this way, the floor would not come into contact with water levels during the base flood, which may occur under the current requirements.

Furthermore, in NYC it would be useful to add more freeboard to the current elevation requirements. For example, currently no freeboard is required for category II buildings, while this is advised by the ASCE standard (+1 ft) and NYS building codes (+2 ft). This could improve the protection of many buildings against floods, since these category II buildings comprise most residential buildings. The City Council can adopt the federal regulations for category II buildings, which are more stringent than those of the ASCE. The political dynamics of imposing upon the city development industry a standard that would make development much more expensive in the short term would create difficulties, but in the long term could save money. Nevertheless, the additional cost of adding freeboard when a new building is constructed is small. For the residential buildings, the additional costs of adding freeboard to the at-BFE building cost are estimated to be between 0.8% and 1.5% per ft of freeboard in a masonry wall with an interior pier (crawlspace) foundation; between 0.8% and 3.0% per ft of freeboard in a fill foundation; and between 0.25% and 0.5% per ft of freeboard in a pile or masonry pier foundation (Jones *et al.*, 2006). For the evaluation of the NFIP, Jones *et al.* (2006) conducted cost–benefit analyses of adding freeboard up to 4 ft for single family homes. The analyses were performed for various discount rates, flood conditions, elevation methods, and damage functions. The results show that, most of the time, the benefits of freeboard in terms of reduced flood vulnerability exceed its costs, especially for coastal V flood zones. Therefore, it is advisable that NYC adopts the freeboard requirement of NYS of at least 2 ft above BFE and perhaps 4 ft for single family homes. It should be further examined how the ease of accessibility to these elevated buildings can be guaranteed for disabled persons, for example, by making ramps. Moreover, design and policy considerations for adding freeboard need to be explored. Adding freeboard to the building regulations of waterfront development could be a fruitful measure to make waterfronts more resilient to climate change. Making new waterfront development as a levee could be useful, as long as current requirements for public accessibility are complied with, e.g., make ramps for wheelchairs and no steps.

Although adding freeboard to the current 1/100 year flood zone could be a good strategy to reduce vulnerability to flooding and climate of buildings within that zone, it does not floodproof buildings currently outside this zone, that are expected to be within the 1/100 year flood zone in the future. Hence, an alternative to implementing building codes in the future 1/100 year zone would be to implement flood building codes also in the existing 1/500 year zone. This could be a useful policy to accommodate future flood hazards, if it is expected that the future 1/100 year flood zone will be approximately the same as the current 1/500 year flood zone. Alternatively, it could be explored how to design buildings at the edges of the 1/100 year flood zone differently without imposing full compliance with the current strict regulation in the 1/100 year zone. For example, some floodproofing measures could be applied to the buildings near the boundaries of the zone that are currently not regulated at all. However, this could be complicated to implement, because it is necessary to examine what kind of measures need to be taken where.

If the above suggestions of stricter building codes are to be effective in accommodating future risks, then it is important to design policies that ensure that these building regulations are complied with. Kunreuther and Michel-Kerjan (2009) propose that banks and other lenders play a greater role in checking compliance with building code standards. A higher level of compliance could be attained if homeowners have to provide seals of approval from certified inspectors to financial institutions as a condition for mortgages. Such seals of approval could be provided by contractors to buyers of a new property, while for existing buildings the owners could be made responsible for obtaining this seal of approval.

Floodproofing of existing buildings and critical infrastructure. A particular challenge is how to make existing buildings more resilient to flooding and climate change. The current regulation of flood building code applications to existing buildings that are substantially repaired or renovated is often side-stepped by performing smaller construction works consecutively. Therefore, it seem sensible to improve the floodproofing of existing buildings by requiring that the building code regulations apply to buildings with *cumulative* losses or repair costs of 50% or more of their value over a designated time period. This change implies that older buildings will more often be subject to the current building codes that apply to new structures. In addition, it could be useful to explore how less expensive and simpler floodproofing measures than elevation can be applied to existing buildings. For example, the experience in Germany with the 2002 floods of the Elbe shows that considerable flood damage can be avoided by applying relatively simple measures, such as placing utility installations on higher floors, installing temporary water barriers, and the dedication of lower floors to low-value uses (Kreibich *et al.*, 2005; Thieken *et al.*, 2006). It could be required that some of these measures are undertaken, for example, when a building is renovated. Moreover, NYC could explore how to better regulate the flood vulnerability of critical infrastructure. A thorough assessment of the costs and benefits of additional regulations for critical infrastructure would be in order. For example, consideration could be given to imposing strict elevation requirements for the entrances of the NYC Subway.

The question arises how homeowners should pay for floodproofing measures. Although these measures could save homeowners money in the future in terms of lower flood damage, budget constraints may preclude them from making these investments. To help homeowners, the scope of FEMA grants could be increased by funding less expensive mitigation measures undertaken by homeowners as opposed to focusing only on expensive measures, such as elevation (U.S. Department of Homeland Security, 2009). Moreover, homeowners might be more inclined to invest in expensive mitigation measures, such as elevation of their homes, if long-term mitigation loans were available (Kunreuther and Michel-Kerjan, 2009). Long-term mitigation loans could enable homeowners to spread the often high upfront costs of mitigation over a long period of time, such as 10 or 15 years. Investments in mitigation may be more attractive for households if they could spread the mitigation costs in smaller monthly payments that could be matched by (larger) monthly reductions in insurance premiums that reflect lower risk. This would be especially useful for homeowners with budget constraints, who are unable to afford a large upfront payment for mitigation. Furthermore, communities can encourage their citizens to invest in mitigation measures by giving them tax incentives. A reduction in state or property taxes could be granted to those homeowners who invest in measures that reduce their exposure to flooding. The rationale for providing tax cuts for mitigation is the broader communal benefits derived from a reduced exposure to natural hazards, such as a reduced reliance on federal relief funds after disasters, and a lower probability that families need to be housed and fed elsewhere by their local government because their homes are destroyed by disasters (Kunreuther and Michel-Kerjan, 2009).

7. Urban waterfront architecture and planning: an international perspective

7.1. Super-levees: Tokyo

Japan has been experimenting with a fail-proof, low-maintenance levee for the protection of urban areas in flood-prone cities like Tokyo and Osaka. These super-levees improve on the typical levee by widening its footprint and reducing the backslope to a low gradient. The result is a flood-protection zone instead of a mere barrier. These super-levees minimize the risk of breach and underseepage that threaten thinner levees. Water that does overtop a super-levee is slowed as it flows down the long backslope; water overtopping a normal levee cascades down the back, quickly eroding and compromising the integrity of the structure. With their broad bases, the super-levees are also less likely to fail during earthquakes. The super-levee offers advantages besides the structural and flood protection aspects. The stabilized and strengthened sides can be developed, extending the urban development area to the top of the levee and allowing easier visual and physical access to the water. In Japan, these developments are high-rise and interwoven with parks and open spaces and wetlands that are scarce throughout much of NYC (Fig. 7.1).

The super-levees are, however, not free of problems. Their extreme width means that land of approximately one block wide along the river or coastal front needs to be free and available. Since most of this land is occupied, the majority of new super-levees have been built on vacant or postindustrial land. The super bulk of a super-levee also demands problematically large amounts of fill material. Some of the fill can be offset by including parking and service structures in the body of the levee. The lesson from Japan is to consider flood protection not as the isolated endeavor of a single agency, but as part of a larger body of work that is intertwined with urban redevelopment, open space planning, land rehabilitation, and habitat generation.

During the Brooklyn–Rotterdam Waterfront exchange workshop organized by the the Port Authority of New York and New Jersey (PANYNJ), several options to both revitalize the waterfront and enhance flood protection were explored. For example, there is a potential opportunity for the replacement of the existing elevated Gowanus Expressway. Ongoing reconstruction is expected to extend the life

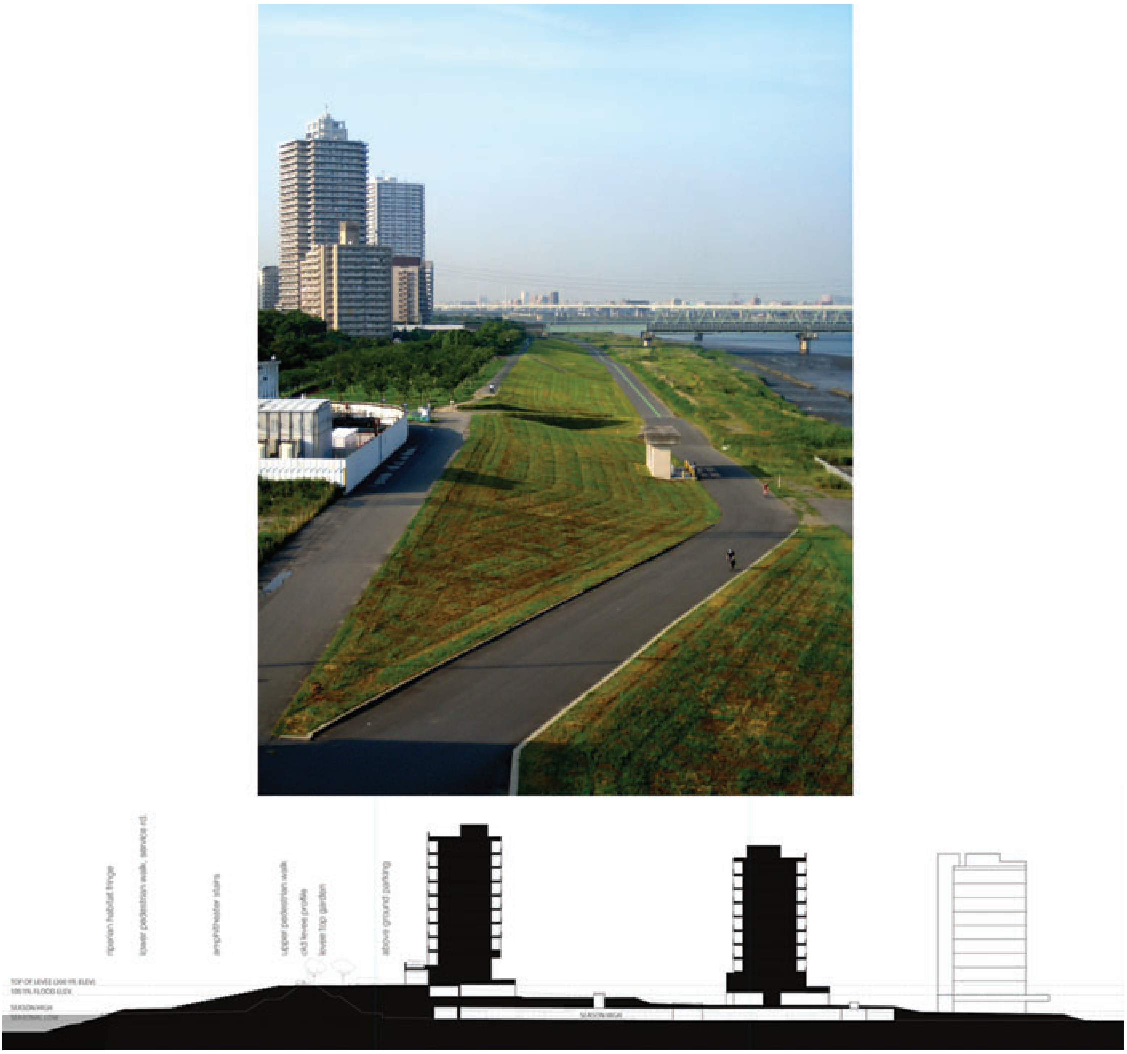

Figure 7.1. **Super-levee on the Edogawa in Tokyo (top). Source: William Verbeek. Cross-section through a super-levee in Osaka (bottom). Source: Stalenberg (2010).**

of the structure for only another 20–25 years. The concept moves the highway one avenue closer to the water, and constructing it above-grade within a berm (on a super-levee). The replacement highway could provide improved regional mobility and local flood protection.

For the NYC area, this would imply a joint effort between local, state, and federal governments, especially the U.S. Army Corps of Engineers. However, the Japanese example shows that protecting cities from floods with super-levees is feasible and affordable. Waterfront developments on super-levees are technically feasible, and this would not necessarily mean shutting them off from the water as often perceived.

7.2. Elevated residential areas: old port facility, Hamburg

HafenCity in Hamburg (Germany) is a city-planning project where the old harbor quarter of Hamburg has been built on with offices, hotels, shops, official buildings, and residential areas. The project is one of the largest rebuilding projects in Europe in the 21st century. The area of the HafenCity used to be part of the port, but with the decreased economic importance of ports in an era of European

Figure 7.2. HafenCity (City of Hamburg, Germany) with the boardwalk at about 9 ft and the residential apartments at a level of 22 ft (top). Emergency serviceway above the design water level at HafenCity (bottom). Source: Jeroen Aerts.

Union free trade, large container ships and increased border security, the Hamburg free port was reduced in size, freeing the current HafenCity area from its restrictions. When completely developed it will be home to about 12,000 people and the workplace of 40,000 people, mostly in office complexes.

The site of HafenCity is located on the waterside of the main dike line, and is thus within the flooding area of the Elbe estuary. HafenCity is located outside Hamburg's main dike line; in other words, at its historic level of 16.4–18 ft (4–5.5 m) above sea level, the area would also be prone to flooding. Therefore, almost every public road, bridge, and all buildings will be elevated to a minimum height of 22 ft (7 m) above sea level (Fig. 7.2). The buildings' foundations will serve as ground floor garages, which can be flooded in severe cases. Roads and paths are constructed above the flood line to ensure access for emergency services in the event of an extreme storm tide (HafenCity Hamburg, 2011) (Fig. 7.2, bottom).

Figure 7.3. Artist impression of the new new outer harbor of Rotterdam (Maasvlakte 2). Source: Port of Rotterdam (2011).

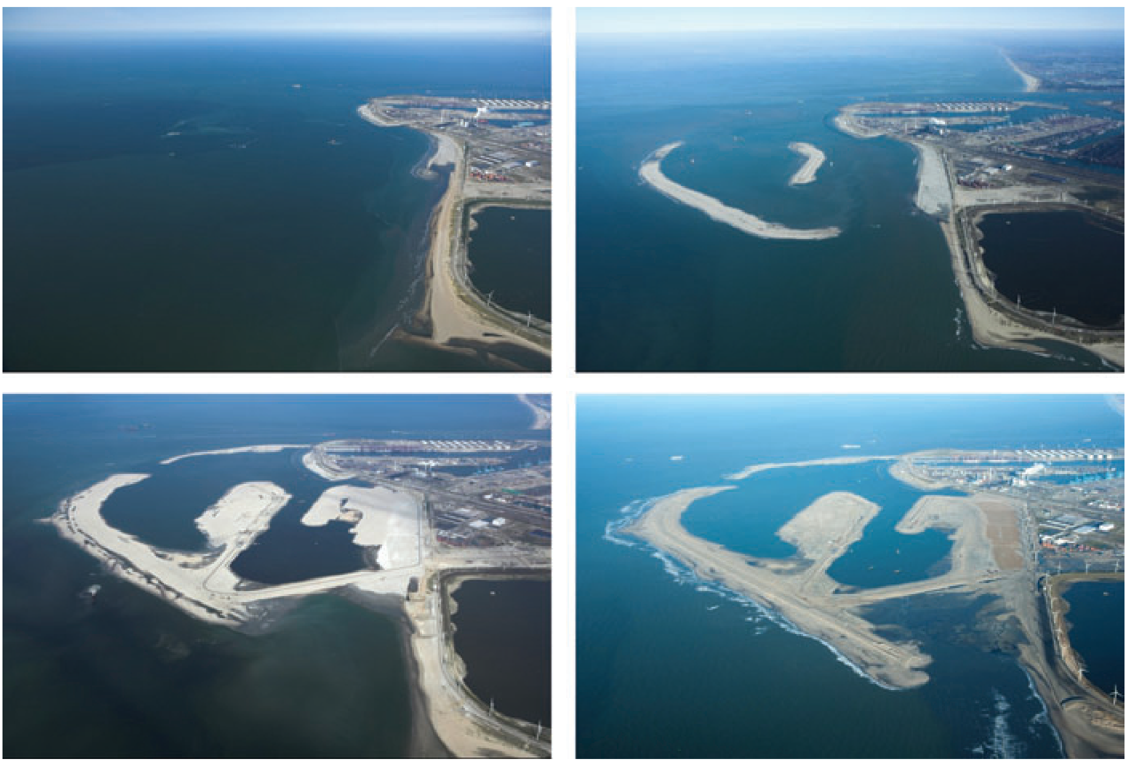

Figure 7.4. Series of aerial photographs of the new Maasvlakte 2 harbor near Rotterdam that is currently being nourished with sand from the North Sea. Upper left: May 2009; Upper right: October 2009; Lower left: July 2010; Lower right: January 2011. Source: Port of Rotterdam (2011).

It was this solution that made possible the gradual development of the entire HafenCity: it eliminates the need for an enormous technical and economic operation to make the whole project area impregnable to high water—for example, by reclamation—before building construction could even begin. Total costs are estimated to reach about €600 million.

Twenty percent of its total area is devoted to public open space. Although another 20% of the area is privately owned, it is subject to right-of-way and other public obligations. Even the 34 hectares of water surface (excluding the River Elbe) is partially restructured and in public use, for the plinths are not directly adjacent to the quay edges. A broad strip up to 50 ft (15 m) wide remains at a lower level, that is, down near the water. On the whole it takes the form of promenades, but in some places, it becomes a square. In addition—and often even parallel to river walkways—other urban spaces are laid out on the plinths themselves. The resulting topography thus creates a townscape on two levels, both of which relate to the water, while an intervening dike would have destroyed that relationship (Hafencity).

The design of promenades and parts of squares has already taken into consideration the risk that extreme high water will flood them once or twice a year for a few hours. They can withstand such flooding without damage. As water levels in the Elbe fluctuate by more than 11 ft (3.5 m) with the tide, perceptions of the district are constantly shifting. The relationship between water levels, quay walls and edges, pontoons, ships, and buildings also shifts continuously.

7.3. Environmental aspects: using open water and nature compensation (the Netherlands)

There are international examples of how to deal with seaward waterfront development while preserving environmental values. For example, the new outer harbor of Rotterdam (Maasvlakte 2) will be developed by creating new elevated land at a height of +/− 15 ft above amsl (+5 m above mean sea level) in open water at the coast near Rotterdam (Figs. 7.3 and 7.4). The new area measures 2,000 ha (about 4,900 acres). This open water area falls under several pieces of national and European legislation for the protection of environmental values and legislation preserving natural flood protection values by means of beaches and dunes. Environmental impact statements were executed to estimate the potential change in ocean currents and hence beach erosion, the loss of biodiversity, and loss of fishing grounds. On the basis of these studies, it was decided that, with the development of the new harbor, a nature conservation and compensation program should be developed and implemented. The Dutch Environmental conservation legislation, enacted in 1998, is very much tied to EU legislation: for example, to the EU Natura 2000 law, which has designated areas that come under special protection. Urban development in those areas (which include areas of water) is only possible in compliance with Article 19 of the Dutch Environmental Conservation Law (Natuurbeschermingswet, 1998) which says "the development in Natura 2000 areas is only possible in the absence of alternative solutions for a project and in case the project has overriding public interest including those of a social or economic nature." In addition, a permit to develop in Natura 2000 areas is only granted if sufficient compensating measures are implemented to sustain the same biodiversity and environmental values that existed before the development. The decision to grant a permit is political, and no clear rules exist as to exactly how many compensating measures are needed.

The compensation program in Rotterdam has two tracks: (1) the development of a nature protection area of about 20,000 ha (49,420 acres) south of the new harbor, in which only limited recreation is allowed and natural processes are further stimulated; and (2) the seaward development of a new dune area of 35 ha (86 acres) at a location north of the new harbor, which is known as a weak spot in the dune flood defense system of the Rotterdam region.

8. Recommendations: climate-resilient waterfronts in New York City

The main outcome of this study is that flood zoning policies, flood insurance, and building codes are powerful tools for controlling changing future land use, and hence the potential vulnerability of land use to flood risks. The study has focused on recommendations that are rooted in existing legislation on flood insurance, zoning policies, and building codes. It also illustrates the need for improved cooperation between the NFIP coordinated by FEMA, the NYC Department of Buildings, and the NYC Department of City Planning to ensure that all existing regulations are applied with maximum efficiency.

International examples of such cooperation are presented and how these could apply to the situation in NYC is discussed.

The NFIP and climate change

The NFIP is an important program for achieving risk reduction, because it imposes the minimum requirements for local authorities flood zoning and flood building codes, and it provides incentives to homeowners to invest in risk reduction beyond these minimum standards. The NFIP sets the minimum building requirements in the 1/100 flood zone, and local authorities are allowed to impose zoning regulations and building codes in addition to these minimum standards. Climate change or other future developments, such as urban development, are not addressed in the NFIP. The general recommendation for the NFIP is the need for a thorough assessment of how the NFIP can be geared toward accommodating, and ameliorating the impacts of, increased flood risk. Nevertheless, there seems to be considerable scope to improve the current program even if flood risk does not increase as a result of climate change.

Cooperation between the NFIP and New York City zoning policies

An important recommendation for improved cooperation between the NFIP, the NYC Department of Buildings, and the NYC Department of City Planning is to take into account future flood-risk maps (e.g., the future 1/100 year floodplain) in flood insurance, zoning, and building code policies.

In view of climate change, the geographical extent of the 1/100 year flood zone is likely to increase, and insurance and zoning regulations could be made applicable to what is expected to be the future 1/100 year floodplain. Knowing the future 1/100 flood zone offers the possibility to impose the same requirements that apply to the current 1/100 year flood zone, such as elevation of new buildings and floodproofing measures, to the future 1/100 year flood zone. Each new development or revitalization program could then be overlaid with the future 1/100 floodplain maps, and the current NFIP regulation with BFE requirements could be applied to these future flood zones.

Currently freeboard is added for certain new constructions in the current 1/100 year flood zone, which means additional elevation of the base line floor level above the BFE determined by FEMA. Allowing for freeboard in the future 1/100 zones anticipates future climate risk. An alternative policy to mapping the future 1/100 flood zone is to regulate not only the current 1/100 flood zone, but also other flood zones, such as the current 1/500 year flood zone.

Other issues that could be addressed by the NFIP include the need to:

- *Improve the accuracy of FIRMs.*
  It appears that FIRMs are often inaccurate, which results in premiums that do not completely reflect actual risk. This is a recommendation with national implications. The lack of detail of the maps is problematic for local authorities if they wish to implement stricter building codes than the NFIP regulations and regulate land use in floodplains.
- *Reassess premiums and the relationship to the BFE for A zones.*
  It is recommended that the NFIP should reevaluate flood insurance premium discounts for buildings in A zones, because A zone discounts effectively cease at 1 to 2 ft above the BFE, but higher elevation could be desirable owing to climate change. The current regulation for such properties is that property owners who are remapped to a more costly zone classification are charged the lower insurance premium of the former flood zone, which is also referred to as grandfathering. It may be considered that this grandfathering mechanism should be abolished since it would result in an increase in subsidized policies over time.
- *FEMA mitigation grants are not suitable as a climate adaptation tool.*
  The availability of the grant programs can often be a motivation for communities to join the NFIP. It seems unlikely, however, that the current grant programs will free up sufficient financial resources to finance the required climate adaptation policies for the NYC waterfronts. Moreover, the grants mainly focus on flood damage to mitigating existing buildings.
- *Increasing the NFIP's market penetration.*
  The market penetration of the NFIP is rather low, which is an impediment for stimulating flood-risk reduction measures through insurance, such as premium discounts. This is a

nationwide problem and not only specific to NYC. This could be resolved through mandatory purchase requirements for homeowners with federally backed mortgages who live in the current 1/500 year flood zone or future 1/100 flood zones.

- *Setting risk-based insurance premiums.*
  It is recommended that premiums should be set that reflect risk. Otherwise, incentives for homeowners to implement risk reduction measures are distorted, which can be especially troublesome if more investments in flood damage mitigation are needed in the future because of risk increases.
- *Long-term insurance.*
  The short-term nature of the current flood insurance policies of only one year may restrain an active collaboration between insurers and policyholders in reducing exposure to flooding. It has been suggested by several scientific experts to introduce long-term flood insurance contracts that are tied to properties instead of the individuals for durations of, for example, 5, 10, or 20 years.
- *More attention for vital infrastructure.*
  Infrastructure damage is not adequately addressed through the NFIP, whereas potential flood damage is, for a large part, determined by the infrastructure at risk. The NFIP only recommends restrictions for the development of critical infrastructure through the CRS, but these recommendations are not strictly enforced.

Adjusting zoning controls

The following recommendations are made with respect to zoning policies:

- *Eliminating the zoning building height penalty.*
  The zoning resolution could provide additional flexibility for buildings in flood-risk areas to allow for "freeboard," which means additional elevation of the BFL above the FEMA BFE in order to earn a discount on insurance premiums. However, these elevated buildings are also subject to zoning height limits in the same way as buildings that do not increase their elevation. A logical next step would be to eliminate this zoning penalty.
- *Additional restrictions for existing buildings in flood zones.*
  For existing buildings, set back, relocation, or elevation in areas susceptible to flooding is perceived as infeasible. Additional regulation could stimulate homeowners to implement measures to floodproof telephone, electricity switchboards, heating and gas installations above the BFE for residential buildings (structural occupancy category II). Furthermore, experience with the 1961 zoning policies shows that a limit on development or enlargement of existing properties could lower densities and hence vulnerability.
- *Preserving open space.*
  The required percentage of open space on waterfront lots should be increased or at least maintained to limit building footprints and hence reduce potential flood damage.
- *Lowering density.*
  Adjusting the FAR is not seen as a feasible option to reduce flood risk, although lower urban densities may reduce the population at risk. Urban development is also seen as a way to finance adaptation measures.
- *Tradable Floor Area (TFA).*
  The option of further stimulating a market based system of TFA in order to shift potential new floor area to nearby inland lots is not seen as a feasible option.

Waterfront development and environmental legislation

The issue of climate change and sea-level rise puts an additional burden on waterfront developments and policies, and the challenge is to create a greener waterfront that is more resilient to climate change and attractive for business and residents. An issue is that both urban development and flood protection measures (e.g., levees and flood walls) are often perceived as activities that disturb environmental values. Thus, the challenge is to develop the waterfront such that it enhances flood protection levels by applying measures that also improve environmental values. This study, therefore, recommends to prioritize waterfront development in areas where coastal flood protection and nature preservation can be co-developed and, hence, where local government and the state and federal environmental and coastal zone policies have a mutual interest. Such an approach could be addressed by better integrating federal and state coastal zone protection into local waterfront revitalization programs. Environmentally based flood protection to anticipate climate change is receiving support from communities, as has been communicated during the Borough workshops initiated for *Vision 2020*. This implies that, in some instances, the land–water boundary should be moved inland and, in some instances seaward, to compensate for the loss of urban space. Recent research supports the notion that modifications in the open water zone and intertidal wetland area should be evaluated to determine whether waterfront activities can enhance the resilience to climate change. Many of such modifications, however, require discretionary permits. Currently, the manner in which NYS environmental regulations have been administered has effectively prohibited any waterfront development into open water space. This may hamper the development of attractive waterfronts in conjunction with improvements in environmental quality.

Building codes

While the NFIP determines minimum building code standards, NYC has designed its own building codes that can go beyond these minimum standards. The building codes apply to new structures and substantial improvements of the existing structure. "Substantial" means improvement with a value of more than 50% of the market value of the property. The additional flood building code regulation for NYC consists of three main components: (1) building above the BFE level (freeboard); (2) dry, as well as wet floodproofing; and (3) requirements per flood zone for different types of buildings (categories I–IV).

Current regulations should be made stricter, on the basis of the existing flood hazard maps:

- Foundation standards other than those that currently exist in the more strictly regulated V zone to the coastal A zone should be applied.
- Elevation standards that currently exist in the more stringently regulated V zone to the coastal A zone should be applied.
- Additional freeboard should be added to the current elevation requirements to achieve safety standards at least as strict as NYS and ASCE 24. For example, currently no freeboard is required for category II buildings, but this is advised by the ASCE standard (+1 ft) and NYS building codes (+2 ft) for one- and two-family houses. This would improve protection of many buildings against floods, since these category II buildings comprise most residential buildings. The City Council should adopt NYS standards for category II buildings, which are more stringent than those of the ASCE.
- Cost–benefit analyses of adding freeboard up to 4 ft for single-family homes showed that, most of the time, the benefits of freeboard, in terms of reduced flood vulnerability, exceed its costs, especially for coastal V flood zones. Therefore, it is advisable that NYC should adopt the freeboard requirement of NYS of at least 2 ft above BFE and perhaps 4 feet. It should be further examined how the ease of accessibility to these elevated buildings can be guaranteed for disabled persons, for example, by making ramps or elevating streets. Moreover, design and public realm considerations for adding freeboard need to be explored. Adding freeboard to the building regulations of waterfront development could be a fruitful measure to make waterfronts more resilient to climate change.
- Flood-resistant construction standards in the 1/500 flood zone should be applied.

Flood protection and architecture

There are several examples where waterfront developments have been combined with flood-protection measures. Examples from the city of Tokyo in Japan could be explored for developing parts of the waterfront in NYC, especially the old manufacturing areas such as old port facilities. For example, the city of Tokyo has been experimenting with a fail-proof, low-maintenance levee for the protection of urban areas. These super-levees improve on the typical levee by widening its footprint and reducing the backslope to a low gradient. In Japan, these developments are high-rise and interwoven with parks, open spaces, and wetlands that are scarce throughout much of the city. In the city of Hamburg (Germany), an old port facility has been rebuilt and the entire new waterfront has been elevated to an elevation of about 20 feet. Above this elevation, residential housing is permitted and a service and emergency road system exist at 20 ft to maintain accessibility in case of a flood.

Toward an integral flood management and climate adaptation plan

The complexity of the issue and the inherent uncertainty associated with future projections such as climate change require an integrated approach to flood management in NYC. The existing community rating system coordinated by the NFIP is not an attractive program to facilitate the development of such a plan. A coordinated effort is needed between insurers and governmental planners to develop a more comprehensive flood management plan that outlines the effects from climate change, alternative solutions, and the costs and benefits of the different adaptation options (e.g., Aerts *et al.*, 2008). The NYC's Mayor's Office of Long-Term Planning and Sustainability, with its established relationships with multiple stakeholders, is well positioned to coordinate, explore, and foster the implementation of such a plan.

Conflicts of interest

The authors declare no conflicts of interest.

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Jeroen Aerts is a professor in the area of risk management, insurance, and water resources management. His scientific expertise is in risk analysis, multicriteria analysis, and uncertainty assessment. In recent years, he has developed robustness analysis techniques, such as portfolio analysis within catastrophe modeling to identify optimal and flexible adaptation strategies in flood-risk management. His research and consultancy activities include a large number of international risk and water-resources management projects in the Netherlands, Central Asia, Bangladesh, Kenya, Southern Africa, India, Vietnam, and the United States. These projects mainly focus on water management related to such issues as disaster management, insurance arrangements, poverty and vulnerability reduction, and risk-management strategies. The kernel of most projects is a science-policy approach where both scientists and policymakers jointly assess risk indicators and evaluate management strategies. Jeroen Aerts has contributed to the IPCC FAR WGII. He is, furthermore, theme coordinator of the Dutch adaptation research program BSIk KvR (24 Million Euro). Jeroen Aerts has published over 70 peer-reviewed papers.

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Wouter Botzen is assistant professor at the Department of Environmental Economics, Institute for Environmental Studies (IVM), VU University Amsterdam. He obtained his PhD degree in 2010 with a cum laude distinction for his dissertation titled "The Economics of Insurance against Climate Change." Such a distinction is rarely awarded at the Economics Faculty of the VU University. He won the prestigious Junior Societal Impact Award of the VU University in 2010. Wouter has a shared responsibility for teaching provided by the department and is mainly involved in the master's course environmental economics provided by the institute. Currently, he is working on a variety of projects dealing with natural disaster insurance, climate change adaptation, and decision making under uncertainty. He has published many articles in international peer-reviewed journals on these topics.

Appendix A. Interviewed experts

Table A1 lists the persons with whom the authors had interviews and discussions to obtain information for this study. In most cases, detailed notes were made of the meeting and these summaries were provided to those interviewed with a request that they review the accuracy of the summary.

Appendix B. Zoning glossary

These definitions are taken from NYC-DCP (2010c).

Base flood elevation (BFE): The estimated level of water associated with the 100-year flood, which is a severe flood reaching or surpassing a certain water level that has a 1% chance of occurrence in any given year.

Bulk regulations: The combination of controls (lot size, floor area ratio, lot coverage, open space, yards, height, and setback) that determine the maximum size and placement of a building on a zoning lot.

Density: The intensity of development within a zoning district. In residence districts, density is generally measured by the maximum number of dwelling units permitted on a zoning lot. The maximum number of units is calculated by dividing the maximum residential floor area permitted on a zoning lot by the applicable factor for each zoning district. (Fractions equal to at least $\frac{3}{4}$ are considered one unit.) The factors for each district are approximations of average unit size plus allowances for any common areas. Special density regulations apply to

Table A1. **Interviews and discussions with experts in the public and private sectors**

Name	Affiliation	Relevant expertise
Fabrice Felden	Swiss Re	Flood insurance, catastrophe modeling
Megan Linkin	Swiss Re	Flood insurance, climate change
Tom Wargo	NYC Department of City Planning	Zoning specialist
Claudia Herasme	NYC Department of City Planning	Zoning specialist
Scot Duel	FEMA	NFIP
Patricia Griggs	FEMA	NFIP
Mary Colvin	FEMA	NFIP
Joshua Friedman	OEM	Risk Management & GIS
James McConnell	OEM	Risk Management
Dennis Suszkowski	Hudson River Foundation	Hudson River Foundation
Clay Hiles	Hudson River Foundation	Hudson River Foundation
James Colgate	NYC Department of Buildings	Standards and requirements
Sandy Hornick	NYC Department of City Planning	Flood zoning
Bill Woods	NYC Department of City Planning	Director, Waterfront Division
Michael Marrella	NYC Department of City Planning	Project Director, Waterfront Plan
Howard Slatkin	NYC Department of City Planning	Deputy Director of Strategic Planning
Aaron Koch	NYC Mayor's office	Long-term planning and sustainability

Residential Density	
District	Dwelling Unit Factor
R1-1	4,750
R1-2	2,850
R2 R2A	1,900
R2X	2,900
R3-1 R3-2[1]	625
R3A	710
R3-2 R4 R4-1 R4B	870
R3X	1,000
R4A	1,280
R5 R5D	760
R4(infill) R5(infill) R5B	900
R5A	1,560
R5B[2]	1,350
R6 R7 R8B	680
R8 R8A R8X R9 R9A	740
R9-1 R9X R10	790

[1] for single- and two-family detached and semi-detached residences
[2] for single- and two-family residences

Figure B1. Source: NYC-DCP (2010c).

mixed buildings that contain both residential and community facility uses (Fig. B1).

Dwelling Unit: A dwelling unit (d.u.) consists of one or more rooms that contain lawful cooking and sanitary facilities, inhabited by one or more persons living together and maintaining a common household, in a residential building or residential portion of a building.

Enlargement: A built addition to an existing building that increases the floor area of the building.

Floor area ratio (FAR): The principal bulk regulation controlling the size of buildings. The FAR can be used in zoning to limit the amount of construction in a certain area. FAR is the ratio of total building floor area to the area of its zoning lot. Each zoning district has a FAR control that when multiplied by the lot area of the zoning lot produces the maximum amount of floor area allowable in a building on the zoning lot. For example, on a 10,000 ft^2 zoning lot in a district with a maximum FAR of 1.0, the floor area of a building cannot exceed 10,000 ft^2 (Fig. B2).

Lot or zoning lot: A tract of land comprising a single tax lot or two or more adjacent tax lots within a block. An apartment building on a single zoning lot, for example, may contain separate condominium units, each occupying its own tax lot. Similarly, a building containing a row of townhouses may occupy several separate tax lots within a single zoning lot, or two or more detached homes on one zoning lot may each have its own tax lot.

Mixed Building: A building in a commercial district used partly for residential use and partly for community facility or commercial use. A building that contains any combination of uses is often referred to as a mixed-use building. When a building contains more than one use, the maximum FAR permitted on the zoning lot is the highest FAR allowed for any of the uses, provided that the FAR for each use does not exceed the maximum FAR permitted for that use. In a C1–8A district, for example, where the maximum commercial FAR is 2.0 and the maximum residential FAR is 7.52, the total permitted FAR for a mixed residential/commercial building would be 7.52, of which no more than 2.0 FAR may be applied to the commercial space.

Mixed Use District: A special zoning district in which new residential and non-residential (commercial, community facility and light industrial) uses are permitted as-of-right. In these districts, designated on zoning maps as MX with a numerical suffix, an M1 district is paired with an R3 through R9 district.

Open space: The part of a residential zoning lot (which may include courts or yards) that is open and unobstructed from its lowest level to the sky, except for specific permitted obstructions, and accessible to and usable by all persons occupying dwelling units on the zoning lot. Depending upon the district, the

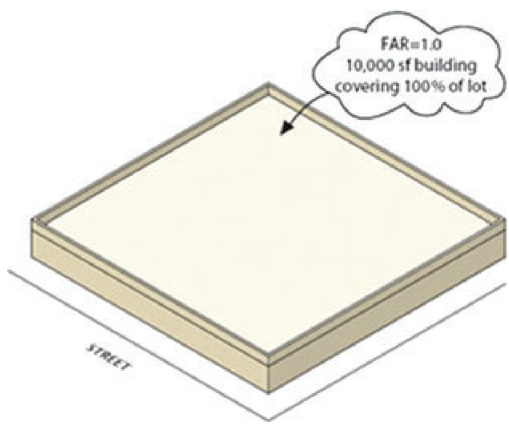

Figure B2. Source: NYC-DCP (2010c).

amount of required open space is determined by the open space ratio (OSR), minimum yard regulations, or by maximum lot coverage.

Open space ratio (OSR): The amount of open space (in ft^2) required on a residential zoning lot in non-contextual districts, expressed as a percentage of the total floor area on the zoning lot. For example, if a building with 20,000 ft^2 of floor area has an OSR of 20, 4,000 square ft of open space would be required on the zoning lot (0.20 × 20,000).

Uniform land use review procedure (ULURP): The public review process, mandated by the City Charter, for all proposed zoning map amendments, special permits, and other actions such as site selections and acquisitions for city capital projects and disposition of city property. The procedure sets forth time frames and other requirements for public participation at the community board, borough board and borough president levels, and for the public hearings and determinations of the community boards and City Planning Commission (CPC). Zoning text amendments follow a similar review process, but without a time limit for CPC review. (For a full explanation of ULURP, including a diagram of the ULURP time clock, see Land use review procedure)

Use: Any activity, occupation, business or operation, listed in Use Groups 1 through 18, which is conducted in a building or on a tract of land. Certain uses are allowed only by special permit of the CPC or BSA.

Use group: Uses that have similar functional characteristics and/or nuisance impacts and are generally compatible with each other are listed in one or more of 18 groups that are ranked from residential uses (Use Groups 1–2), community facility uses (Use Groups 3–4), retail and service uses (Use Groups 5–9), regional commercial centers/amusement uses (Use Groups 10–12), waterfront/recreation uses (Use Groups 13–15), and heavy automotive uses (Use Group 16) to manufacturing uses (Use Groups 17–18). Use group charts can be found in Chapter 2 of Articles II, III, and IV of the zoning resolution.

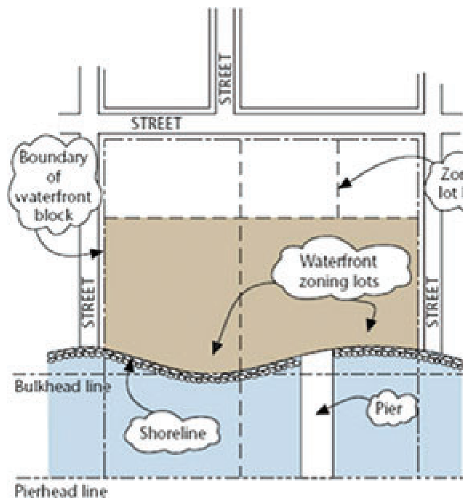

Figure B3. Source: NYC-DCP (2010c).

The waterfront access plan (WAP): The specific plan, set forth in the NYC Zoning Resolution that tailors waterfront bulk regulations and public access requirements to the specific conditions of a particular waterfront. Development of individual waterfront parcels governed by the plan triggers a requirement to build and maintain public access areas in accordance with the WAP.

Waterfront area: The geographical area comprising all blocks between the pierhead line and a line 800 ft landward from the shoreline. Where the line intersects a block, the entire block is included in the waterfront area.

The bulkhead line is a line shown on the zoning maps that divides the upland and seaward portions of waterfront zoning lots.

The pierhead line is a line shown on the zoning maps that defines the outermost seaward boundary of the area regulated by the zoning resolution.

The shoreline is the mean high water line.

A waterfront block is a waterfront public park or waterfront zoning lot in a block, public park, or zoning lot in the waterfront area that is adjacent to or intersected by the shoreline (Fig. B3). Source: NYC-DCP (2010c).

Appendix C. Databases

Name/ Database	Year	Description	Source	Website
MapPLUTO	2009	Tax lot information	Department of City Planning (DCP)	http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml
Building footprints	2009	Building location and perimeter	The New York City Department of Information Technology and Telecommunications (DoITT)	www.nyc.gov/datamine
Transportation database	2009	Location of stations, ventilation grates, tunnel entrances	DoITT	www.nyc.gov/datamine
PAD (Property Address Directory)	2009	Addresses, tax lots, and BIN (building identification number)	DCP	http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml
FIRM (flood insurance rate maps)	2010	FEMA flood zones / special flood hazard areas	FEMA	http://www.fema.gov/hazard/map/firm.shtm
Digital Q3 flood zone data	2009	The Q3 flood data are derived from the FIRMs published by FEMA	FEMA	http://www.nysgis.state.ny.us/gisdata
Multi-Coloured Manual	2008	Flood damage curves	Flood Hazard Research Centre (FHRC), UK	http://www.mdx.ac.uk/research/areas/geography/flood-hazard/publications/index.aspx#Multi-Coloured%20Manual
MTA / Rail data	2009	Shapefiles on MTA tracks		http://spatialityblog.com/2010/07/08/mta-gis-data-update/

Appendix D. Vital facilities per flood zone

Table D1. Vital structures in the 1/100 V zone

#	Building class	Description
1	G4	Gas station with workshop
2	W1	Public elementary, junior high, and senior high schools
1	W2	Parochial schools, yeshivas
1	W3	Schools or academies
1	W4	Training schools
1	W9	Miscellaneous education
1	Y1	Fire department
2	Y3	Prisons, jails, houses of detention
8	Y4	Military and naval
18		

Table D2. Vital structures in the 1/100 A zone

#	Building class	Description
1	G3	Garage and gas station combined
22	G4	Gas station with workshop
15	G5	Gas station without workshop
13	I1	Hospitals, sanitariums, mental institutions
3	I4	(Health) Staff facilities
10	I5	Health centers, Child centers, clinics
13	I6	Nursing homes
10	I7	Adult care facilities
63	W1	Public elementary, junior high, and senior high schools
14	W2	Parochial schools, yeshivas
7	W3	Schools or academies
2	W4	Training schools
4	W5	City university
4	W6	Other colleges and universities
2	W7	Theological seminaries
13	W8	Other private schools
16	W9	Miscellaneous education
11	Y1	Fire department
11	Y2	Police department
5	Y3	Prisons, jails, houses of detention
13	Y4	Military and naval
252		

Table D3. Vital structures in the 1/500 zone

#	Building class	Description
2	G3	Garage and gas station combined
52	G4	Gas station with workshop
32	G5	Gas station without workshop
19	I1	Hospitals, sanitariums, mental institutions
3	I4	(Health) Staff facilities
23	I5	Health centers, child centers, clinics
21	I6	Nursing homes
25	I7	Adult care facilities
107	W1	Public elementary, junior high, and senior high schools

Table D3. *(Continued)*

#	Building class	Description
29	W2	Parochial schools, yeshivas
9	W3	Schools or academies
4	W4	Training schools
5	W5	City university
5	W6	Other colleges and universities
3	W7	Theological seminaries
21	W8	Other private schools
23	W9	Miscellaneous education
22	Y1	Fire department
12	Y2	Police department
5	Y3	Prisons, jails, houses of detention
14	Y4	Military and naval
436		

Appendix E. Value of tax lots without buildings

The PLUTO datasets contain value assessments for 859,328 distinct lots, but not every lot has building footprints associated with it—so when we map lot value to building footprints to calculate the value/ft^2, the value of these lots without buildings is omitted (gets multiplied in with 0). To give an impression of the loss of value at risk data, Table E1 shows "disappearing value" by borough.

Table E1. Disappearing value by borough

Borough	# lots	# lots with buildings	Value lots without building
Brooklyn	278,418	263,697	$670,371,994.00
Bronx	89,838	82,360	$308,827,009.00
Manhattan	43,435	40,612	$2,317,541,683.00
Queens	324,324	309,863	$550,773,632.00
Staten Island	123,313	111,603	$139,119,570.00
Total	859,328	808,135	$3,986,633,888.00

Appendix F. Classification of "other land use"

Q0: Open space
Q1: Parks
Q2: Playgrounds
Q3: Outdoor pools
Q4: Beaches
Q5: Golf courses
Q6: Stadiums, race tracks, baseball fields
Q7: Tennis court
Q8: Marinas/yacht clubs
Q9: Miscellaneous outdoor recreation facilities
G6: Licensed parking lots
G7: Unlicensed parking lots
T1: Airports, air fields, terminals
T2: Piers, docks, bulkheads
T9: Miscellaneous
V0: Vacant land zones, residential, except not Manhattan below 110 St.
V1: Vacant land not zoned residential, or Manhattan below 110 St.
V2: Vacant land not zoned residential, but adjacent to Tax Class 1 dwelling
V3: Vacant land zoned, primarily residential, except not Manhattan below 110 St.
V4: Vacant land, police or fire department
V5: Vacant land, school site or yard
V6: Vacant land, libraries, hospitals, or museums
V7: Vacant land, Port Authority of NY and NJ
V8: Vacant land, state and federal
V9: Vacant land, miscellaneous (Department of Real Estate and other public places)
Y5: Department of Real Estate land
Z2: Public parking areas
Z6: Land under water
Z7: Easements
Z8: Cemetaries
Z9: Miscellaneous other

Appendix G. Flood damage to subway systems

1. Empirical data on flood damage to subway systems

Compton *et al.* (2009) have summarized empirical data from historical flood events in subways. These are listed below in Table G1. *Note:* the "computed damage per km" is in millions of 2009 Euros.

Table G1. Summary of reported damage in subway flooding incidents (Compton *et al.*, 2009)

	Boston 1996	Seoul 1998	Taipei 2001	Prague 2002
Total construction cost (mln €)	n/a	790*	15000**	n/a
Total construction cost per km (mln €/km)	n/a	18	~ 180	n/a
Km track flooded	2–3	11	9–12	15–20
Volume of water (thousand m^3)	53	800	n/a	>1,000
Reported flood damage (mln €)	~10	40	60–140	66–240
Computed damage per km	1.3–4	3.6	0.9–12	4.4–16

*Line 7 only.
**entire system (86 km).

2. Direct flood damage to subway systems (after Compton et al., 2009)

The basic approach to estimating the flood damage during flooding of the subway is to presume that there is a relationship between the length of track flooded and the resulting direct damages, as carried out by Neukirchen (1993). This relationship can be expressed as follows:

$$DD = \alpha L$$

where:
DD is the direct damage, L is the length of track flooded, and α is the relationship between the two variables. A regression was performed on the empirical data to evaluate α for the overall data set. α was estimated between 3.2 and 20 with a mean of 9.4. In the study by Compton *et al.* (2009), they also included a function describing the relationship between flood velocity and direct damage. We did not address flood velocity in this study.

3. Indirect flood damage to subway systems (after Compton et al., 2009)

Method 1. Compton *et al.* (2009) have computed the loss in revenues to flooding in M€ per flooded km track. For the subway system in Vienna (Austria), they roughly estimated the revenue loss at 2M€/km. This is equal to 2.68M US$/km = 1.66M US$/mile (2010 values). Note that they used an average ride cost of 2€/ride, which is comparable to the average ride in NYC (~US$2.25). Obviously other indirect effects ("production loss") are important for determining overall losses due a subway flood, but we did not address these in this study. Therefore, our estimates are probably at the lower end of the loss distribution.

Method 2. In the EU FLOODsite study, a handbook was developed to estimate flood damage to different objects, including direct damage to rail infrastructure and losses from rail disruption (FHRC, 2008). This study, however, mainly focuses on above ground commuter rail. The suggested algorithm for rail disruption suggests calculating the number of people traveling through the floodplain, and then divides losses per passenger into costs for either delays (40–45% of total disruption costs) and cost for cancelations (55–60% of total disruption costs). The calculation, based on estimates for compensation for either delay or cancelations, is an average of £0.037 per hour, per passenger for commuter train services. This is £1.3/day per passenger, which equals US$2.05/day per passenger.

4. Estimate of total flood damage to subway systems

Table G2 list different scenarios and different methods for estimating indirect costs. Method 1 uses a price per flooded km the basis of Compton *et al.* (2009). Method 2 uses an average fare per disrupted passenger the basis of FHRC (2008). The latter method assumes all passengers will be disrupted. We only used an estimation of the number of MTA passengers (see Table G3) that are disrupted for a period of 1 or 30 days, respectively.

Table G2. 2009 MTA Subway Ridership. Source: MTA (2009) (http://mta.info/nyct/facts/ridership/index.htm)

Annual Ridership	Average Weekday	Average Saturday	Average Sunday
1,579,866,600	5,086,833	2,928,247	2,283,601

Table G3. Different methods for estimating indirect costs

	Minimum [US$]	Maximum [US$]
Method 1: indirect damage using loss/flooded km track		
km flooded tunnels 22–30 km[a]	440,000,000	600,000,000
km tracks at grade 30–50 km[a]	300,000,000	300,000,000
Total	740,000,000	900,000,000
Method 2: indirect losses using average fare and number of passengers		
Rides[c]	2,283,601	5,086,833
1 day loss at US$2.25/ride[a]	5,138,102	11,445,374
1 day loss at US$2.05/ride[b]	4,681,382	10,428,008
30 day loss at US$2.25/ride	154,143,068	343,361,228
30 day loss at US$2.05/ride	140,441,462	312,840,230

[a]Based on Compton *et al.* (2009).
[b]Based on FHRC (2008).
[c]Based on MTA (2009) (http://mta.info/nyct/facts/ridership/index.htm).

Appendix H. Population at risk per borough

Data in Table H1 is based on Maantay and Maroko (2009). Note: these data are not cumulative, and in order to calculate the population at risk in the 1/100 flood zone, one has to add the numbers from the VE, AE, AO, and A zones. Similarly, the population at risk for the X500 zone can be derived by adding the numbers for the 1/100 and the X500 zones.

Table H1. **BK, Brooklyn; BX, Bronx; MN, Manhattan; QN, Queens; SI, Staten Island**

Zone	Borough	Clipped population at risk
VE	BK	24
AE	BK	58166
X500	BK	85785
VE	BX	1502
AE	BX	13163
X500	BX	22139
VE	MN	99
AE	MN	80681
X500	MN	57290
VE	QN	1035
AE	QN	38917
X500	QN	65790
VE	SI	273
A	SI	5919
AE	SI	15193
AO	SI	8
X500	SI	11063
HUR1	BK	75780

Table H1. *(Continued)*

Zone	Borough	Clipped population at risk
HUR2	BK	281564
HUR3	BK	297425
HUR4	BK	281060
HUR1	BX	3083
HUR2	BX	6089
HUR3	BX	39915
HUR4	BX	93207
HUR1	MN	25510
HUR2	MN	135783
HUR3	MN	148176
HUR4	MN	143317
HUR1	QN	11520
HUR2	QN	128960
HUR3	QN	148043
HUR4	QN	80890
HUR1	SI	3314
HUR2	SI	30070
HUR3	SI	17450
HUR4	SI	22420