

## **Adaptive planning for resilient coastal waterfronts**

### **Linking flood risk reduction with urban development in Rotterdam and New York City**

van Veelen, Peter

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## Adaptive planning for resilient coastal waterfronts

Linking flood risk reduction with urban development  
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Peter Christiaan van Veelen



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Peter Christiaan van Veelen

*Delft University of Technology, Faculty of Architecture and the Built Environment,  
Department of Urbanism*

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# Adaptive planning for resilient coastal waterfronts

**Linking flood risk reduction with urban development  
in Rotterdam and New York City**

Proefschrift

ter verkrijging van de graad van doctor  
aan de Technische Universiteit Delft,  
op gezag van de Rector Magnificus prof. ir. K.C.A.M. Luyben,  
voorzitter van het College voor Promoties,  
in het openbaar te verdedigen op vrijdag 25 november 2016 om 15:00 uur  
door Peter Christiaan VAN VEELLEN  
Ingenieur  
geboren te Rotterdam

## Dit proefschrift is goedgekeurd door de

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Peter van Veelen, Rotterdam 2016

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# Summary

Many delta and coastal cities worldwide face increasing flood risk due to changing climate conditions and sea level rise. The question is how to develop measures and strategies for existing urban coastal areas that can anticipate these slowly changing conditions, such as gradually increasing sea levels and extreme river discharges.

There is growing recognition that the increasing vulnerability of urbanised delta and coastal cities is strongly related to urbanisation, changing socio-economic conditions and human-induced land subsidence. Consequently, in response to climate change, it is likely to be most effective to adapt existing urban environments and urban assets, and promote flood sensitive behaviour in combination with prevention based approaches, aiming to improve the *whole capacity* of the urban system to deal with changing and more extreme conditions in the future. This approach is known as the *resilience approach*. Although there is much focus on resilience in research and practice, it still lacks knowledge on the effectiveness of measures, and increasing coastal flood resilience is mostly understood in terms of risk reduction and not yet as an opportunity for change and creating liveability. In addition, it lacks knowledge on processes of urban development, management and change at the neighbourhood level as an important condition for creating coastal flood risk resilience and to create added value. The main research question of this thesis is therefore twofold: “how can we adapt existing coastal urban waterfront areas to changing climatic circumstances and how can we take this adaptation process as an opportunity for creating added value?”

When adapting urban environments three challenges can be identified. First of all, it is necessary to understand under what conditions coastal urban systems become less resilient and adaptation is needed, and what (combinations) of measures are most effective to improve resilience. Secondly, key to the successful adaptation of urban environments is effectively using moments of change in urban development and management as windows of opportunity for low-cost adaptation, and to yield additional benefits. This requires a better understanding of the opportunities to spatially and in a timely manner, synchronise adaptation measures with investments in urban development, urban management and infrastructure maintenance projects at the neighbourhood level. Changes can be both *incremental*, for example building renovation cycles as an opportunity for retrofitting flood resilience measures into buildings, or can be *transformative*, for example by using urban redevelopment projects that create new options for adaptation. Finally, a major challenge of adapting existing urban environments to the effects of climate change is that it requires anticipating long-term trends and changes that easily exceed periods of 50 to 100 years. This brings large uncertainties into the design and planning process. When facing deep uncertainty it is necessary to improve flexibility. Improving flexibility can be either tactical-

operational (designed) or strategic (planned). Designed flexibility can be achieved by developing design that anticipates, or can adapt according to future conditions or functional requirements. This can be achieved by incorporating modifications in the design, through preserving space, by over-dimensioning critical elements or by built-in redundancies. On a strategic level, flexibility can be achieved by developing sequences of adaptation options that keep options open in anticipation of future conditions. Sequences of adaptation options (pathways) that are reversible and offer multiple options to adapt should be favoured over irreversible and non-flexible paths.

To answer the research question, this research applies a resilience based planning method (the Adaptive Pathways Method, or APM) to develop and assess adaptation pathways at the level of neighbourhood development in two flood prone waterfront cases in Rotterdam. APM is a structured, iterative approach based on defining the conditions under which policy objectives are no longer attainable and adaptation is required, and the assessment of sequences of adaptation actions. It enables policy makers to explore and develop adaptive strategies

The case study research in two flood prone urbanised areas in Rotterdam showed that Rotterdam's land elevation policy for new building plots is expensive and offers no solution to reduce the flood risk of existing homes and businesses in the area. In this study, two alternative solutions (water robust and keeping water out) were developed and tested for spatial integration, (cost) effectiveness and opportunities for creating added value. The Feijenoord case shows that a district-wide flood protection strategy provides the most beneficial solution and opens up opportunities for capitalising on investments in waterfront development and improvements of the urban realm. The Noordereiland case shows a more diverse portfolio of adaptation responses, although there are only a few combinations of adaptation responses that are complementary to deal with change in the long run. A potential adaptation strategy for the Noordereiland is based on sequencing property level protection (wet-proofing and dry-proofing adaptation measures), followed by the development of a permanent or temporary floodwall strategy. However, this strategy offers few opportunities to link with spatial dynamics and to create added value.

Based on case study research, this research concludes that the APM is an effective tool to evaluate and select appropriate adaptation measures. In particular, the value of this method is that it helps to bridge the gap between highly uncertain long-term climate change effects and the short-term decision making horizons of urban planning and development. Additionally, the method helps to better grasp the timing of adaptation and develop a wide portfolio of adaptation actions, which opens up opportunities to couple adaptation measures with other planned investments, or to anticipate by developing urban design that allows for easier adaptation in the future. Both cases underline the fact that strategies to enhance the resilience of urban waterfronts must be based on a detailed assessment of local vulnerabilities, and should select site-specific adaptation measures leading to a tailor-made portfolio of solutions.

An important element of adaptive planning is the assumption that a transfer between, or sequencing alternative interventions (and thus developing alternative pathways) is straightforward. However, in reality there is no smooth transfer between alternatives. Both cases clearly show that a change of strategy, for example from property-level to a district-wide solution, is accompanied with 'transfer costs' that creates an economic lock-in and is constrained by legal, financial and institutional barriers. For example, every investment to reduce a household's sensitivity to flooding reduces the overall flood risks of the larger area and hence the benefits accruing to a wider floodwall option, making a 'transfer' to a district-level solution less feasible from an economic point of view. In addition, the potential loss of investments for individual homeowners caused by a change of strategy could lead to societal and political resistance to change. Overcoming the economic and political path dependencies is a major challenge and it unfortunately often needs a disaster to change the course of an adaptation path. Possibly, co-benefits and added value arising from flood protection investments (e.g. increase in real estate value) may have a positive effect on reducing the transfer costs, although the effects strongly depend on site conditions. In view of the above, it is necessary to decide early in the adaptation process on the long-term preferred strategy and to support this strategy with short-cycle, low cost incremental interventions aimed at "buying time" to increase the opportunities for creating district-wide protection at low costs.

In addition to this, there is also a second, more fundamental shortcoming of the method. Although the APM is adaptive, in the sense that it allows for uncertainties to be resolved in time, the method ignores the dynamic aspect of urban development and new opportunities for adaptation that might arise from it. For example, a redesign of industrial waterfronts to residential functions creates new financial and spatial opportunities for creating integrated flood protection at relatively low costs. Research by Design is an important tool to explore these new opportunities.

A more effective approach is to focus on interventions in the economic and institutional processes of urban development and changes that create new opportunities for adaptation. In the second part of this research an urban dynamics based adaptation method is introduced that focuses on identifying the following: adaptation intervention *points*, which are defined as the actual moments of change that potentially may be used for adaptation; adaptation *transitions* that are defined as changes in legal, institutional and financial structures that are needed to improve or unlock the full potential of adaptation intervention points; and adaptation *transformations* that are fundamental changes in urban form, policies, institutional arrangements and norms that could create new adaptation *opportunities*.

The method follows three basic steps: (1) assessing the spatial and timely synchronisation of adaptation measures with planned urban development projects and public and private infrastructure maintenance investments; (2) assessing the

institutional and financial barriers to be removed in order to mainstream climate adaptation measures in these urban development processes, and (3) assessing what opportunities derived from urban development are able to ‘break through’ the path dependencies that lock-in more sustainable adaptive paths. The method is based on mapping all planned spatial investments in brownfield development, urban renovation, and maintenance projects of public and private infrastructure and assets and by assessing the effectiveness of prevailing policies. Using design research, new opportunities for adaptation are explored and assessed. The urban dynamics based adaptation pathways method is tested at two waterfront areas in Rotterdam (Feijenoord) and New York (Red Hook). Both cases show that identifying intervention opportunities and potential transitional interventions is helpful in selecting and assessing adaptive pathways. Moreover, it helps to identify legal or financial arrangements that are needed to unlock the potential of adaptation paths. One of the key findings of the case study research is that in high density urban conditions there is limited potential to build resilience from household redevelopment or renovation, even when new complementary policies and regulative instruments that support building-level resilience would be developed. District-wide flood protection is effective in terms of flood risk, but requires large-scale transformations of the waterfront zone to seize opportunities to develop integrated protection at low costs. This strategy, however, needs new governance structures and financial arrangements to redistribute costs and benefits fairly among stakeholders.

# Samenvatting

Veel deltasteden en verstedelijkte kustgebieden worden geconfronteerd met toenemende overstromingsrisico's als gevolg van de effecten van klimaatverandering. De vraag is op welke manier deze bestaande verstedelijkte gebieden kunnen anticiperen op langzaam veranderende omstandigheden, zoals een stijgende zeespiegel of extremere rivierafvoeren. Er is een groeiend besef dat de toenemende kwetsbaarheid van verstedelijkte delta's en kuststeden voor overstromingen voor een belangrijk deel wordt veroorzaakt door verstedelijking, socio-economische veranderingen en door de mens veroorzaakte bodemdaling. Om het overstromingsrisico te beheersen is het dus verstandig om niet alleen overstromingen te voorkomen maar ook om stedelijke gebieden aan te passen zodat deze gebieden beter om kunnen gaan met rampen en beter voorbereid zijn op extremere omstandigheden in de toekomst. Dit kan bijvoorbeeld door woningen en infrastructuur waterbestendig te maken. Deze benadering wordt ook wel veerkracht (resilience) genoemd. Hoewel er inmiddels veel aandacht is voor resilience ontbreekt het nog aan kennis welke maatregelen en strategieën het meest effectief zijn en wordt ruimtelijke adaptatie aan overstromingsrisico's nog vooral begrepen als risicoreductie en niet gezien als een kans voor het vergroten van leefbaarheid van kuststeden. De centrale onderzoeksvraag van dit proefschrift is dan ook tweeledig: hoe kunnen bestaande stedelijke waterfrontgebieden worden aangepast aan stijgende overstromingsrisico's en hoe kan adaptatie een kans worden voor het creëren van toegevoegde waarde en ruimtelijke kwaliteit?

Om deze vraag te kunnen beantwoorden zijn drie belangrijke uitdagingen geïdentificeerd. In de eerste plaats is het nodig om te weten wanneer en onder welke omstandigheden de grenzen van veerkracht worden bereikt en aanpassing nodig is. Hiervoor is het nodig om beter te begrijpen wat de effecten zijn van een overstroming op het lokale stedelijk systeem en welke (combinaties van) maatregelen het meest effectief zijn om het risico te reduceren en de veerkracht te vergroten. Hiervoor is een goede definitie van veerkracht nodig. Een tweede uitdaging is om beter te begrijpen op welke manier het meekoppelen van adaptatie maatregelen met ruimtelijke dynamiek kansen biedt om de kosten van adaptatie te drukken en de implementatie van adaptatie te versnellen. Daarbij gaat het zowel om stapsgewijze aanpassingen, door bijvoorbeeld gebruik te maken van gebouwrenovaties en reguliere beheer en onderhoudsprogramma's om woningen waterbestendiger te maken, en om grootschalige ruimtelijke transformaties die kansen bieden om adaptatiemogelijkheden te realiseren die niet eerder kansrijk werden geacht. Dit vereist een beter begrip van de mogelijkheden om adaptatiemaatregelen zowel in de ruimte als tijd te synchroniseren met ruimtelijke ontwikkelingen en investeringen en het verkennen van ruimtelijke transformaties.

Een laatste uitdaging is dat klimaatverandering als langzaam verlopend proces vraagt om het anticiperen op lange termijn veranderingen. Dit brengt grote onzekerheden in het planningsproces die van invloed zijn voor het bepalen van de meest effectieve strategie. Een manier om met deze onzekerheid om te gaan is het vergroten van flexibiliteit. Dit kan zowel door het vergroten van de operationele (*designed*) flexibiliteit als door vergroten van het strategische (*planned*) flexibiliteit. Het vergroten van de flexibiliteit in het ruimtelijk ontwerp kan door in het ontwerp maatregelen op te nemen waarmee eenvoudiger aan mogelijke veranderende omstandigheden kunnen worden aangepast. Op het strategische niveau kan flexibiliteit worden vergroot door het selecteren van combinaties van adaptatieopties die de meeste keuzevrijheid bieden om in de toekomst van strategie te veranderen of die opties open houden in afwachting van toekomstige omstandigheden. Deze combinaties van maatregelen worden adaptatiepaden genoemd.

Om de onderzoeksvraag te beantwoorden is een bestaande Adaptatiepadenmethode (APM) gebruikt om adaptatiestrategieën te ontwikkelen voor twee buitendijks gelegen, overstromingsgevoelige bestaande woonwijken in Rotterdam. De APM is een gestructureerd, iteratief proces gebaseerd op het analyseren van de omstandigheden waaronder beleidsdoelstellingen niet langer haalbaar zijn en adaptatie noodzakelijk is (Adaptation Tipping Points), en het verkennen van mogelijke combinaties van adaptatiemaatregelen (adaptatiepaden) waarmee de beleidsdoelen kunnen worden gerealiseerd. Deze methode biedt beleidsmakers inzicht in de effectiviteit van mogelijke adaptatiepaden en consequenties van beleidsbeslissingen voor andere beleidsagenda's. Hoewel deze methode al succesvol is toegepast bij de ontwikkeling van adaptatiestrategieën op het hogere schaalniveau, is de methode niet eerder toegepast op het schaalniveau en de problematiek van een stadsdeel.

Het casestudie onderzoek in het buitendijkse gebied van Rotterdam laat zien dat het huidige beleid van de gemeente Rotterdam waarbij nieuwbouwkavels worden opgehoogd tot waterveilige hoogte tot hoge kosten en inpassingproblemen leidt. Daarnaast biedt deze aanpak geen oplossing voor het overstromingsrisico van de bestaande woningen en bedrijven in het gebied. In dit onderzoek zijn twee alternatieve oplossingen (water robuust inrichten en water buiten houden) ontwikkeld en getoetst op ruimtelijke inpassing, (kosten)effectiviteit en kansen voor het creëren van toegevoegde waarde. Uit dit onderzoek blijkt dat in het gebied Kop van Feijenoord alleen een preventieve oplossing een kosteneffectieve oplossing is die bovendien goed te combineren is met ruimtelijke ontwikkelingen en investeringen in de buitenruimte. Voor het Noordereiland geldt dat op de korte en middellange termijn waterbestendig inrichten kosteneffectief is hoewel deze strategie weinig kansen biedt om mee te koppelen met ruimtelijke dynamiek en om toegevoegde waarde te creëren. Op de lange termijn is deze aanpak echter niet langer houdbaar en is een preventieve gebiedsgerichte oplossing noodzakelijk.

Op basis van de cases kan worden geconstateerd dat de APM helpt om een brug te slaan tussen de onzekere lange termijn gevolgen van klimaatverandering en de noodzaak om op korte termijn beslissingen te nemen over de te volgen strategie. De methode biedt inzicht in de bandbreedte in tijd waarin adaptatie noodzakelijk is. Hiermee wordt lange termijn adaptatieplanning binnen de korte planningshorizon van stedelijke planning en ontwikkeling getrokken en worden mogelijkheden geopend om adaptatie te koppelen aan andere geplande investeringen, of om maatregelen te treffen om toekomstige stedelijke ontwikkeling en investeringen in de toekomst eenvoudiger aan te passen. Beide casussen laten zien dat het aanpassen van bestaande stedelijke waterfrontgebieden maatwerk vereist die gebaseerd is op een gedetailleerde analyse van de lokale kwetsbaarheden voor overstromen en het selecteren van locatie-specifieke maatregelen.

Een belangrijk element van adaptieve planning is de veronderstelling dat het combineren van verschillende adaptatieopties in de tijd (en dus de ontwikkeling van adaptatiepaden) de flexibiliteit vergroot. Beide casestudies laten echter duidelijk zien dat een verandering van strategie op gebiedsniveau, bijvoorbeeld van water robuuste inrichting naar een gebiedsgerichte preventieve oplossing gepaard gaat met 'transactiekosten' en tegen financiële en organisatorische belemmeringen loopt. Elke investering op gebouwniveau om de schades als gevolg van overstromingen te verminderen verkleint de totale overstromingsschade van een gebied en dus ook de economische baten van een preventieve oplossing zoals een waterkering. Daar komt nog bij dat het potentiële verlies van investeringen van individuele vastgoedeigenaren bij een verandering van strategie tot maatschappelijke en politieke weerstand kan leiden. Het doorbreken van deze economische en maatschappelijke padafhankelijkheid is een belangrijke beperking voor de implementatie van een adaptieve strategie en vaak kan pas na een ramp voldoende draagvlak worden gevonden voor een structurele koerswijziging. Gezien het bovenstaande is het verstandig om vroeg in het besluitvormingsproces een keuze te maken over de lange termijn strategie en deze strategie te ondersteunen met kort-cyclische en betaalbare aanpassingen met als doel om tijd te winnen voor een duurzame goed geïntegreerde gebiedsgerichte oplossing.

Daarnaast is er een tweede, meer fundamentele tekortkoming van de methode. De methode negeert nieuwe mogelijkheden voor adaptatie die voorkomen uit ruimtelijke transformaties in de toekomst die nog niet eerder zijn geïdentificeerd of positief beoordeeld. Het herbestemmen van industriële waterfrontgebieden naar woonfuncties creëert bijvoorbeeld nieuwe economische en ruimtelijke kansen die benut kunnen worden voor het realiseren van hoogwaardige overstromingsbescherming tegen relatief lage kosten. Ontwerpend onderzoek kan een belangrijke bijdrage leveren aan het verkennen van deze mogelijkheden. Om deze kansen te benutten is het vaak nodig om het beleid aan te passen of om nieuwe financiële arrangementen te ontwikkelen. In het tweede deel van dit onderzoek wordt een iteratieve methode geïntroduceerd die gebaseerd is op het analyseren van stedelijke dynamiek en het verkennen van nieuwe

ruimtelijke mogelijkheden voor adaptatie. De methode bestaat uit drie eenvoudige stappen: (1) het beoordelen van de mogelijkheden om adaptatiemaatregelen zowel in ruimte als tijd te synchroniseren met geplande projecten voor stedelijke ontwikkeling en publieke en private investeringen in onderhoud van de infrastructuur (*adaptatie interventie momenten*); (2) het analyseren van de institutionele en financiële barrières en optimalisatiemogelijkheden van het staande beleid die nodig zijn om de klimaatadaptatiekansen te realiseren of implementatie te versnellen (*adaptatie transities*); (3) en het identificeren van nieuwe ruimtelijke mogelijkheden in stedelijke ontwikkeling die in staat zijn om een lock-in te doorbreken en de weg openen voor een duurzamer adaptatiepad (*adaptatie transformaties*)

De methode is getest in een casestudie onderzoek in Rotterdam (Feijenoord) en New York (Red Hook). Beide cases hebben aangetoond dat de identificatie van adaptatie interventie mogelijkheden, op basis van een evaluatie van de levenscycli en investeringsprojecten en mogelijkheden om het beleidssysteem te optimaliseren helpt om systematisch de effectiviteit van adaptatiepaden te kunnen beoordelen. Bovendien helpt het om de kansrijkheid van ingrijpende maatregelen zoals ruimtelijke transities en beleidsmatige innovaties te identificeren die nodig zijn om nieuwe adaptatiekansen te vergroten. De casussen laten zien dat in intensief bebouwde condities adaptatie op gebouwniveau, ondanks aanpassingen in de bouwregelgeving niet leidt tot een duurzame oplossing voor toenemend overstromingsrisico. Op de lange termijn is een integrale oplossing door integreren van hoogwaterbescherming in een herontwikkelen van het waterfront noodzakelijk. Om dit mogelijk te maken is het echter wel nodig om financiële arrangementen te ontwikkelen die de kosten en baten eerlijk verdelen over de stakeholders en veranderingen in het beleidsstelsel door te voeren.

# 1 Introduction

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## § 1.1 Problem definition

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### § 1.1.1 Flood risk of coastal cities is increasing

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A large part of the world's population lives in low-lying urbanised coastal zones or river deltas (UN Habitat, 2013). These urbanised low elevation coastal areas are vulnerable to flooding due to a combination of natural high tides, storm surges and high river discharges, and human induced stresses such as subsidence and urbanisation (Hallegatte et al., 2013; IPCC, 2007; Nicholls et al., 2007). Many of these coastal cities are facing a higher risk of flooding in the future due to changing climate conditions and sea level rise. Global warming is expected to accelerate sea level rise and increase the number of tropical storms, creating stronger waves and surges, and more extreme downpours resulting in coastal, fluvial and storm water flooding and more extreme river run-off (IPCC, 2007). Although the extent of climate change effects on individual regions may vary considerably, it is expected that these changing conditions will contribute to increased coastal flooding through direct exposure to higher flood levels, or, indirectly, for example through coastal erosion of marshlands that act as a natural buffer. Intensive waterfront urbanisation and human-induced stresses on the natural landscape add to increasing flood risk, as many of the coastal areas remain attractive places for urban development. Several studies indicate that the expected increase in population exposed to flooding by storm surges over the 21st century is likely to grow tenfold or more and will affect more than 100 million people each year due to sea level rise alone (Nicholls et al., 2007). In particular, coastal urban agglomerations located in deltaic conditions, such as Guangzhou, Jakarta, Ho Chi Minh City and Bangkok are highly vulnerable to increasing flood risk due to rising sea levels and changing river runoff in combination with significant subsidence and rapid urbanisation and socio-economic change. Among the most vulnerable cities are also a growing number of US cities, including New Orleans, Miami and New York due to their high wealth and low protection levels (Hallegatte et al., 2013). Recent disastrous flooding of urbanised deltas such as New Orleans in 2005, Bangkok in 2011 and coastal cities such as New York City in 2012 painfully exposed the relative vulnerability of coastal urban areas to flooding. The question is, how to avoid urbanised river deltas and coastal cities becoming more vulnerable.

## § 1.1.2 Towards a system-approach

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Simultaneously to this increasing flood risk, there is a clear shift from an engineered, prevention-based flood risk management approach towards a more holistic, systemic approach (Pahl-Wostl, 2007, Zevenbergen et al., 2010, Pelling, 2011). Preventing flooding through large-scale infrastructure such as dams and barriers is increasingly regarded as less appropriate due to growing concerns over their negative ecological and socio-economic impacts, but also because these solutions address the symptoms and not necessarily the root causes of increasing vulnerability (Pelling, 2011). There is an emerging attention to more holistic, integrated and multi-levelled approaches that are based on adapting existing urban environments to cope with flood risk. This new attention to the limitations of “defending against floods” and a focus on more systemic approaches can be recognised in the Rebuilding by Design competition that was launched as part of the post-Sandy strategy development in New York and New Jersey (NYC, 2013, Rebuildbydesign.org), and projects such as Urban Flood Management Dordrecht (Zevenbergen et al., 2010). Also, recent policy reforms such as the Dutch “multi-level safety” approach to flood risk (Ministerie I&M, 2009), in which adapted land use and urban design for more resilient communities, and disaster and emergency management are introduced, mirror the new attention to more integrated and holistic approaches to flood risk management.

This emerging attention to more comprehensive approaches is related to two main changes:

### A Urbanisation and socio-economic change as root causes of increased vulnerability

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Firstly, there is a growing awareness that the increasing vulnerability of urbanised deltas and coastal cities to flood risk is related to processes of urbanisation and changing socio-economic conditions. There is a strong global trend of migration towards coastal mega cities. In particular, cities in Asia show unprecedented levels of growth and a clear tendency to coastward migration in recent decades. This trend of coastward migration is due to high population growth and processes of (informal) urbanisation in general, but it is also stimulated through economic policies, especially in China (Mc Granahan et al., 1995). It is expected that this trend is to continue over the coming years (UN Habitat, 2013).

Secondly, in many ways closely related to this process of urbanisation, there is a growing awareness that human induced changes of the natural landscape are a major cause of increasing risk. In particular, coastal cities in deltaic conditions face an increasing risk of flooding due to land subsidence, often as a result of excessive ground water withdrawal. This is particularly a major problem for younger Asian mega cities such as Bangkok, Jakarta and Metro Manila where the rate of subsidence in some cases locally exceeds the maximum projected rates for sea level rise (Nicholls 1995).

In older urbanised deltas such as the Rotterdam-Amsterdam conurbation and Greater New Orleans Region, the process of subsidence due to drainage of marshlands and settling (land compaction) due to urbanisation is, though with local exceptions, less dramatic. However it is still one of the root causes of increasing flood risk, particularly for the deeply subsided urbanised polders (Meyer et al., 2010). Also large-scale adjustments of the natural environment, such as up-stream river regulation schemes or drainage of coastal marshlands adversely affects flood risk by reducing the rate of sediment deposition and removing a buffer against tidal flooding (Mc Granahan et al., 2007). This is another challenge for the city of New Orleans in the Mississippi delta (Campanella, 2010).

Thirdly, the increasing prosperity and changing nature of residential and economic activities itself in coastal communities is, although yet poorly researched, a major source of increased vulnerability to flooding. In particular, port cities in more developed countries have long been transforming and gentrifying former industrial waterfront zones into more intensively used residential areas. The transformation of the former docklands and ports in New York, London, Amsterdam, Hamburg and Rotterdam are all iconic examples of the new attention to the waterfront as an attractive location for urbanisation. Some numbers clearly illustrate the situation. In New York City, since the adoption of the first comprehensive Waterfront Plan in 1992, more than 20,000 new residential units have been added on waterfront sites (NYCDCP, 2011) and even greater numbers are expected in the next decades due to rezoning of the waterfront allowing for higher-density residential development (Findlan et al., 2014). The extreme accumulation of wealth over the last decades in Lower Manhattan in New York City illustrates a process that can be recognised in delta cities globally. This process of gentrification of waterfront communities by redeveloping industrial buildings, infill projects on vacant or under-utilised land, and improvement of individual properties, has concentrated more wealth and assets in flood prone areas. Although it lacks scientific research on the relative effect of gentrification on flood risk, it is an undeniable contributor to flood vulnerability. Finally, changing economic activities such as high tech industrialisation, ICT and worldwide just-in-time delivery infrastructure have dramatically increased the damage sensitivity of urban areas towards flooding.

There is growing evidence that in many world cities the increase in flood risk due to the effects of human induced environmental changes, unplanned urbanisation and socio-economic change is expected to surpass climate change as the most important factor in increasing flood risks (Nicholls et al., 1995, Mc Granahan et al., 2007, Hallegatte et al., 2013, Winsemius et al., 2015). In other words, the increase of risk in coastal cities is largely driven by urbanisation, changes in the natural landscape, increased sensitivity of economic activities and the accumulation of wealth in coastal areas, rather than the increase in flood levels.

## B Deltas as complex systems

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The emerging focus on the complex root causes of flood risk vulnerability of urbanised deltas has contributed to an increasing understanding that urbanised deltas are highly complex systems consisting of many subsystems that interact and show high interdependencies (Roggema, 2012, Dammers et al., 2014). In this view, urbanised coastal areas are understood as a *complex adaptive system* (Waldrop, 1992). These complex systems are influenced by both external pressure, such as climate and demographic change and by the interaction and interventions of agents within the system itself, at multiple spatial scales and within different time frames. Complex systems constantly change through self-organisation and learning, and through transformation of their components (Waldrop, 1992). An important feature of a complex adaptive system is that the behaviour of the system emerges from the interactions between the system's higher and lower level components (Manson, 2001). An intervention in one of the subsystems may adversely affect other subsystems and thus spread or increase risk across the system. As an illustration, in New York City improved flood risk protection of waterfront locations brings concerns about increasing real estate values and a loss of affordable housing (Findlan, et al., 2014). In the Netherlands, closing off the open delta systems in reaction to the 1953 floods resulted in high level flood protection, but also triggered an increasing accumulation of economic value and activities 'behind the dikes', contributing to more riskier floods. A complex system shows path dependent behaviour (e.g. earlier decisions and established behaviour largely determine responses to change) but it also behaves in an unpredictable and non-linear manner as the behaviour of the system is produced by many individual decisions and actions (Walker et al., 2004).

### § 1.1.3 Urban resilience as the new paradigm

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Understanding urbanised deltas as complex adaptive systems in which climate change vulnerability is created through the interacting processes of urbanisation, human-induced environmental change, socio-economic development and climate change, requires an integrative and system-based approach in adaptation planning. Consequently, in response to climate change, the most effective option is likely to be to influence patterns of urbanisation, adapt existing urban environments and urban assets, and promote flood sensitive behaviour in combination with prevention based approaches, aiming to improve the *whole capacity* of the urban system to deal with changing and more extreme conditions in the future. This approach is known as the *resilience approach*.

The concept of resilience, although contested and sometimes ill defined, offers a system-based perspective to understand complex and linked natural and human

systems, such as urbanised coastal zones, in the face of stress and change (Klein, et al., 2004). Simply defined, resilience is the ability to bounce back after disturbance. Resilience in this definition, is, however, criticised as being backward looking and reactive, in the sense that it focuses on restoring the pre-existing situation including its systemic errors and structural vulnerabilities, and that it is not aimed at adapting to slow environmental change. However, a key element of complex social systems is the ability to adapt and transform. The adaptive and transformative element of resilience offers many opportunities for linking climate change adaptation actions with other urban transitions, needs or local agendas, for example improving urban liveability or poverty reduction (Pelling, 2011).

Although the notion of resilience is widely embraced as a guiding concept, the transformative element of resilience remains, until now, underexposed. In addition, there is no comprehensive framework or planning method that enables us to operationalise the resilience approach at the local level of urban planning and development. As a consequence, there is a need to develop a resilience based planning approach that addresses the root causes of urban vulnerability and deals with complex system behaviour.

#### § 1.1.4 Planning and designing for adaptive urban coastal waterfronts

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##### Towards pro-active integrated adaptation planning

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Understanding processes of urbanisation, gentrification, social-economic change and human-induced stresses to the natural environment as significant root causes of increasing vulnerability also indicates that urban design and land use planning become important tools to reduce urban vulnerability and to mitigate risks associated with climate change (Winsemius et al., 2015). The question is how to plan for adapting urban waterfront areas to anticipate slowly changing climate conditions.

A premise that lies behind planned adaptation is that it is more cost-effective to act now or at least to prepare for action than to suffer larger climate damages in the future. In particular, investments that come with long life cycles or low capital turnover rates need to anticipate longer-term climate change to avoid costly planning errors (Adger et al., 2005a). For example, the additional costs of incorporating future risks into buildings or large infrastructure designs are relatively small, while retrofitting adaptation into infrastructure and buildings is expensive and requires significant interventions (Nicholls, 1995, Hallegatte et al., 2013). In other words, proactive based adaptation seems to be cost-effective. However, this is true considering general socio-economic and long-term cost-benefit assessments. In the short term, adaptation is challenged by relatively high costs and unfairly distributed costs and benefits among

stakeholders (Adger et al., 2005a). Additionally, planned adaptation is expected to avoid poorly integrated solutions (**Fig. 1.1**) or even to yield synergetic benefits (Ven et al., 2011). In climate adaptation research, much attention has been given to analysing the impacts of climate change, and the development and assessment of strategies that mitigate those effects. Additionally, a wide body of literature has identified institutional, cultural or financial obstacles to incorporating adaptation in policy making (Smit & Wandel, 2006, Pahl-Wostl, 2007, van Buuren et al., 2013). There is still little research that focuses on the implementation process of adaptation at the local level (Smit & Wandel, 2006). Emerging research emphasises the need for “mainstreaming”, “incorporating into” or “marrying” climate change adaptation with policies, strategies and decision-making processes. It is however still a generic concept that has not yet been applied at the operational level of urban planning and development. In particular, there is a lack of research that focuses on the actual processes of urban development, management and change as an important condition for successful implementation of climate adaptation strategies. The proposition underlying this research is that integrating adaptation responses to increased flood risk into urban planning and design of coastal waterfront areas is a more flexible, (cost) effective and value-adding approach to enhancing the resilience of coastal cities.



**FIGURE 1.1** Reactive adaptation. Pictures show the Brede Hilledijk, Rotterdam in 1954 (left) and 2016 (right). In response to the 1953 flood a levee and floodwall was constructed that changed the form and function of the street and forms a major physical barrier between two neighbourhoods. Left picture RotterdamO10.nl. Right picture: by author.

## Challenges

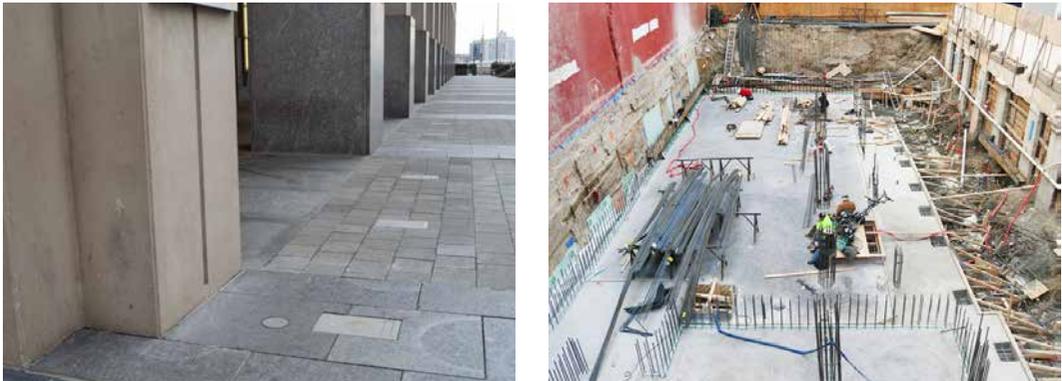
When adapting existing urban environments to flood risk several challenges complicate adaptation planning. First of all, to effectively integrate resilience and adaptation into urban development and planning it is necessary to understand when in time, or under what conditions, adaptation is needed and what (combinations of) measures are the most effective to improve resilience. However, it lacks tools to empirically measure

and monitor resilience at the level of communities (Cumming et al., 2005, cited in Cutter, et al., 2008, Revi et al., 2014). In particular, there is a lack of knowledge on the effectiveness of adaptive measures and design strategies to reduce risks along coastal urban waterfronts. Although there is a wide portfolio of local adaptation responses available, there is still not much research been done on what adaptive responses and design strategies are most effective in relation to different flood conditions, urban typologies, governance arrangements, and cultural beliefs and values. Moreover, only little attention has been paid to understanding the adverse effects of adaptation interventions on other elements of an urbanised coastal area. As an example, in reaction to the devastating flooding of large parts of the financial district in Lower Manhattan, companies and real estate owners invested in property level protection measures such as demountable flood walls (**Fig. 1.2**). This process of dry-proofing office buildings in lower Manhattan may be an effective short-term response to reduce the consequences of a flood; however it also reduces the willingness among stakeholders to contribute to a district-wide solution that would benefit the poorer communities along the waterfront. In the long run these unplanned adaptation strategies may have a negative effect on the overall resilience of the system on a larger scale. Thus, an essential element of flood risk adaptation is the ability to proactively plan to adapt a system's structure and address the root causes of vulnerability, while avoiding adverse impacts.

Secondly, adapting urban environments to the effects of climate change requires anticipating long-term trends and changes. This brings large uncertainties into the decision-making process, for instance from environmental, demographic or economic projections (Hallegatte et al., 2012), but also uncertainties arising from the complex behaviour of the system itself, for example through unexpected cross-scale effects over space and time (Folke, 2006, Wise et al., 2014). The problem of deep uncertainty has profound implications for incorporating adaptation into urban planning and design. Urban planning and design need to plan for conditions in 50 to 100 years, which are difficult to predict with any certainty. Large infrastructure development and adaptation strategies that come with long lead times are confronted with large up-front costs that may be redundant when climatic conditions develop more slowly than predicted or when new technologies become available (Hallegatte et al., 2012, Nicholls et al., 1995). When facing deep uncertainty it is necessary to improve adaptability. The challenge is to make urban environments more adaptable and flexible to allow them to function under fast changing socio-economic conditions and climate change (Pahl-Wostl, 2007, Zevenbergen et al., 2010). The question is how to incorporate flexibility into the design and planning of integrated urban waterfront and flood risk management systems.

Flexibility can be achieved through 'adaptive engineering' at project level by carefully designing provisions to allow future extensions or adaptations, or strategically at the system level, by keeping options open to shift to alternative or complementary measures and plan to avoid lock-ins (Rosenhead, 1980b). Designing tactical-operational flexibility can be achieved by oversizing crucial elements, by enlarging

flexibility, or by shortening economic life cycles of urban assets to create more options to adapt. On a strategic level flexibility can be achieved by developing sequences of adaptation options that keep options open in anticipation of future conditions, or by shortening decision life cycles (Hallegatte et al., 2012).



**FIGURE 1.2** On site flood protection provisions protecting an office (left) and new residential building (right) in Lower Manhattan. The new building is equipped with a watertight bathtub foundation and a backup roof top generator to provide basic services during a flood. Building level resilience may reduce the willingness among real estate owners to invest in district-wide solutions. Left picture by author, right picture: courtesy Peter Wilk at metropolismag.com.

Thirdly, the key to successful adaptation of urban environments is to effectively use moments of change to enhance flood resilience. Adaptation is still mainly seen as way to reduce risks, and not yet as an opportunity to create a more liveable, attractive and socially just environment. Additionally, there is a growing belief that “added value” created through multifunctional flood resilient urban environments may act as an important trigger to speed up the process of adaptation. This transformative-based adaptation requires using moments of change in urban development and management as windows of opportunity for low-cost adaptation and to yield additional benefits. This approach calls not only for a better understanding of the effectiveness of adaptation actions, but also a better understanding of the opportunities to spatially, and in a timely manner, synchronise adaptation measures with spatial development, urban management and infrastructure maintenance projects. To do so, it is necessary to develop more knowledge to understand if incorporating adaptation into urban development processes is an effective strategy to enhance the overall resilience of urban waterfronts within an acceptable time frame. Additionally, a better understanding of the institutional, financial or organisational transitions needed to speed up the process is required. The question is how to plan for urban waterfront areas that are able to adapt to changing circumstances and how do we take change as an opportunity to create more attractive, inclusive and liveable urban waterfront communities.

## Resiliency-based planning methods

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The question that needs to be addressed is, which resilience-based planning methods are effective in improving the flexibility of coastal waterfront areas? Complex systems are no longer behaving in a linear and reasonably predictable way, making traditional planning and management approaches that are based on optimisation of sub-systems less effective (Folke, 2006). *Resilience based planning strategies* embrace the idea that the future is so uncertain that it is wise to develop a flexible path towards a sustainable future, while avoiding future lock-in situations arising from incremental developments or path dependencies. This can be achieved through keeping options open as long as possible or by developing sequences of interventions that allow for an easy exchange of strategies. Sequences of adaptation options (pathways) that are reversible and flexible should be favoured over the irreversible and non-flexible (Hallegatte et al., 2012). This argues for taking small-step interventions along shorter time lines, to avoid future lock-ins, reduce potential regrets, or to seize advantage of possible adaptation opportunities (Dessai & van de Sluijs, 2007, Gersonius, 2012, Haasnoot, 2013). This approach is called the *adaptive approach* (Gersonius, 2012, Haasnoot, 2013). Recently, within the realm of urban storm water management and flood risk management, resilience-based planning methods have been developed that help to dynamically respond to changing circumstances. These methods, the Adaptation Tipping Point (ATP) method and Adaptive Pathways Method (APM), take critical system vulnerabilities as a starting point to develop a portfolio of adaptation options. Kwadijk et al. (2010), Gersonius (2012), Haasnoot (2013), Werner et al. (2013), and Jeuken et al. (2014) show examples of applications ranging from retrofitting an urban drainage system to assessing key priorities for adaptation of water systems on a national scale. However, these two methods have not yet been applied to the complex socio-economic context of planning for urbanised waterfront areas. One of the questions addressed in this thesis is how these planning methods can contribute to a more resilient urban coastal development.

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## § 1.2 Research Question

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The previous section started with the observation that the increasing vulnerability of urbanised deltas and coastal cities to flood risk is largely caused by processes of urbanisation, socio-economic change and human-induced stresses to the natural system. As a consequence, in response to climate change it is likely to be most effective to focus on addressing the root causes of the increasing vulnerability of coastal cities. A basic assumption underlying this thesis is that a system-based approach to flood risk is more effective to reduce risk, particularly in the context of uncertain climate change.

Additionally, this research assumes that the integration of adaptation responses to increased flood risk into urban planning and design is a more flexible, (cost) effective and value-adding approach to enhancing the resilience of delta cities and urban waterfronts in particular.

**The main research question of this thesis is: “how can we adapt existing coastal urban waterfront areas to changing climatic circumstances and how can we take this adaptation process as an opportunity for creating added value?”**

To answer the main research question, this main question is broken down into four sub-questions:

- 1 What adaptive measures and design principles are effective when improving the flood resilience of existing urban waterfront areas?
- 2 What pathways to resilience are most effective, provide flexibility and deliver added value in the long run?
- 3 How can we use urban change and development as opportunities to enhance resilience?

Methodological question:

- 4 Is the Adaptation Pathway Method (Haasnoot, 2013) an effective method to develop adaptation strategies at the tactical-operational level of urban development?

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## § 1.3 Approach and methods

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### § 1.3.1 Synchronising adaptive pathways with urban development

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In order to develop local adaptation strategies the Adaptation Pathway Method (APM) is used. The APM (Haasnoot, 2013) describes a sequence of water management policies (or measures), enabling policy makers to explore options for adapting to changing environmental and societal conditions over time. By developing several Adaptive Pathways (APs), decision-makers are provided with insight into the effectiveness of different flood risk management approaches over time, possible lock-in situations, path dependencies or the availability to switch to other options in the future. The APM provides an alternative method to the traditional end-point scenario planning approaches, often used in long-term water management studies.

Although the APM proved to be a helpful instrument to define possible adaptation paths, it however does not help to synchronise or find mainstreaming opportunities with spatial investments and interventions in actual urban area development processes. Moreover, finding adaptation opportunities (Gersonius, 2012) may well be essential in defining a viable strategy, in addition to criteria such as long-term flexibility and robustness. To prove the efficacy of adaptation pathways in the context of urban development, it is necessary to assess:

- 1 The spatial and timely synchronisation of adaptation measures with planning of spatial development and public and private infrastructure maintenance projects;
- 2 Institutional and financial barriers that need to be removed in order to mainstream climate adaptation measures in urban development processes;
- 3 Adaptation pathways to possible (socio-economic) futures that influence synchronisation and adaptation opportunities in time, and
- 4 To elaborate how “added value” influences the adoption of adaptation pathways.

### § 1.3.2 Action based research

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The methodology of this research is action-oriented, in the sense that it sees knowledge as a coproduction of actors in applied contexts (Mills et al., 2010, Stringer, 2007). Originating from social sciences, *action research* is a family of research methods that takes research as a social process of collaborative learning through actively involving stakeholders, participants and communities as producers of knowledge, and aiming to empower communities and change certain practices (Kemmis & McTaggart, 2007, Mills, et al., 2010, van Buuren et al., 2014). Action research seeks to ‘...engage the complex dynamics involved in any social context’ (Stringer, 2007: 1). In action based research methods the role of a researcher changes from observer to participant, particularly when researchers are researching their own practice, or when actively involved in social change and community empowerment (Mills et al., 2010). Schön (1983) speaks, in this respect, about the ‘reflective practitioner’. However, the aim of action-based research is not only to transform practitioners’ theories and practices but also the theories and practices of others (Kemmis & McTaggart (2007). Moreover, a change of perspective is needed: *‘[The] action research movement in professional practice, argues that practitioners themselves must become active critical researchers constantly examining and critiquing their own practice and that of their community of peers. In other words, one’s own practice and the practice of one’s peers become an ongoing case study aimed at improving a situated professional practice (Mills et al., 2010: 668.)’*

## Why action based research?

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There are a number of reasons for using an action-based research methodology. First, the research focuses on the development of knowledge on the effectiveness and added value of local adaptation responses and adaptive strategies, which requires information that can only be developed in close collaboration with local communities, stakeholders and city officials. Secondly, given the relative obscurity of community-based adaptation planning, there is a lack of realised examples suitable for ex-post case-study research. And finally, this research in itself is part of a transition towards a more community-based flood risk management approach and is embedded in wider policy development processes in the Netherlands, both at the city (e.g. Rotterdam Adaptation Strategy) and regional (e.g. Delta Programme Rijnmond-Drechtsteden) level. Finally, and probably the most decisive argument is that working as an urban planner at the City of Rotterdam provided a unique opportunity to work within these policy development processes and intensively work together with stakeholders and the professional community.

## Critical reflection

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Given its activist and praxis-oriented research focus, the action-based research methodology has been criticised for the risk of biases, conflicting interests, and lack of critical distances (Mills et al., 2010). Moreover, knowledge generated in an action-based research context may directly affect the outcomes and direction of change, making it difficult to disentangle cause-effect relationships (Kemmis & McTaggart, 2007). Additionally, finding a balance between problem solving and the production of scientific knowledge within an action based research project is a major challenge (Marshall et al., 2010). However, there are several ways to deal with the concerns related to action based research methods, for example by providing transparency about basic assumptions explicitly at the outset of a research project, by using verifiable data and standardised forms of data-collection and through critical reflection (Mills et al., 2010). Action based research usually involves an iterative process of critical self-reflection at all stages of the research, in which several cycles of developing system models, acting and observing, and revising the system models, alternate and produce knowledge along the way (Kemmis & McTaggart, 2007, Stringer, 2007). In short, critical reflection means that the researcher carefully describes their assumptions, beliefs and ideas at several stages of the research and critically reflects on how jointly developed knowledge has influenced their or others assumptions and beliefs. In a way, working both as a practitioner responsible for the adaptation of waterfront areas and, simultaneously, as a researcher aiming to reflect on the practice of coastal adaptation planning, is, in itself, a critical reflection. As the actual research process is more likely to be fluid, open and iterative (Kemmis & McTaggart, 2007), an effective tool to reflect on action-based research is to develop a story line reflecting the actual process of research

and praxis. A retrospective discussion on the issues introduced above is provided in chapter 8. In Chapter 8.3.3 a graphical representation of the research process, interactions between research and praxis, and the wider urban policy context, as well as the evolution of research assumptions are provided and reflected upon.

### § 1.3.3 Case study areas and case selection

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The research design is centred on real-life case studies. To answer research question 2 ('what pathways to resilience are most effective, provide flexibility and deliver added value in the long run?') and 3 ('How can we use urban change and development as opportunities to enhance resilience?') it proved to be necessary to engage with real-life contexts in which long term coastal climate change adaptation processes were being undertaken. The goal of the case study research is twofold: firstly, to understand the causal links between local flood risk characteristics, urban typologies and urban dynamics, and the effectiveness of co-beneficiary adaptive responses and strategies, and, secondly, to test and evaluate the adaptation planning method (APM) at the scale of tactical-operational urban development. To achieve these objectives, a multiple case study research design (Yin, 2009) is proposed, in which first a more extensive case study is used to develop a toolbox of adaptation responses and to test and revise the APM. For this purpose an embedded case study research design is selected, in which multiple subcases representing different urban typologies are selected. The main purpose of the second case study however, is not to do a literal replication of the proposed method and test its application under different urban and social contexts – as would be the case of a comparative research design (Yin, 2009) – but is to test the revised adaptation planning method that is developed as an outcome of the first case (**Fig. 1.3**). Additionally, the second case serves as a real-life case with the objective to assess flood vulnerabilities and learn from adaptation responses in a flood affected urban waterfront area. However, there is an element of comparative case study research approach involved, as both cases are meant to compare and assess the effectiveness of, in many ways contrasting, flood risk management approaches, and to provide a real-life context in which the effectiveness and potential co-benefits of adaptation responses can be evaluated.

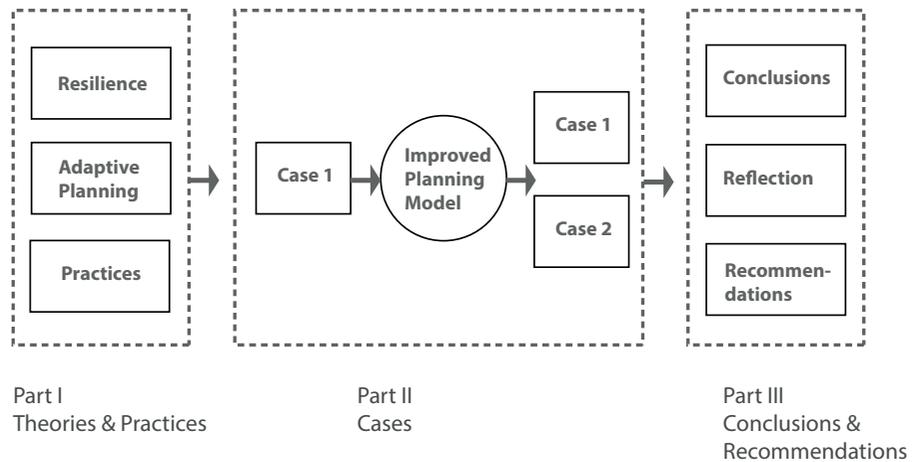
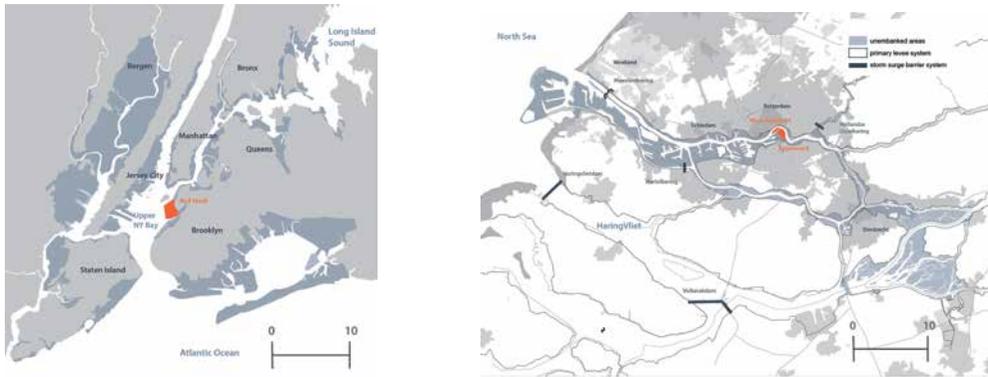


FIGURE 1.3 Research structure and position of case studies within the research design.

### Rhine Estuary and New York – New Jersey estuary

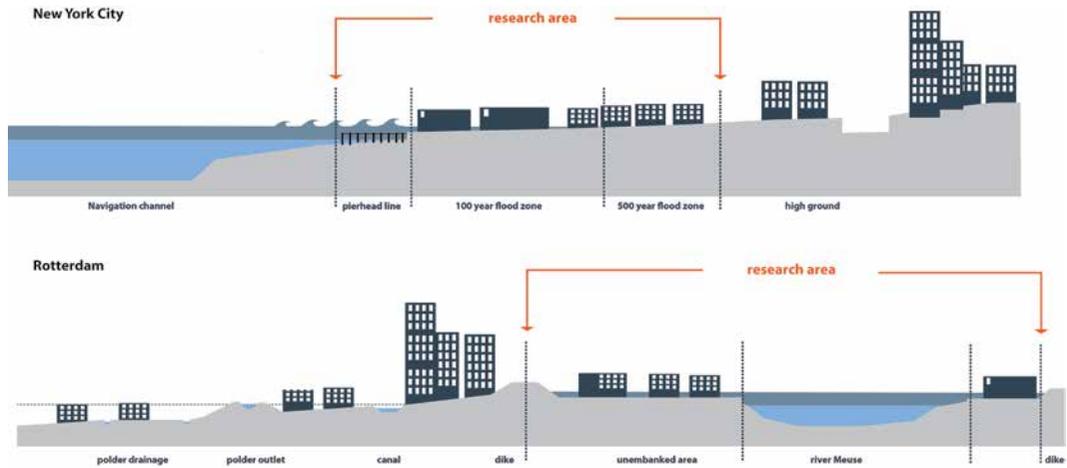
The case study areas are selected based on similarities in terms of flood risk and urban typology conditions but with contrasting flood risk management approaches, and cultural differences, such as differences in risk perception and distribution of responsibilities between the public and private sector. The urbanised Rhine estuary, known as Rijnmond-Drechtsteden metropolitan region and the New York-New Jersey metropolitan area were selected because both are large metropolitan urbanised coastal zones in an intertidal estuary that share surprising similarities in flood characteristics, vulnerabilities and urban typologies along the waterfront (Fig. 1.4 and 1.5).

However, both case study areas differ when it comes to regulatory systems, planning models, urban development, and flood risk management approaches, making both metropolitan regions interesting cases to compare and test the planned adaptation approach. Flood risk management in the Netherlands is almost exclusively publicly funded and prevention-based. The US approach to flood risk is mainly focused on disaster management (adaptation, recovery and relief programmes) and less on disaster avoidance and prevention, as is the case in the Netherlands. Furthermore, the urban planning approaches differ. Urban development in the Netherlands is publicly managed and based on large-scale transformations and integral (re)development projects in which public and private stakeholders participate, although recently there is a change towards more incremental and bottom-up urban development (Krabben, 2011). Urban development in the US is more bottom-up, private sector-oriented and regulated by building codes and zoning (Cullingworth & Caves, 1997).



**FIGURE 1.4** Projected 100-year flood zones (blue) in the New York – New Jersey metropolitan region (left picture) and the unembanked areas (blue) and primary flood defence system in the Rhine Estuary and Rijnmond-Drechtsteden metropolitan region (right picture). The case study areas are highlighted in orange.

Additionally, during the research phase both metropolitan areas were engaged in a policy-development process on long-term adaptation to flood risk. During the research years (2011-2015), the Rhine Estuary (Rijnmond-Drechtsteden) region developed a long-term adaptation strategy addressing the effects of climate change on flood risk and fresh water supply. This strategy was embedded in a larger nationwide policy development process to proactively adapt the current flood risk policies in anticipation of climate change and urbanisation. At the same time, the New York metropolitan area developed, in the aftermath of the Hurricane Sandy flooding of 2012, several strategic policy changes focussing on rebuilding and recovery (see for example NYC, 2013). In addition, in 2013, the Rebuild by Design competition was launched aimed at developing design strategies for adapting coastal waterfront areas and strengthening community resilience. Both long-term policy development processes, although different in terms of proactive or reactive planning approaches, offered a wealth of empirical data and scientific reports.



**FIGURE 1.5** Cross section showing the waterfront conditions of New York City (above) and Rotterdam. In Rotterdam the research area focuses on the flood prone unembanked areas located “outside” of the primary flood defence system (dikes) that protects the low-lying urban areas from flooding. In New York the research focuses on the 100-year flood zone that is located between the shoreline and the natural higher grounds.

### Local community-level cases

To gain detailed knowledge on flood vulnerabilities, potential adaptation interventions and adaptation strategies for existing urbanised waterfronts, two case study areas were selected that represented different typologies of residential waterfront communities that can be found throughout the Rhine Estuary Region. The Noordereiland case is a predominantly privately owned historical waterfront area that represents other historical waterfront areas that can be found throughout the region, such as the historical ports of Vlaardingen, Maassluis and Dordrecht. The Feijenoord area is an example of a dynamic waterfront area representing other urban renewal locations in the region. Although it is recognised that other typologies such as the industrial areas and former industrial sites in transition may serve as reference cases, as this research focuses on adapting residential waterfront areas, these locations were not included in the case selection. The New York City waterfront case has been used to test the applicability of the APM method for adaptation planning under different spatial planning and urban development conditions. As one of New York City’s most flood prone areas, the case of Red Hook was selected on similarities in flood risk, socio-economic challenges, and potential for urban redevelopment (Fig. 1.5). Both the Feijenoord case and the Red Hook case are (former) port areas in transition in close

proximity to high-end redeveloped waterfront locations. Both cases are deprived, disadvantaged neighbourhoods that have the potential for urban change and uplift. The unfortunate flooding that Red Hook experienced during super storm Sandy provided an opportunity to research the vulnerability of urban assets and the physical and economic effectiveness of local adaptation responses. Again, the similarities allow for a detailed comparison of both cases and the chance to reflect on the relation between local adaptation planning and differences in regional planning and flood risk management.

The research design however, differed between the two case study areas with regards to the research approach. Being able to work as a consultant for the Delta Programme and the City of Rotterdam in the Rotterdam case, action-based research techniques could be used. For the Red Hook case this action-based approach was not an option. The research approach of the Red Hook case is based on data selection derived from interviews with city officials, urban designers, landscape architects, consultants and stakeholders in local adaptation planning, complemented with GIS analysis, research by design and literature review.

### Research by Design

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At several phases of this research, sketch design is used as a means to analyse the spatial and visual effects of adaptation response actions and strategies, to communicate with stakeholders within a collaborative learning process, and to identify new and unexplored opportunities that may derive from combining different agendas and ambitions. In this sense, Cross (2006) speaks about 'designerly ways of knowing', which he defines as the ability of design to solve ill-defined problems, adopt solution-focussed strategies and use non-verbal, graphic media (sketches, drawings, models) to test, communicate and integrate a solution into a wider context.

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## § 1.4 Objective and scope

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### § 1.4.1 Objectives

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The practical objective of this research is to develop a resilience-oriented design and planning method that facilitates the integration of flood management with urban development, taking into account the dynamism of urban development processes and

the long-term uncertainty of climate change. Related to this, the research objective is to develop knowledge on the (cost) effectiveness of local adaptation measures to enhance the resilience of urban waterfront areas. The final objective of this research is to test the applicability of existing methods for adaptation planning at the local scale of urban development and change, and to revise these methods if necessary.

## § 1.4.2 Scope

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The scope of the research is limited to existing urban waterfront areas in deltas, estuaries and along coasts that suffer from coastal and fluvial flooding and are at risk of climate change, particularly sea level rise and increasing river run-off. Although it is acknowledged that in many delta cities concurrently occurring pluvial, fluvial and coastal flooding is a major challenge, this research excludes all issues related to pluvial flooding; flooding due to extreme rainfall is handled separately with other approaches and techniques, approaches and techniques that lie beyond the scope of this research. In addition, this research excludes multi hazard conditions, such as earthquake and tsunami prone coastal areas, for example in Japan and the East Java Sea. This limitation in scope is also drawn in order to keep differences between the case studies in terms of flood characteristics as low as possible for reasons of comparison. Secondly, the focus of this research is limited to adapting existing urban coastal waterfront areas as these environments are generally most vulnerable and require not only flood adaptive design but also, more importantly, strategic long-term planning. Finally, the main focus of this research is on building physical resilience, not social resilience. However, as will be explained in more detail in the theoretical chapters, both physical and social resilience in urban areas are closely linked and strongly related to cultural, institutional, financial and organisational aspects. Acknowledging this, the more social aspects of resilience are assessed and evaluated as long as they pose constraints or opportunities for a successful implementation of physical resilience.

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## § 1.5 Outline and structure

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This thesis is structured around three sections: a theoretical section, an empirical section and a synthesis section (**Fig. 1.3**). The theoretical section starts with chapter 2, in which different definitions of resilience and adaptation are discussed in more detail and a conceptual model of urban flood resilience is provided that is used throughout the research. Chapter 3 continues with a brief overview of adaptation

planning approaches and introduces the Adaptation Tipping Point and Adaptation Pathways Method (APM). Finally, it reflects on the question of how to define and assess effective adaptation. Chapter 4 focuses on the question of what adaptive measures, practices and design strategies are effective to both reduce flood risk along coastal urban waterfronts as a consequence of climate change, and also to add value when improving the flood resilience of urban waterfront areas. This chapter provides an overview and classification of local adaptation responses based on an understanding of local flood characteristics and effectiveness at reducing flooding, cost-effectiveness and opportunities to create co-benefits. The final section of this chapter addresses design strategies that increase flexibility to respond to uncertainty.

Part II, the empirical section of this thesis, aims to provide quantitative and qualitative evidence for answering the main research question of this thesis: "how can we adapt existing coastal urban waterfront areas to changing climatic circumstances and how can we take this adaptation process as an opportunity for creating added value?". This section starts with an introduction and comparison of the flood risk characteristics and vulnerabilities of the Rhine Estuary Region and the New York City-New Jersey region and discusses the effectiveness of the current flood risk policy of both regions. It then continues with chapter 6, which is structured around the application of the adaptive pathways method at the Rhine Estuary Region and the Noordereiland and Feijenoord case. Chapter 7 focuses on the question of how to use urban change and development as moments of change to enhance the resilience of coastal areas to increasing flood risk. This chapter introduces a revised Adaptive Pathway Approach based on identifying intervention options, opportunities and transformative actions. This improved approach is tested in a real case, Red Hook in Brooklyn, NYC. Finally, part III discusses strengths and weaknesses of this revised adaptation-planning approach and elaborates on the central research question and sub questions, reflects on the meaning of these conclusions for the Dutch and US water management approach and the transferability of the results to other planning sectors, and provides recommendations for further research.



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# PART 1 Theories & Practices





# 2 Theoretical background

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## § 2.1 Introduction

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In the previous chapter the problem, hypothesis, research question and research frame are introduced. This chapter further explores the underlying principles of resilience thinking in socio-ecological systems and focuses on the question if the resilience concept is an effective frame to manage urbanized deltas under climate change. The following questions are addressed:

- What is resilience and adaptation?
- What are key elements of resilient and adaptive systems?
- How can we construct resilient and adaptive systems?

In the first section three dominant perspectives on resilience are introduced: the engineered resilience perspective, the ecological resilience perspective and the socio-ecological perspective. It is then argued that if urbanized deltas and coastal areas are understood as complex systems in which the natural system interacts with, and sets the conditions for, its social, economical and technical (sub) systems, the engineered resilience definition that is based on bouncing back after disturbance does not capture resilience on systemic scale. It requires a definition of resilience that acknowledges that the ability to adapt is a crucial element in socio-ecological-technical system's resilience. In the second section, this chapter continues to investigate the key elements of resilient and adaptive systems. Two domains produce the sustainability of urbanized deltas and coastal areas: a resilience domain and adaptation domain. The resilience domain is closely related to the concept of vulnerability and is based on (1) the capacity to cope with small disturbances within the systems natural variation and (2) the capacity to recover from extreme situations and return to equilibrium after a certain period of time. Adaptation capacity is based on (3) the capacity to adapt to deal with slowly changing environmental conditions and large disturbances and, finally, (4) the capacity to transform its basic structures when adaptation is no longer an option. These processes of adaptation and transformations, however, are scale-dependent: local transformations may be part of an adaptation strategy on the larger scale. These four capacities are used as a frame to evaluate the resilience of urbanized coastal areas. In the third section options to operationalize the resilience - adaptation - transformation frame in planning and urban development are elaborated. Based on a review of resilience-based planning and management approaches, this section provides a

strategic planning framework and step-wise method that will be used and empirically tested at two case study areas in chapter 4.

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## § 2.2 Defining resilience

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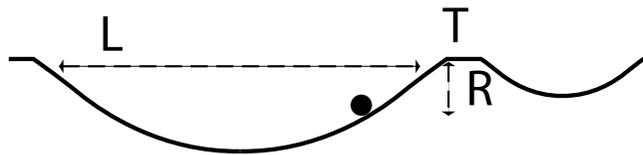
### § 2.2.1 Ecological resilience

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The concept of resilience shares roots with a larger family of complexity theories that emerged in the late seventies to explain the non-linear behaviour of complex systems (Walker & Salt, 2012). Resilience actually originates from ecological-system science. The concept of resilience is based on the notion that ecological systems should be understood as being essentially unstable and subject of constant change. In its basic definition, resilience describes the ability of an ecosystem to absorb, or accommodate disturbances or changes without experiencing structural changes to the system as a whole (Holling, 1973, Carpenter, 2001, Folke, 2006). Resilience proved to be a useful concept to understand the vulnerability of natural systems to change and to explain why some ecosystems show a remarkable ability to rebound easily after disturbance and others are vulnerable for sudden irreversible changes in complex ecosystems (Scheffer, 2009, Folke et al., 2002). Key to the resilience concept is the notion that complex systems are attracted by a stable mode of behaviour (Davidson, 2010), which is known as a *stability regime*. More resilient systems show a certain level of persistence towards changing external conditions. However, when external conditions exceed the level of persistence, the system needs to adapt or transform into a new stable state (Scheffer, 2009). These, sometimes abrupt and unexpected changes, are known as a *regime shift* or a *critical transition* (Scheffer, 2009) and have been observed in different ecological systems, such as the sudden replacement of forest ecosystems with grassland or a change in turbidity of shallow lakes (Scheffer, 2009, Walker & Salt, 2012). These sudden dramatic changes are largely irreversible.

Within ecological systems theory, the moment when changing conditions are forcing a normally stable state of a system into another state, or urge a system to adapt, is known as a *threshold* or *tipping point* (Scheffer, 2009, Walker & Salt, 2012). Resilience of natural systems can be measured as the distance a system is away from its tipping point or the time that is needed to return to its previously stable situation (Walker & Salt, 2012). Systems that are close or near to this point tend to be unstable and extremely vulnerable for change. Ecological resilience can be measured by *resistance*,

which is defined as ‘the amount of external pressure needed to bring about a given amount of disturbance in the system’ (Carpenter et al., 2001: 766). Or, using resilience terminology, resistance is defined as how easy or difficult it is to influence the system towards its tipping point. This level of resistance is also known as *buffer capacity* (Walker et al., 2004). **Fig. 2.1** shows natural systems that have a strong resistance (R) and latitude (L), which is the maximum amount a system can change before it loses the ability to recover (Walker et al., 2004) are more stable or show a higher resilience towards change.



**FIGURE 2.1** Resilience represented as stability landscape. The black dot represents the position of a system in a certain stability regime (bowl). When the level of resistance (R) is crossed the system reaches a tipping point (T), which causes the system to transform into another stable condition. This new stability regime, however, may have different characteristics in terms of resistance and latitude (L), which is the maximum amount a system, can be changed before losing its ability to recover. Picture adapted from: Walker et al. (2004)

Management of ecological systems’ resilience is concerned with ‘maintaining a system within a given stability domain after disturbance’ (Healy & Mesman, 2013: 25). Thus, to manage resilience it is important to identify the key variables that determine the significant changes in the system (Walker & Salt, 2012) and to explore the position of its critical thresholds or tipping points. The concept of tipping points is applied at both large scale and small-scale system assessments. For example, in climate change science, the climate threshold theory refers to the limit value associated with a dramatic and irreversible transition of the earth’s climate, for example the potential reversal of oceanic circulation system in the North Atlantic (IPCC, 2007, Pelling, 2011). It also has proved to be an effective way to describe sudden changes in small-scale systems, for example shallow lakes and grasslands (Scheffer, 2009, Folke et al., 2002).

In the past years the resilience concept has been enriched with the notion that complex ecological systems are attracted by multiple stability regimes (Gunderson & Holling, 2002) that constitutes a *stability landscape* consisting of stable ‘valleys’ and unstable ‘mountains’. Under changing conditions, these complex ecological systems now may manifest several responses. First, as long as changing conditions remain within the system’s level of resistance or buffering capacity the system may recover from any disturbance and remain within its stability regime. This is known as the *resistance domain*. However, when conditions reach the system’s critical threshold or tipping

point, the system may adapt its crucial elements to remain the same identity and structure. This is known as the *adaptive domain*. When the system is no longer able to adapt, it is forced to *transform* into a new regime. Complex ecosystems are capable to move between several stability domains (Davidson, 2010). This conceptual model of different stability domains in a stability landscape serves as an explanation of observed sudden seasonal changes in behaviour of ecosystems or to explain gradual processes based on a series of incremental adaptations in response of slow evolving change. As stated by Walker & Salt (2012): resilience, adaptation and transformation are three complementary attributes of ecosystems.

Additionally, the concept of resilience emerged in relation with ideas on cross-scale interactions and interdependencies between sub systems within a larger system (Folke, 2006). A crucial part of the concept is the notion that resilience is produced and influenced by the dynamics and interactions between lower and higher system elements, which takes place on different temporal and spatial scales (Fig. 2.2).

Processes of adaptation and transformation on the smallest scale might influence higher scale resilience. But also higher scale dynamics constrain and initiate lower-scale resilience (Adger et al., 2005a).

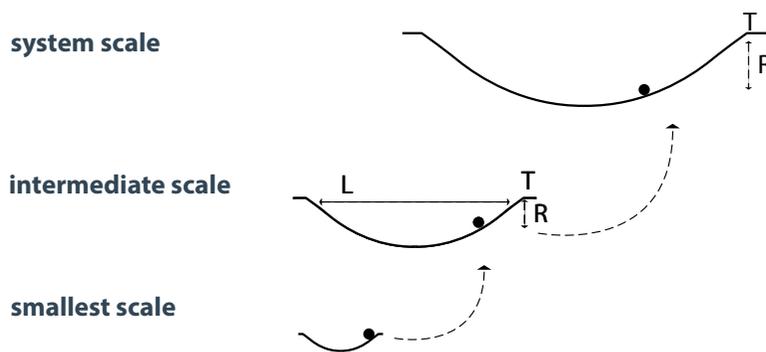


FIGURE 2.2 Resilience is produced as an interaction across scales. Picture adapted from Walker et al. (2004)

A well-researched example of these cross-scale dynamics in ecosystem science is the positive effect of local small-scale forest fires on the overall resilience of forest ecosystems (Walker & Salt, 2012). Small-scale forest fires create a pattern of forests in varying stages of maturity that avoids disruptive effects of a fire to the forest as a whole. Paradoxically, allowing forests to burn regularly creates resilience on an intermediate or even system scale (the forest). Gunderson & Holling (2002) concluded that understanding these linked cross-scale interactions and time dimension is key to understand and enhance resilience within a system. Given this interaction of lower-level and higher-level system resilience, it is of the highest importance to

define resilience related to the level of the system assessed. In the next section the issue of scale, among some other reasons, is identified as a major cause of semantic discussions on definitions of resilience, adaptation and transformation in socio-ecological systems.

While being undeniably a valuable concept to describe and understand the complex behaviour of natural systems, the question is if resilience is just as effective in understanding the behaviour of coupled human-natural systems. To answer that question, it is necessary to delve deeper into the literature on resilience, adaptation and transformation in socio-ecological systems.

### § 2.2.2 Engineered and socio-ecological resilience

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Resilience is widely adopted as a concept to understand the behaviour of closely linked natural and human systems, such as urbanized coastal zones, in the face of stress and change (Klein et al., 2004). However, when applying the resilience concept to social-ecological systems a wide range of interpretations is available, ranging from resilience as a metaphor for the ability of communities to self-organize to the interpretation of resilience as an internal property of a whole socio-ecological system to bounce back, adapt or transform to face changing circumstances. According to Folke (2006), Klein et al. (2004) and Walker & Salt (2012) there are two interpretations of the concept of resilience in coupled social-ecological systems. First, resilience can be interpreted in a more technical perspective as the ability of a component, or a set of components, to provide a certain level of resistance or buffering to changing circumstances. Resilience in this more narrow interpretation can be understood as the capacity of a (sub) system to buffer or cope with natural variations, recover from disturbances and return to its previous state (Klein et al., 2004, Folke, 2006). This interpretation is closely related to the definition of resilience in Mechanical Engineering Science in which resilience is commonly understood as the capability of a component, unit, or engineered system to occasionally withstand small overloads that cause either minimal deformation or that result in gradual failure modes rather than sudden failure modes (PIANC, 2014).

*Engineered resilience* (Folke, 2006), is closely related to the original ecological resilience view in the sense that it implicitly assumes that there is only one possible or desired stable situation to return to. To put it simply, engineered resilience is the ability to “bounce back to normal”. The engineered perspective on resilience can be useful to manage subsystems under stress of an external pressure or to manage systems that are in situation of near equilibrium (Folke, 2006). Engineered resilience tends to be used synonymously with the term *robustness*, particularly in infrastructure design and flood risk management. Walker & Salt (2012) argue that robustness is commonly used with a connotation of “designed resilience”, which is *bounded uncertainty* in

the sense that ‘the kinds and ranges of disturbances and shocks are known, and the system being built is designed to be robust in the face of these shocks (*idem*: 3)’. Designed robustness or resilience is thus the range of potential or known conditions the engineered system is designed to cope with (Walker & Salt, 2012). Mens et al. (2011) introduce the term *system robustness*. System robustness is defined as to the ability of (river) systems to maintain desired system characteristics when subjected to disturbances. However, both designed and system robustness differs from the system resilience perspective in the sense that they are based on ‘specifying the range of uncertainty (conditions) the system must be able to cope with (Walker & salt, 2012: 92)’. Also, the definitions of designed and system robustness echoes the engineered resilience view of bouncing back to normal after disturbance.

The engineered resilience approach is commonly applied in governed infrastructure systems such as road infrastructure, sewer systems, or flood risk infrastructures, but it also dominates in environmental management practices. Engineered resilience involves robust design strategies, such as the implementation of “safety margins” in the design of levees or “headroom” in sewer systems that aim to over-design infrastructures to cope with almost any possible variation. Engineered resilience or robustness is often applied when uncertainties on performances requirements are high or when it proves to be difficult to calculate the strength of a construction with any precision. In social systems, the engineered perspective on resilience refers to the ability of a social system to cope with and recover quickly after a disturbance and return or restore the previous existing situation. The engineered perspective on resilience can easily be recognised in the wording used in the New York City’s post-Sandy responses in which the message of “build it back” (Hurricane Sandy Rebuilding Taskforce, 2013, Goldstein et al., 2014) clearly reflects a tendency to understand resilience as the ability to bounce back to a previous state.

Resilience as bouncing back, however, is criticised as to be backward looking and reactive, in the sense that it focuses on restoring the pre-existing situation, including its systemic errors and structural vulnerabilities, and that it is not aimed at adapting to slow environmental change (Twigger-Ross et al., 2014). Thus, resilience is not only about being able to absorb disturbance and recover quickly. Socio-ecological system’s vulnerability emerges from complex and interacting factors and drivers. Although the engineered resilience approach acknowledges the multi-faceted nature of socio-technical systems (Healy & Mesman, 2013), it ignores the fact that within social-ecological systems agents are able to influence the system’s components to increase its resilience to change, when recovery is no longer an option. A crucial element of resilience of social-ecological systems is the ability to adapt and transform to face slow environmental changes (Carpenter et al., 2001, Adger, 2006, Walker & Salt, 2012) by reducing exposure to, or minimising the impacts of, disturbances (Adger et al., 2005b, Davidson, 2010). This interactive situation opens up opportunities for renewal of the system and for the developing of new trajectories that lead to a higher level of resilience (Folke, 2006). Revi et al. (2014) termed this process “bounce forward” to a more

resilient state, or to “building back better” (Lyons, 2009, cited in Revi et al., 2014). Resilience in this interpretation is the capacity of a system to absorb disturbance as well as the capacity to *re-organize* while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al., 2004, Folke, 2006). This interpretation is known as *social-ecological* resilience.

CONCEPT	CONTEXT	CAPACITY	MEASURE
Engineered resilience	Return to equilibrium (single equilibrium)	Buffering capacity	Resistance/robustness rate
Ecological resilience	Stability within a particular domain	Recovery capacity	Recovery rate
Socio-ecological resilience	Cross-scale dynamic interactions	Adaptive and Transformative capacity	Self-organize and learn and development of desirable trajectories

TABLE 2.1 Resilience applied to social-ecological systems can be understood from a focus on resistance or robustness (engineered resilience), a focus on maintaining stability and ability to return back to normal (ecological resilience) and a focus on adapting and transforming the system’s components (socio-ecological resilience). Table based on Folke (2004)

### § 2.2.3 Socio-ecological resilience in urbanized deltas

As already briefly discussed in the introduction, urbanized deltas can be regarded as complex and dynamic systems consisting of many subsystems that interact and show high interdependencies. Urbanized deltas are either described as socio-technical systems or socio-ecological systems (Twigger-Ross et al., 2014). The concept of socio-technical system (STS) is coined by Geels (2004) to describe the complex system’s behaviour of actors (clients, companies, institutions) that are connected through rules (standards and norms) and social behaviour (learning processes) that interacts with a physical technological system. Gersonius (2012) uses Geels’ socio-technical definition to assess a flood risk management system as one that ‘links a physical system (e.g. flood risk infrastructure) with actors (e.g. flood risk management organisations, communities, individuals), rules (e.g. acceptable flood risk standards) and norms (e.g. appropriate action in emergencies) in order to provide a particular function (e.g. flood risk management) (Gersonius, 2012:2)’. Whilst it is tempting to follow this view, it is important to realise that understanding an urbanised delta in terms of a socio-technical system is a misleading simplification of a more complex reality. It neglects the fact that an urbanised delta is part of a larger complex social, economic and ecological system of which a flood risk management system constitutes only a part, and that greatly affects and interacts with the subsystems that it comprises. As an

example, the dominant perception of risk of a society is of major influence for defining the performance criteria (rules and norms) to which of a flood risk management system should comply. These perceptions may change as a result of changing cultural values or increasing prosperity.

Another strand of literature, originating from disaster management and developing studies conceptualises urbanised deltas as coupled socio-ecological systems (SESs). The idea of urbanised deltas as socio-ecological system emphasises the close relations between human development and ecological sustainability, in which any distinction between social and natural systems is arbitrary (Adger, 2006, Klein et al., 2004). Although, the concept of socio-ecological systems is a powerful concept, it is particularly useful in urbanised systems where a complex multiplicity of interdependencies between social, economic and the natural subsystems defines the sustainability performance of the urbanised delta as a whole. This concerns mostly coastal communities that are directly dependent on natural resources for their survival or large urbanised coastal areas in which the natural system (e.g. a natural dune and shore) is an essential part of the flood risk management system. The importance of the vitality of flood plain swamps in the Mississippi delta for reducing flood risk of the city of New Orleans serves as a great example in this respect (Campanella, 2010). Arguably, in many highly developed urbanised deltas or coastal areas this close relationship with the ecological system is less significant in defining the sustainability of a system. In this thesis both concepts of understanding a flood risk management system as a socio-technical system and an urbanized delta as a socio-ecological system are used. This thesis takes the socio-ecological perspective on resilience as starting point to build a conceptual model for planning more resilient coastal waterfront areas. Before continuing elaborating the adaptive and transformative aspects of adaptive systems in section 2.3, first, it is necessary to explore some key elements of resilient systems.

#### § 2.2.4 What makes a system resilient?

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What makes a system resilient? To answer this question there are some considerations to be made. Firstly, it is important to differentiate between *general* and *specified* resilience. Walker & Salt (2012) define specified resilience as 'the resilience of some parts of the system to particular kinds of disturbance (idem:68)'. General resilience is the capacity of a system 'that allows it to absorb disturbances of all kinds, including novel unforeseen ones, so that all parts of the system keeps functioning as they were (idem: 90)'. General resilience in this sense relates to the systemic resilience as introduced in the previous section. Specified resilience can be interpreted as the ability of a system to provide a certain level of resistance to a particular kind of disturbance or changing circumstances. It is therefore important to differentiate between more general *systemic* resilience principles and resilient *design* principles that enhance

resilience to specified environmental change. However, this research is not so much interested in general resilience principles but focuses on specified resilience, particularly resilience of urban waterfront areas to coastal flooding.

A second consideration is that many classifications of resilient system's features do not distinguish between principles that support resilience and principles that increase the capacity to adapt. Modularity, for example, is often referred to as a resilience attribute, but may both refer to a physical situation (e.g. as in the design of power infrastructure networks) but also may refer to a modular governance structure with non-hierarchical or independent decision structures that supports a quick identification and implementation of adaptation measures. The latter is a crucial element of the adaptive capacity of a system. In this section only resilience principles that have a clear physical or spatial component are reviewed.

Thirdly, although there is a wide range of interpretations and terms used to describe the attributes of resilient systems there is not one single attribute that makes a system resilient. Attributes that create resilience can be complementary, contradictory or show a high level of interaction depending on specific system properties (Walker & Salt, 2012). Resilient systems are often characterised by apparently opposite characteristics. For example, the resilience of systems increases when individual components or subsystems are able to survive as isolated units separate from the larger system. However, isolation also increases the sensitivity of the subsystems for disaster. The challenge is to seek an optimal combination of resilient features. There is consensus that resilient systems share three pairs of physical characteristics that need to be balanced to create systemic resilience:

### Functional redundancy and response diversity

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In ecosystems, the greater the number of species and resources, and more importantly, the higher the diversity in overlapping or complementary functions, the less likely it is that a system becomes unstable. This is known as the diversity and redundancy principle (Wardekker et al., 2010, Biggs et al., 2012). In literature, a distinction is made between *functional redundancy* and *response diversity* (Walker & Salt, 2012). Functional redundancy is generated when functionally similar elements within a system partially or fully deliver the same functionality. For instance, flood proofed buildings, acting as a second line of defence increase the redundancy of a system because they reduce damages when a dam or floodwall fails. *Response diversity* is defined as the variety of responses that is available in reaction to a disturbance or slow environmental change (Biggs et al., 2012). In flood risk management, the diversity principle is reflected in increasing the array of actions that reduces flood exposure or sensitivity. However, high levels of redundancy and diversity also run the risk of increasing costs and system stagnation as decision-making processes and flows of information are hindered (Biggs et al., 2012).

## High connectivity and autonomous components

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Secondly, more resilient systems show a rapid exchange of resources and information throughout the system that enhance the ability to prepare for and recover from disturbances quickly (Walker & Salt, 2012). This is referred to as *high flux* (Wardekker et al., 2010), *openness* (Walker & salt, 2012) or the *connectivity principle* (Biggs et al, 2012). The connectivity of certain communities of species to the larger ecosystem is used as indicator of population vitality, in contrast to isolated communities that show a higher level of vulnerability for disaster. However, strongly connected systems may also lose resilience as the effects of disturbances spread more quickly through the system (Biggs et al., 2012). For instance, a power outage due to a local flood event may affect a much larger area and result in cascading effects and higher costs than expected from a single local flood event. This problem of quickly expanding risk through highly interconnected parts of a system is probably the most important source of increased vulnerability of our modern networked cities.

Paradoxically perhaps, an opposing characteristic of resilient systems is that system components show a high level of autonomy, making them able function independently from the embedding systems (Biggs et al., 2012). In many ways opposite to the high connectivity principle is the principle of *autonomy*. Autonomous systems or objects are capable of providing basic functionality or survive for a certain period of time as isolated units separate from the larger system (Fricke and Schultz, 2005). As an illustration of this principle, self-supporting households in the Mekong delta are able to survive flood events independent from larger system functionality, due to their rainwater harvesting tanks and decentralised power system. Autonomous system elements increase the capacity to respond more rapidly towards changing conditions or requirements (Fricke et al., 2005). Conversely, autonomous, self-supporting or decentralized systems are generally more expensive. Resilient systems are able to manage connectivity. Systems that balance semi-autonomous functioning subcomponents (e.g. modular systems) with high connectivity between the components and between the components and higher-level systems are more resilient (Biggs et al., 2012, Walker & Salt, 2012). This principle is also known as *loosely coupling*. Developed by Weick (1976), the concept of loosely coupled systems is based on minimizing interdependencies between system components with the aim to increase flexibility and reduce the risks that change in one or more elements have negative effects to other elements. *Modularity* is a design principle that is based on loosely coupling and aims to maximize the cohesion between separate elements within a module, while minimizing the coupling between modules (Fricke and Schultz, 2005). Loosely coupled system improves the ability for local adaptation because subsystems can adapt without having effects on the large system.

## Critical feedbacks and buffering

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Finally, resilient systems are kept in a stable system regime because of multiple positive and negative feedback loops that help to counteract disturbances. A changing variable –either environmental or socioeconomic– may affect these feedback loops and result in a decrease of resilience. As an example, an increase in flood insurance premium may have a negative effect on house prices in flood prone areas and aggravates a process of urban decay, which drives down prices more rapidly (Findlan et al., 2014). Related to this, resilient systems show higher levels of reserves or buffering capacity. Reserves can be financial resources, human or natural capital (Biggs et al., 2012 and Walker & Salt, 2012) or the ability to over-dimensioning critical system assets (Wardekker, et al., 2010). This is also known as buffering capacity. The higher the buffer capacity, the larger the tolerance levels towards changing variables and the lower the vulnerability for critical feedback loops. Coming back to the example of the effect of flood insurance premiums on affordability of housing in the flood zones, more affluent households are less vulnerable for critical feedback loops triggered by an increase in flood insurance.

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## § 2.3 Adaptation

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### § 2.3.1 Adaptation and transformation

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Key to resilience of socio-ecological systems is the ability to adapt or transform the system's key components to deal with changing conditions. Adaptation is commonly regarded as the process of a social-ecological or socio-technical system to improve its resilience, or — to use the ecosystem resilience language— to move a system away from unsustainable conditions. As stated by Pelling (2011), adaptation is creating opportunities for alternative pathways that could lead to different social and socio-ecological futures. Smit & Wandel (2006) define adaptation as individual or collective efforts to increase the resilience of a system by reducing exposure to, or minimizing the impacts of, disturbances. Adaptation actions are usually associated with technological or physical interventions, but it may just as well include social, economic, institutional, infrastructure, and behavioural interventions, such as risk awareness programmes (Pelling, 2011). In many cases, these “soft” interventions that change essential preconditions can be very effective in reducing the consequences of a disaster, particularly when applied in combination with structural adaptation actions.

In some cases, it may be necessary to create a fundamentally new social-ecological system under pressure of changing ecological, social, political or economic conditions (Walker et al., 2004). This is known as *transformation*. Transformation, in the context of socio-ecological systems resilience, is, however, the equivalent of societal collapse: ‘the whole-scale breakdown of multiple institutions characterising a social system’ (Davidson, 2010: 1145). Arguably, within the context of urbanised deltas the collapse of the system is a situation that is to be avoided at any costs. However, processes of transformation on a lower level within the system can be an effective way to enhance the resilience of the system as a whole. As explained in the previous section, the socio-ecological resilience perspective emphasises that resilience emerges from complementary and interacting processes of resilience and adaptation between higher and lower levels of a system and between several subsystems. In this view, cross-scale and cross-sectoral dynamics are essential in producing resilience as an internal property of a system as a whole (Zevenbergen et al., 2008a). These cross-scale interactions of transformation and adaptation are well illustrated by the example of property buy-out programmes that emerged in the US after Hurricane Sandy. These programmes aim to buy-out and relocate private properties from severely flood-affected areas, and transform these areas into recreation or nature. In this case, transformation on a local level is part of a larger adaptation strategy and contributes to the resilience of an urbanised coastal waterfront as a whole.

### § 2.3.2 Planned adaptation

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The capacity of a society to adapt to change is known as *adaptive capacity* or *adaptability* (IPCC, 2007). Walker et al. (2004) define adaptability as the collective capacity of the human actors in the system to manage resilience. Human systems that are able to respond to change quickly are considered to have high adaptability (Smit & Wandel, 2006). The capacity of a society to adapt to change is shaped by its specific spatial and environmental conditions, but also by social, political and economic aspects of society (Smit & Wandel, 2006). For example, the attitude of political and institutional agencies towards climate change will largely determine the nature of measures, the scale of interventions and speed of implementation trajectories. Understanding this interaction between spatial-technical adaptation and underlying social factors and mechanisms such as economic, social, institutional, political, and cultural dimensions of society are essential to ‘move towards a more sustainable development path’ (Pelling, 2011).

Adaptation can result from unplanned and re-active processes triggered by disasters, or they may result from planned policy development processes, based on an awareness that conditions have changed and that action is required to return to or maintain a desired state (Adger et al., 2005a, IPCC, 2007, Carter et al. 2007, Walker et al., 2010). As a rule

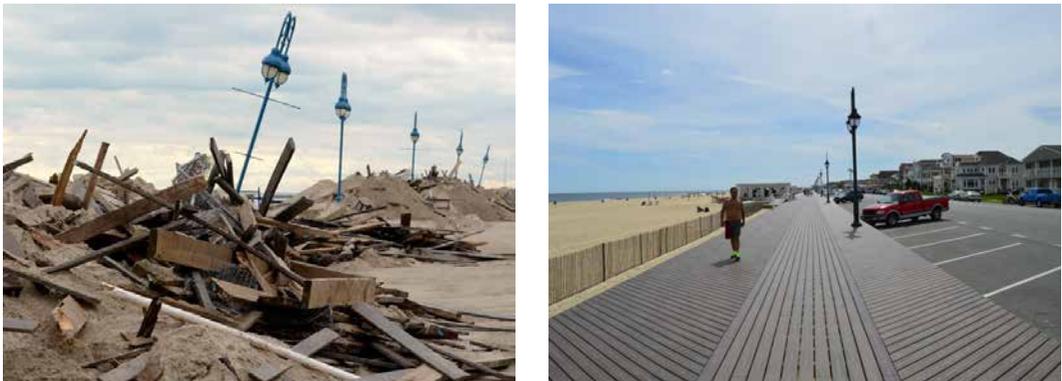
of thumb, spontaneous actions may be effective under conditions of self-organisation and when low-costs adaptation actions are available. Planned adaptation is needed for investment decisions that are irreversible, have long lifetimes and lead-times, and are expensive to adjust or retrofit (Hallegatte, 2009). In addition, there is increasing evidence that inaction would result in unacceptably high losses in the future (Hallegatte, 2009) and that to act now then to suffer larger climate damages in the future is beneficial (Stern, 2007, cited in Haasnoot, 2013). Spontaneous actions and planned adaptation policies may, at best, be complementary and mutually reinforcing. However, it is more likely that in response of a disaster a patchwork of planned and spontaneous adaptation actions is developed in parallel. This may run the risks of an unequal distribution of risks and costs among society, creates adverse socio-economic impacts within different time frames, or trigger other unexpected system responses. Actions that inadvertently increase vulnerability are known as *maladaptation* (Denton et al., 2014). Additionally, many adaptation actions and strategies – whether incremental or planned –, are challenged by path dependencies resulting from conservative policies, cultural values, but also from financial challenges, or rules. These path dependencies may result in incremental adaptation actions that challenges resilience at other levels of the system or moves risk to other places within the system. Also, it may run the risk of a lock-in that results in inertia, less-effective adaptation and higher costs, or less opportunities to couple adaptation actions with other opportunities. Rather than incremental paths, the development of transformation trajectories or pathways aiming at bringing change to established routines is one of the hardest, though most effective approaches in adaptation planning (Pelling, 2011, Davoudi, 2012).

### § 2.3.3 Incremental, transitional and transformative adaptation

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Because the differences between adaptation and transformation can be ambiguous, especially when focussing on lower-scale resilience, it is necessary to explore both concepts in more detail. Pelling (2011) distinguishes three levels of adaptation. In his view, adaptation is a result of processes of *incremental* resilience actions, *transitional* adaptation and *transformational* adaptation actions. Incremental resilience actions aim to improve performance without changing guiding assumptions, rules, or established routines; transitional adaptation actions aim to optimising and improving of current policies, rules and technics, and transformational adaptation actions aim to develop large-scale or radically new trajectories, approaches, techniques and policies. The IPCC (see for example Denton et al., 2014) call the kind of actions that changes the fundamental attributes of a system in response to change *transformational adaptation* as opposite to *incremental adaptation* that aims to ‘maintain the essence and integrity of a system or process at a given scale’ (Denton et al., 2014: 1121). Incremental responses are often referred to as business-as-usual approaches (Fig. 2.3) that focus

on proximity causes (Kates et al., 2012, Denton et al., 2014, Wise et al., 2014), while transformational adaptation, in contrast, involves innovations that contribute to systemic changes (Denton et al., 2014). Incremental adaptation is sometimes also referred to as *restorative* resilience aiming to restore a previous situation, which contrasts with *adaptive* resilience aiming to improve and adapt (Zevenbergen et al., 2010). Because incremental/restorative, transitional and transformational adaptation are difficult to detangle and are often used interchangeably, in the thesis the terms incremental, transitional and transformational adaptation are preferred.



**FIGURE 2.3** Example of incremental or restorative resilience. The 1.3 miles long Belmar Boardwalk along the Jersey coast was almost completely destroyed by hurricane Sandy (left picture: [www.nytimes.com](http://www.nytimes.com)) and rebuilt within 7 months. Rebuilding the boardwalk was, however, not used as an opportunity for improving local flood protection. Right photo by author.

The idea of incremental, transitional and transformational adaptation is closely related to transition science theories on socio-technical system regimes (Geels, 2004, Geels & Schot, 2007). As already briefly introduced in section (2.2.3), a flood risk management system can be described as a socio-technical regime, which is the whole of actors (clients, companies, institutions) that are connected through rules (standards and norms) and social behaviour (learning processes) that interacts with a physical technological system (Geels, 2004). Established regimes transitions can be difficult because of path dependencies, high sunk costs, and regulations and standards, which may force a system to remain in a less-favourable situation or move towards an unsustainable situation (Geels & Schot, 2007). These transformative routes, or pathways may both consist of restorative actions, aiming to restore or slightly improve the performance of the system in anticipation of changing conditions *without* changing policies, rules or standards. Or they can be transitional, aiming to optimise and improve current policies, rules and technics, or transformative, aiming at creating radically new approaches, techniques and policies that transforms the social-technical regime itself. Following the transition theory, 'niche experiments' are needed to develop ways in which the socio-technical en socio-ecological regime may transform (Geels & Schot, 2007).

Although the difference between restorative, transitional and transformational adaptation is not always clear-cut (Kates et al., 2012) and is somewhat academic, it is, in particular, of importance for a better understanding of the mechanisms, constraint and limitations of local adaptation processes. In the next sections, particularly chapter 7, the concepts of incremental, transitional and transformational adaptation will be used to revise the adaptation planning method.

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## § 2.4 Conclusion and discussion

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To conclude, within resilience theory, the resilience of a system can be described as the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control its behaviour (Holling, 1973). Change can be induced by sudden external shocks or through slow gradual changes in environmental conditions. Resilience applied to social-ecological systems can be understood from a focus on resistance or robustness (engineered resilience), a focus on maintaining stability and ability to return back to normal (ecological resilience) and a focus on adaptation and transformation of systems (socio-ecological resilience). The socio-ecological resilience perspective emphasises that resilience emerges from complementary and interacting processes of resilience and adaptation between higher and lower levels of a system and between several subsystems. In this view, cross-scale and cross-sectoral dynamics are essential in producing resilience as an internal property of a system as a whole (Zevenbergen et al., 2008a). Engineered resilience, in contrast, is an effective perspective to assess the resilience (or robustness) of subsystems to withstand and absorb disturbances. This adaptive and transformative perspective on resilience will be used as frame for this thesis, however, for clarification, in this thesis, the term *resilience* is used to refer to the ability of the larger system to bounce back and adapt or transform after disturbance, and *resistance/robustness* as the capacity of a subsystem to deal with disturbances at lower system levels.

### From restorative resilience to transformational adaptation

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This chapter argued that in complex systems in which the natural system interacts with its social, economical and technical (sub) systems, the engineered resilience definition, that is based on bouncing back after disturbance is a too narrow perspective on resilience. Key to social-ecological resilience is the ability to adapt and transform to face changing circumstances (Walker & Salt, 2012). Following his broader definition, it was then concluded that the sustainability of socio-ecological systems is based on processes of resilience (bounce back), adaptation (bounce forward) and transformation (systemic change).

Adaptation actions can be incremental, aiming at improving the attributes of a system but maintaining the status quo, be transitional by solving the proximity causes of vulnerability, or transformational, aiming on fundamentally changing the attributes of a system and solving root causes of vulnerability. These processes of adaptation and transformation, however, are scale-dependent: processes that built resilience and adaptation operate and interact at different levels of scale. Transformative adaptation actions on a local level may be part of an adaptation process that increases the resilience of a larger subsystem or the system as a whole. In this thesis the resilience-adaptation-transformation framework is used, in which resilience is a product of four capacities:

- 1 The capacity to cope with small disturbances within the systems natural variation;
- 2 The capacity to recover from extreme situations and return to equilibrium after a certain period of time;
- 3 The capacity to adapt to deal with slowly changing environmental conditions and large disturbances and,
- 4 The capacity to transform when adaptation is no longer an option and the system is forced to shift into another stable situation with a higher level of resistance.

### Resilience as change of perspective

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It is important to state that these different perspectives on resilience should not be seen as conflicting or mutually exclusive conceptual models, but rather as complementary perspectives that can be applied depending on the scale on which resilience is examined, or depending on the extent to which the complexity of the system is taken into consideration. More importantly, it is worth bearing in mind there is not a single resilience concept. Resilience is more 'like a landscape of ideas' (Pelling, 2011:123). Furthermore, resilience is rather about a change of perspective from a desire to 'control change in systems that assumed to be stable, to manage the capacity of socio-ecological systems to cope with, adapt to and shape changes' (Berkes et al., 2003, cited in Folke, 2006). Key to the resilience perspective is a willingness to understand the complex behaviour and the underlying mechanisms that steer systems towards sustainable states. However, following this line of argument, planning for resilience implicitly assumes that we know, or can define, the boundaries of unsustainable or unstable states. Or, to be more precise, that we know – with some precision – the position of critical tipping points of complex systems. One key question that remains, however, is whether we are able to define these unsustainable (or unstable) states in complex urban conditions. And does the concept of tipping points offer enough guidance for strategic adaptation planning? Secondly, a question that arises is how to judge whether a process of adaptation is successful in adapting and shaping systems towards a more sustainable, better future? Success in adaptation planning is mainly limited to an assessment of its effectiveness to reduce the

vulnerability of coastal waterfronts to changing conditions or its direct economic values generated. Can we define other, more comprehensive indicators of success?

In the next chapter the focus will be on these two questions. This chapter aims to answer how to make the socio-ecological resilience concept applicable for the long-term planning of urbanised deltas or coastal waterfront areas under stress of climate change.



# 3 Planning for adaptation

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## § 3.1 Can we plan for adaptation?

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As argued in the previous section, resilience is an emergent feature of complex systems that results from cross-scale and cross-sectoral interacting processes on various system levels. Resilience of human-natural systems, such as urban coastal areas, is, however, based on capacities to resist to, cope with and recover from disturbances *and* capacities to adapt to social, environmental, technological change. Resilience can thus be considered as an inherent feature of complex systems that is produced by complex interactions of resistance, adaptation and transformation on lower and higher level system scales. However, both unplanned incremental adaptation and planned adaptation may run the risk of lock-ins and adverse affects to other system elements. Thus, an essential part of adaptation planning is to develop strategies that move systems to more sustainable futures. Adaptation can be understood as a system's transition that is limited by its regime, defined as the whole of "rules and norms" and institutional structures that governs a socio-technical system (Geels, 2004). Changing these regimes is, however, difficult and adaptation pathways should therefor both consists of incremental actions, aiming to improve performance without changing the policies, and transitional or transformational adaptation actions that are aiming to optimise and improve current policies, rules and technics, or creating radically new approaches, techniques and policies. The question is what planning methods are able to support planned adaptation and the development of these adaptation trajectories or strategies.

The common decision-making process to plan for an uncertain future is based on predicting of a future state (or multiple states) and the design of plans or projects for the conditions of that state (Hallegatte et al., 2012). In scenario-based planning approaches, scenarios are used to analyse the effect of plausible futures on short-term decision-making processes and prepare adaptation strategies for the conditions of that state (Walker et al., 2010, Hallegatte et al., 2012). Approaches that have been developed include scenario planning, exploratory scenario planning and backward planning, or back casting, in which a preferred future state is defined and used to identify operational goals backward to the present situation (Hooimeijer et al., 2001). These approaches share an assumption that the future, although uncertain, can be explored through developing potential futures based on extrapolations of past long-term trends. A scenario describes a future perspective based on an assumption of

several key variables that changes independently. Scenarios can be quantitative, based on story lines, or qualitative, based on system models (Kok & van Vliet, 2011). Usually one of these futures is chosen as the most probable future, “best guess” or “central estimate reference” to which the plan is designed (Haasnoot, 2013). Plans are selected to achieve the most optimal performance – usually the most cost-beneficial solution – within the range of change explored in the scenarios. However, a main limitation of these “predict-then-act” planning approaches is their inability to predict complexity behaviour of urban systems and dynamic interactions between the components of a system (Haasnoot, 2013). Additionally, a limitation of these planning approaches is their vulnerability for unexpected changing conditions. When underlying assumptions of the scenario-based strategy or plan are changing, continuously adaptation of the strategy or plan is necessary (Jeuken & te Linde, 2010). In particular for the planning of adaptation strategies for complex systems in a context of many social, physical and technical uncertainties, scenario-based planning lacks the ability for dealing with dynamic conditions.

Both in the field of spatial planning, corporate management and ecological resources management, resilience-based planning and management approaches have been developed. These methods take as starting point a process of continuous learning and adapting (Rosenhead, 1980a). In the next sections the question: ‘can we plan for adaptation’ is centre stage. First, a brief overview of resilience-based and adaptive planning approaches is presented that can be considered the precursors of adaptive planning (section 3.2). Then, based on an assessment of the risk frame the relation between vulnerability and resilience is elaborated and used as a frame to define tipping points in coastal flood resilience. This section is then followed by an introduction and evaluation of the Adaptation Tipping Point (ATP) method and the Adaptation Pathway (AP) method (section 3.3 and 3.4), and criteria for defining successful adaptation are addressed. Finally, this chapter will conclude with a discussion and some critics on the proposed methods. The ATP and AP method will be used to evaluate and develop sustainable adaptation strategies for improving flood resilience in two cases in Rotterdam, which are introduced in chapter 7.

## § 3.2 A brief history of adaptive planning approaches

### § 3.2.1 Adaptive management

In ecological systems management the concept of adaptive management arose in conjunction with the development of the concept of resilience (Walters, 1986, Walker & Salt, 2012). Adaptive management, in its simplest form, is treating policy development as a continuous learning experiment, in which hypotheses on responses of a system to an intervention are tested and learned from, in order to improve the policy and achieve a desired goal (Lessard, 1998, Walker & Salt, 2012). Policies and management strategies are formed on the way by systematically comparing and evaluating interventions and establishing a sequence of practices that has proven to positively influence a system towards an agreed future state (Pahl-Wostl, 2007). Basically, adaptive management is an effective policy development strategy to unravel cause-and-effect relationships of complex systems since experimenting provides a better understanding of the system's behaviour and its reaction to interventions (Lessard, 1998). Adaptive management helps to 'reveal processes that build or sustain resilience (Folke, et al., 2002: 439)'. Rather than defining a desired end-point state, central to adaptive management is the focus on defining policy objectives and the definition of critical thresholds that should trigger an adjustment of the policy. Adaptive management methods, therefore, are not focused on developing an "optimal" plan, which is predominantly the case in more rational planning approaches, but are focusing on developing a feasible intervention strategy (Rosenhead, 1980a). In urban planning this approach became known as *incrementalism*, which refers to policy development practices that result from a chain of decisions and interventions, based on a learning and adjusting process, where in earlier decisions and policy objectives are continuously monitored and reconsidered (Rosenhead, 1980a).

Although there is a wide range of methods and procedures developed over the years, adaptive management based approaches are all based on crafting a policy by (1) defining clear policy objectives at the offset of a policy development project, (2) identify policy interventions that are implemented when (3) specific trigger values are reached (Walker et al., 2010). The method is iterative: by evaluating the effectiveness of interventions to achieve the predefined objectives the policy interventions can be adapted, or the policy objectives can be reviewed to better reflect the realities of a complex system. Note that the trigger values mirror the concept of tipping points or thresholds in the resilience theory. A critic of the adaptive management approach is its inability to differ between more strategic and more operational interventions (Rosenhead, 1980a). An improvement of adaptive management method, known as

*mixed scanning*, is based on distinguishing between ‘more fundamental decisions, which set the basic directions of policy, and incremental decisions, that prepare for, or work out consequences of fundamental decision in more detail (Rosenhead, 1980a: 212)’. Within this approach, flexibility is gained through the ability to perform a wide initial search for alternative policies, without losing time by analysing these alternatives in depth. Once the fundamental decisions are defined, incremental decisions follow from the decisions that need to be taken to implement the fundamental decisions. The analyses of the feasibility of incremental decisions, determine the necessity of returning to higher level of fundamental decisions. This approach can be seen as an improvement of the comprehensive rational approach (Rosenhead, 1980a), but it is still based on a narrowing down of options and deliberately ignoring system dynamics.

Although, methods of adaptive or incremental management are effective in terms of adjusting a system to changing conditions or reacting on events as they unfold, one of the more profound criticisms is that the planning process is based on ad-hoc decision-making and therefore lacks a long-term strategic component, making incremental or adaptive methods only effective within non-turbulent or well-defined conditions, or in small-scale systems (Rosenhead, 1980a). Moreover, adaptive management is likely to fail in case of surprises and discontinuities in system responses (Dessai & van de Sluijs, 2007). When applied to social systems, adaptive management is criticised for its inability to deal with social or political aversion towards the experimental aspect of the management process (Pahl-Wostl, 2007). Moreover, in complex social systems it has proven very difficult to define critical thresholds and to define acceptable results (Lessard, 1998). In addition, adaptive management seemed to have failed to function effectively because of rigid existing governance structures (Walker et al., 2004).

### § 3.2.2 Robust planning

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As a reaction on the deficiencies of adaptive management and mixed scanning planning methods, new planning methods were developed that are based on systematically exploring future conditions and test the robustness of strategies within the uncertain scope of possible futures, enabling a more strategically response to long-term changing circumstances. Approaches that take deep uncertainty as their starting point are known as *robust* planning approaches. Robust planning is based on systematically selecting strategies or decision options that are able to perform adequately across a wide range of future and uncertain conditions (Lempert et al., 2013, Ranger, 2011, Hallegatte et al., 2012). Robust planning is particularly effective when investments are long-lived, come with high sunk costs and are sensitive for deep uncertainty – as is for example the case in infrastructure planning—or when there is deep uncertainty on future conditions (Dessai & van de Sluijs, 2007, Reeder & Ranger, 2011, Haasnoot et al., 2013).

One of the well-known approaches within robust planning is Robust Decision-Making (RDM). RDM is based on identifying policies or decisions that work under the widest range of scenarios. RDM is particularly applied to assess the robustness of large-scale investments based on an evaluation of the sensitivity of investment decisions to future trends. Note that RDM is not seeking for an optimal (in the sense of most beneficial) strategy or plan, as would be the case in traditional planning approaches, but strives for robust investment decision or strategies that are likely to perform under the widest range of potential futures (Lempert et al., 2013). A crucial part of the method is to define the 'uncertainty space' (Dessai & van de Sluijs, 2007:42) and an assessment which strategy within that space is successful in meeting the objectives. *Decision robustness* refers to the sensitivity of policies, strategies and strategic decisions for external changes and disturbances (Rosenhead, 1980a). So, a crucial part of robust planning is finding the sensitivities of decision options or strategies to certain conditions. Robust planning, however, still ignores the dynamic character of systems, and, more importantly, it ignores that adaptation decisions itself influences the behaviour of the system at large. In this sense, Walker & Salt (2012) distinguishes between *static* robustness that aims at reducing vulnerability in the largest possible range of conditions, and *dynamic* robustness that aims at developing flexibility to change over time in anticipation of changing conditions. The latter is related to conditional planning and adaptive policy making approaches that are introduced in the following sections.

### § 3.2.3 Conditional planning

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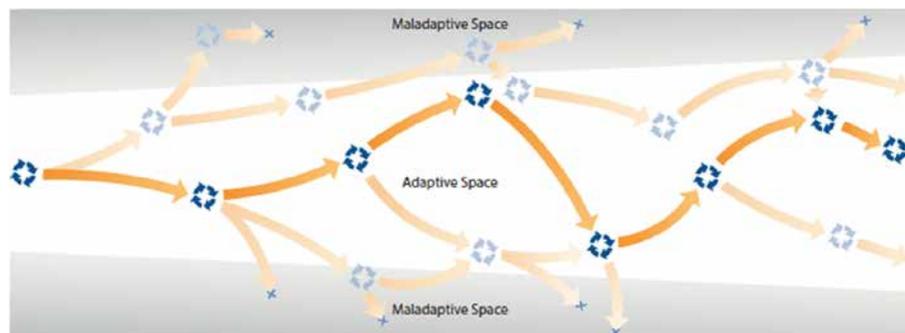
Robust planning is related to *conditional planning* that has its roots in artificial intelligence science. Conditional planning, also known as *contingency* planning, is based on anticipating on future conditions by developing sequences of decisions, which are held open until more accurate predictions can be made (Strangert, 1977). Conditional planning approaches 'takes as its aim not optimization, nor simply adaptive responsiveness, but "keeping options open" (Rosenhead, 1980a: 213)'. Keeping options open can be achieved through avoiding or delaying inflexible decisions in anticipating of better information (Ranger, 2011), and to select strategies that allow options to change to alternative or complementary measures or strategies (Haasnoot et al., 2013). Conditional planning is based on exploring the range of future conditions and by the identification of future decision points (Strangert, 1977). These future decision points must be considered as predefined trigger values that indicate the conditions under which it is necessary to change to alternative measures or strategies or to implement actions that mitigate negative effects of the decision (Haasnoot et al., 2013). Decisions that allow keeping options open for future decisions show a higher level of robustness (Rosenhead, 1980b). Note that these decision points in conditional planning are related to the concept of tipping points or thresholds in the resilience

concept, in the sense that tipping points can be interpreted as the ultimate decision points for adaptation or transformation. Constant observation of decision points and the reconsideration of earlier developed strategies is an essential part of conditional planning. In this sense, conditional planning introduces a structured approach to a dynamic and iterative process of constant learning and adapting.

### § 3.2.4 Adaptive Policy Making (APM)

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As a practical application of the conditional planning, the concept of adaptive planning or adaptive policy-making emerged. Adaptive planning is built on the premise that managing complex systems for long-term change comes with many uncertainties and a change of policy “on the way” is inevitable. This means that policy making should deliberately incorporate the ability to change into policies. Policies that are robust across a wide range of plausible futures should be favoured over optimal strategies. This contrasts with the traditional planning approach that aims to develop an optimal plan for a single best estimated future (Hallegatte et al., 2012). Walker et al. (2001) were one of the first that developed a systematic framework for adaptation planning based on defining specified conditions (signposts and triggers) under which the policy should be reviewed and the development of actions that mitigate adverse effects or seize opportunities of the policy. Adaptive policy making has been applied to several long-term strategic planning problems (Walker et al., 2013) and the method have proven particularly effective in ‘providing a powerful and flexible analytical approach for decision makers in relatively closed, high reliable systems that are largely amenable to technical solutions’ (Wise 2014:330).



**FIGURE 3.1** Adaptive policy making based on selecting sustainable paths towards the future. The blue circles represent decision points where corrective actions or new policies can be developed to manage the system away from maladaptive spaces. Note that the grey area represents a non-sustainable situation. Crossing this line is comparable to a tipping point in the resilience theory. Picture from Wise et al. (2014).

This approach is closely related to the idea of adaptation pathways that emerged in climate adaptation literature (see section 3.4). An adaptive pathway is a policy response to a major shock or slow environmental change, with the aim of managing a system towards a sustainable future, or away from non-sustainable futures. Adaptive pathways are also known as transition pathways (Pelling, 2011), Flexible Adaptation Pathways (Rosenzweig et al., 2010) or route maps (Reeder & Ranger, 2011) and share roots with concepts from the transition theory literature (see Geels & Schot, 2007). The IPCC uses the term climate resilient pathways (Denton et al., 2014), which are defined as 'development trajectories that combine adaptation and mitigation to realize the goal of sustainable development (p: 1104)'. All of these concepts share the idea that under deep uncertainty it is better to develop a path towards a sustainable future, while avoiding lock-in situations arising from incremental developments and to keep as much options open. This can be achieved through 'building flexibility into the overall adaptation strategy (rather than into the individual actions) by sequencing the implementation of actions over time' (Walker et al., 2001) allowing adapting to future conditions as they unfold. **Fig. 3.1** illustrates the main elements of the concept of adaptive pathway planning. Adaptive pathway planning requires (1) to identify key 'triggers' (Walker et al., 2001) that act as warning signals of the system moving towards an unsustainable or maladaptive state and (2) to identify decision points in the future where (3) corrective actions can or need to be implemented. These corrective, – or better: contingency actions –, both aims at improving the performance of the initial plan, or focussing on taking advantage of opportunities that arise, and actions that trigger a total reassessment of the plan itself. These contingency actions resemble the previously made distinction between incremental, transitional and transformational adaptation. The dynamic part of the method allows anticipating on new opportunities that arise. A key element in adaptive pathway planning is monitoring. Monitoring entails both keeping an eye on changing conditions that might delay or advance decision points in time, and monitoring the performance of the plan itself to deal with these changing conditions (Walker et al., 2001, Walker et al., 2013).

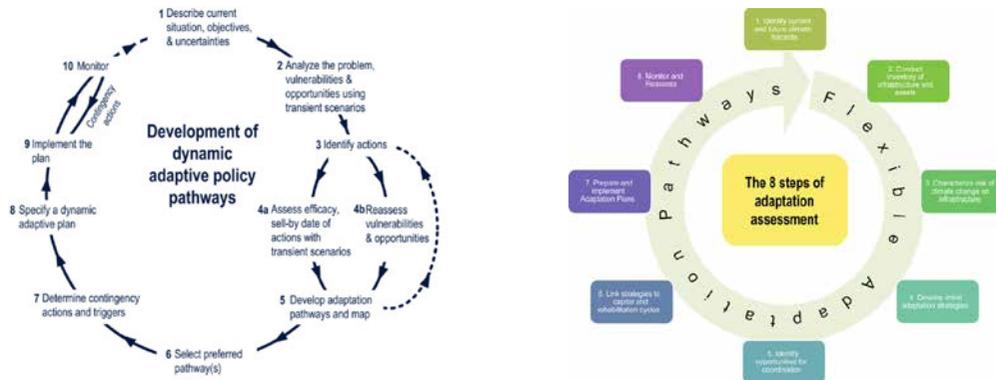


FIGURE 3.2 The Adaptive Policy Pathway method (Haasnoot et al., 2013) and the flexible Adaptation Pathways method (Rosenzweig et al., 2010).

Although there are multiple variations and differences these adaptation policy or planning methods (Fig. 3.2) basically consists of the following steps:

- 1 Defining the system and analysing existing conditions;
- 2 Define policy objectives;
- 3 Analyse when a system reaches the boundaries of resilience
- 4 Find the moments in time when adaptation is needed, based on an assessment of scenarios describing possible futures;
- 5 Define adaptation options and develop adaptive strategies
- 6 Assess adaptive strategies on financial, organisational and institutional constraints, lock-ins, and opportunities;
- 7 Define contingency actions;
- 8 Implement strategies
- 9 Monitor and review.

### § 3.2.5 Conclusion: system-based and adaptive

Although there are a variety of adaptive management and planning methods, all of these methods share some similarities. All of these methods are system-based, in the sense that they take critical system vulnerabilities as a starting point to develop a portfolio of adaptation interventions to manage a system towards a more sustainable, or resilient future. Additionally, a key element that can be found in these adaptive based approaches is a focus on monitoring, learning on the way and continuously adapting the strategy when conditions change or when the plan does not perform as expected. As stated by Reeder & Ranger (2011:10): ‘the effectiveness of the final plan depends on a continuing process of regular review’.

Finally, an important advantage of these adaptive approaches is that they are “scenario neutral” (Reeder & Ranger, 2011) meaning that decision-making is independent of the likelihood of scenarios. Rather, scenarios are used to evaluate the “timing” when conditions are crossed under which the policy should be reviewed and predefined adaptive actions need to be implemented. Central to adaptive planning method is to understand the sensitivity of a system to change rather than to assess the potential effects of the most likely scenarios (Jeuken, & Te Linde, 2011). This approach requires understanding the limits of resilience of a system and, more importantly, understanding the “rules” of agents to explain the emergent behaviour of the system as a whole. Additionally, this system-based approach requires clearly defining policy objectives to be met by the plan or strategy and the assessment of effectiveness of interventions at the offset of a policy-making process.

Although the idea of adaptive planning and adaptive pathways is well established in the climate change discourse, until now it remains a conceptual metaphor to describe the dynamic process of anticipatory adaptation over time. However, within the realm of urban storm water management and flood risk management, resilience-based planning methods have been developed that help to dynamically respond to changing circumstances. These methods, the Adaptation Tipping Point (ATP) method and Adaptive Pathways (AP) Method have been applied and empirically tested in several cases. Kwadijk et al. (2010), Gersonius (2012), Haasnoot (2013), Werner et al. (2013), and Jeuken et al. (2014) show examples of application ranging from retrofitting urban drainage system to assessing key priorities for adaptation on a water system or national scale. In the next sections (3.3 and 3.4) these methods will be introduced in more detail.

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## § 3.3 Adaptation Tipping Point (ATP) and Pathway (AP) Method

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### § 3.3.1 Tipping points: understanding the boundaries of resilience

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To effectively incorporate resilience into urban design and planning of coastal waterfronts it is necessary to understand under what conditions the system is no longer able to recover and needs to adapt. In other words, it is necessary to understand what the boundary limits of resilience are and, additionally, to what future states the system preferably should develop. This brings us to the question how to define the boundary limits of resilience and criteria to describe sustainable or successful adaptation. As explained in the previous section (2.3), within resilience theory, the resilience

of a socio-ecological system can be described as the capacity of a system to absorb disturbance as well as the capacity to *re-organize* while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al., 2004). The maximum perturbation that cannot be tolerated without structural change is called a *tipping point*. Thus, to manage resilience it is important to identify the key *variables* that determine the significant changes in the system and to explore the position of its tipping points and translate these tipping points to limit values (Walker & Salt, 2012). The question is whether the concept of tipping points can be applied to define the boundary limits of resilience of coastal urban waterfronts.

### § 3.3.2 Resilience related to risk and vulnerability definitions

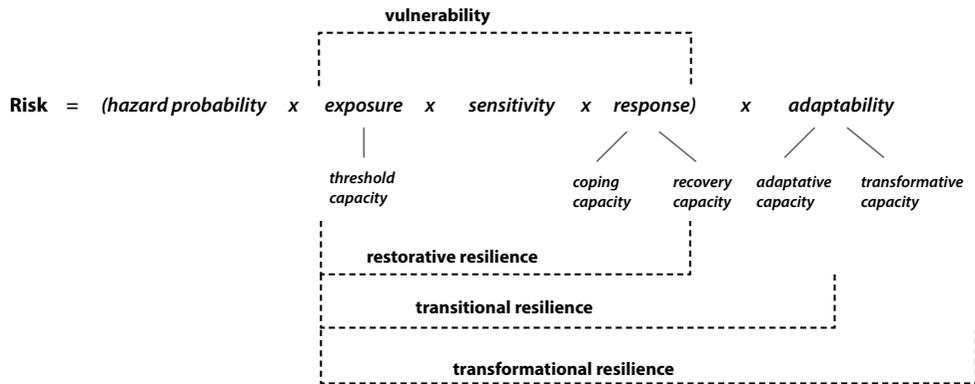
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The resilience of a system is sometimes conceptualised as the opposite — or flip side— of vulnerability. There is an on-going debate on the differences and similarities of vulnerability and resilience (see for an overview Miller et al., 2010). Vulnerability is broadly defined as the sensitivity of a system for hazardous events. The IPCC (2007:6) defines vulnerability as ‘the degree to which a system is susceptible [or sensitive] to, and unable to cope with, adverse effects of climate change [...]’. Smit & Wandel (2006) adds to this definition the element of recovery. They note that ‘the vulnerability of any system (at any scale) is a function of the exposure and sensitivity of that system to hazardous conditions and the ability of the system to cope or recover from the effects of those conditions (*idem*: 286)’. In this thesis we follow their view and define vulnerability as the function of exposure, sensitivity and response, in which:

- Exposure = the size and characteristics of the exposed system
- Sensitivity = the potential for loss
- Response = the extent to which systems are able to cope with and recover from disturbances

How does the vulnerability definition relate to the earlier introduced resilience definitions? The degree to which a system is able to influence exposure to, or its sensitivity for a hazardous event can be understood as incremental (or restorative) resilience (see section 2.2.2) that understands resilience as the ability to deal with disturbances and return to a previous state. Within this narrow definition, resilience is indeed understood as a counterpart of vulnerability. However, as introduced in section 2.3 socio-ecological systems are able to adapt and transform in face of changing conditions. This adds a new element to the definition. Systems that show a high level of adaptive capacity may improve the systems ability to reduce exposure, through building a higher threshold, and to reduce its sensitivity by improving its coping and recovery capacities. This follows de Graaf (2009) who distinguishes between

four capacities that define vulnerability: the threshold (or buffer) capacity, coping capacity, recovery capacity and adaptive capacity. A limitation of this understanding of vulnerability is that it aims to integrate aspects that describe the current vulnerability of a system with aspects that influence the evolution of a system towards a more adapted, less vulnerable future.



**FIGURE 3.3** Relations between definitions of vulnerability, risk, resilience and adaptation concepts. Resilience is a function of five capacities: threshold capacity, coping capacity, recovery capacity, adaptive capacity and transformative capacity

As illustrated in **Fig. 3.3**, the combination of hazard probability, exposure and sensitivity defines the level of risk of a system. Incremental (restorative) resilience is based on the threshold, coping and recovery capacities to “bounce back to normal”, whereas transitional or transformational resilience is based on structurally adapting or transforming critical system elements to reduce exposure to and sensitivity of, or improve the response capacity of systems. Thus, to measure resilience it is necessary to find a system’s threshold, coping, recovery and adaptive (or transformative) tipping points.

Hazard probability can be assessed by the frequency and severity (or probability of occurrence) of an adverse event. For example in flood risk management, the probability of occurrence of a severe storm surge can be determined using complex flood models. The exposure to risks is typically examined through an assessment of the amount of people or assets affected by flooding based on projections of existing or expected sea level rise related to the elevation level of urban areas or critical thresholds of flood protection systems (Brooks, 2003). The sensitivity of urban assets to flooding is usually expressed in flood damages or individual losses. Changing social and economic

conditions may increase a system's sensitivity; similarly, regulations that change land use to low intense use may decrease the impact of flooding (Tobin & Montz, 1997).

### Buffer capacity

The *buffer* capacity — also referred to as threshold capacity (de Graaf, 2009) or resistance capacity (Mens et al., 2011) — is defined as the ability of a system to built a threshold to natural variations within the system. Because threshold is somewhat an ambiguous term — in property flood protection literature it may also refer to the critical flood entry point — in this thesis buffering capacity is preferred. The buffering capacity is to create a “safe operating space” (Walker & Salt, 2012) of a system. Buffering capacities are generally applied in systems that are designed to deal with natural variations such as sewer systems or an elevated urban waterfront. In general, in governed infrastructures or engineered systems the buffering capacity is well defined and serves as a quantitative performance indicator to which the system is designed or managed. Applied to the resilience of urbanised deltas to flood risk, the buffer capacity is the ability to prevent a flood from occurring within the normal natural variations of a river or coastal system. This is usually achieved by developing flood prevention such as floodwall, embankments and elevating building lots, or by lowering the water level through upstream interventions. The buffer capacity of the system can be defined as its ability to let discharge waves or storm surge pass without causing floods or without exceeding the system performance criteria (Bruijn, 2005). In flood risk management the buffer tipping point is in general well defined and can be quantified by the return period of the highest flood level that is associated to the flood protection level (Jeuken & te Linde, 2011).

### Coping and Recovery capacity

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In resilient systems the point of no recovery acts as reference point to where transformation to undesirable system configurations will occur (Renaud et al., 2013). This ‘recovery tipping point’ is defined as the point when disturbance exceeds the system's ability to cope with, and recover from disaster. Obviously, within the context of urbanised deltas, reaching a recovery threshold on the system level is undesirable and all efforts will aim to prevent this situation. However, on lower system levels the coping and recovery tipping point can be assessed and used as reference for adaptation planning.

The recovery tipping point builds on the coping and recovery capacity. The *coping capacity* is defined as the ability of a system to deal with the consequences of a situation that exceed the buffer capacity. In flood risk management, this translates to avoiding or minimizing loss in case the protection system fails. The concept of coping originally derives from disaster management and development studies as a concept in explaining social responses to environmental stress and shock (Pelling, 2011). Coping

ranges, in its original meaning, are the normal variables or disturbances that a system can accommodate and recover from (Smit & Wandel, 2006). Specifically, in flood risk management, coping relates to the ability of a system to reduce or deal with the consequences of a flood (de Graaf, 2009). Coping can be achieved through emergency planning, early warning systems and the adoption of flood resilience measures to reduce the damage to the building fabric and its contents.

The coping capacity is closely related to the *recovery capacity*, which refers to ‘the capacity of a society to recover to the same or to an equivalent state as before the disaster (De Graaf, 2009: 23)’. As defined by Walker et al. (2004) the recovery capacity is the maximum amount a system can be changed before losing its ability to recover. Recovery involves repairing infrastructures, reconstructing buildings and cleaning activities. As the difference between coping and recovery capacities is somewhat ambiguous — coping includes damage control during an emergency and recovery after an emergency—, in this thesis it is preferred to use the term recovery to indicate the whole range of coping and recovery activities.

Many sources (Smit & Wandel, 2006, Mens et al., 2011, de Graaf, 2009) stress that the recovery capacity of a society is determined by factors as the economic (e.g. the ability to finance reconstruction), social capital (e.g. the ability to organise and manage reconstruction), the institutional and political environment and the specific geographical and urban conditions. In addition, the level of acceptable risks (Tobin & Montz, 1997) is balanced between the perceived level of risk and the perceived benefits, or costs of reducing the risks. For example, the costs and annoyances of recurrent flooding of waterfront locations may be balanced against the benefits of the waterfront location. Consequently, the coping and recovery capacities of social systems are difficult to quantify due to the many factors that affect recovery (Pelling, 2011). The question can be raised if such a recovery threshold can be found with any given certainty or be assessed empirically *ex ante*.

### Adaptation Tipping Point

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To overcome this problem, in social-technical or socio-ecological systems it is probably more effective not to focus on defining the system recovery tipping point but to identify the conditions under which the current development trajectory is no longer sustainable and adaptation is needed. Walker & Salt (2012) describe some case studies where the notion of “thresholds of potential concern” (TPC) proved to be a helpful tool. TPCs are basically a set of operational goals within an adaptive management approach that are continually monitored in response of new information and changing policy objectives. Kwadijk et al. (2010) argue to focus on the boundary conditions under which a current policy will no longer be able to meet the political or societal *objectives* and adaptation is needed. This threshold is known as an *Adaptation Tipping Point* (ATP) (Kwadijk et al., 2010, Jeuken & te Linde, 2011). Tipping points, in this context, do not necessarily coincide with a radical change in the behaviour of the system, as it is in ecological system science definition, but

refer to a situation where political or societal objectives prove no longer to be attainable, under pressure from changing conditions. It is important to realise that ATPs within this definition are subject of changing societal perceptions, values and political processes. It is also important to note that an ATP is different from a decision point. A decision point, at best, is planned prior to the attainment of an ATP in order to provide sufficient planning and lead-time necessary to implement a new strategy. Assessing the timing of adaptation is, however, important to prove political urgency for adaptation (Jeuken & te Linde, 2011). Defining the limits to adaptation requires knowing the level of risk associated with climate change that is socially acceptable (Pelling, 2011) and the level of opportunities that emerge from adaptation. Thus, to define ATPs it is necessary to analyse societal perceptions to flood risk, adaptation opportunities and institutional structures that influences recovery and adaptation.

PHASES	CONDITIONS	SYSTEM REACTION	CAPACITY	TIPPING POINTS
Resistant phase	Natural variation	system does not react at all	buffering capacity	Buffer tipping Point
Recovery phase	Extreme situation	system returns to equilibrium	Coping and recovery capacity	Recovery Tipping Point
Adaptive phase	slow environmental change and disaster	system returns to equilibrium with adaptation	Adaptive capacity	Adaptive Tipping Point
Unstable phase	slow environmental change and disasters	System turns into another stable situation	Transformative capacity	Transformative Tipping Point

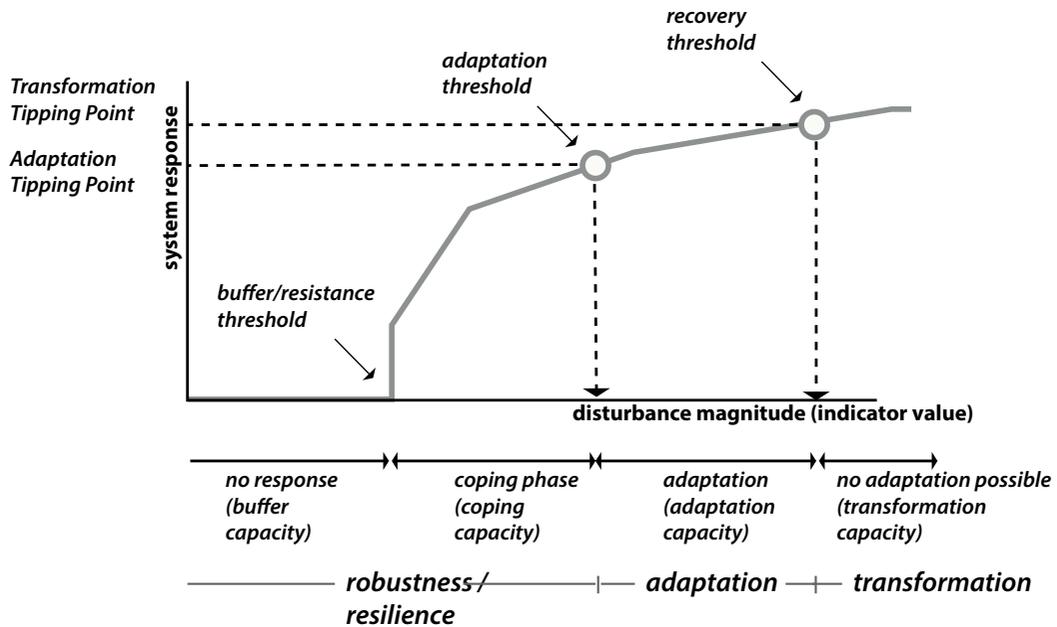
TABLE 3.1 Relation between phases of resilient systems (Gunderson, & Holling, 2002) natural conditions, system reactions and capacities (de Graaf, 2009), and tipping points (de Bruin (2005).

### § 3.3.3 Adaptaton Tipping Point (ATP) method

The ATP method, as develop by (Kwadijk et al. (2010) and improved by Reeder & ranger (2011) and Jeuken & te Linde (2011) is a systematical approach based on understanding the magnitude of change that a system is able to absorb or deal with and assessing the conditions under which it is necessary to move to other strategies (Jeuken & te Linde, 2011). The method is based on the following steps:

- 1 Define the system boundaries and its component that are under review;
- 2 Define policy or societal objectives;
- 3 Define indicators and thresholds for the policy objectives;
- 4 Translate indicators and thresholds to Adaptation Tipping Points;
- 5 Introduce time aspect based on climate scenarios;

- 6 Select effective adaptation actions;
- 7 Assess effectiveness of selected adaptation measures through assessment of step 4 and 5.



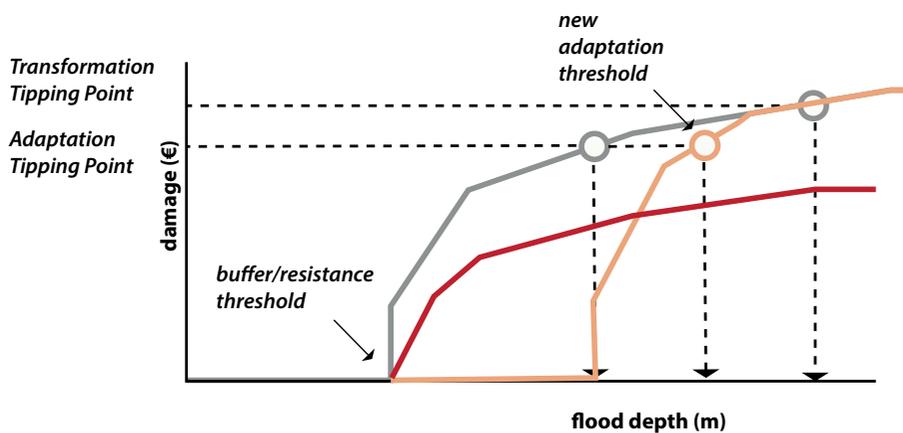
**FIGURE 3.4** Adaptation tipping point (ATP) as a function of the maximum disturbance magnitude and system response under which a current policy will no longer be able to meet the political objectives and need to adapt. Note that the recovery threshold is difficult to quantify and the ATP acts as a substitute threshold that triggers adaptation actions. Picture adapted from Mens et al. (2011)

As shown in **Fig. 3.4**, an ATP can be assessed through defining a performance indicator related to a key variable of concern and the definition of a threshold that acts as a quantifiable value that helps to identify and monitor the critical moments of change (Kwadijk, et al., 2010). This performance indicator can be physical (e.g. a critical flood level), financial (e.g. maximum costs of flooding) or social (amount of households affected) or a combination of these (Kwadijk et al., 2010). Applied to urbanised delta areas, a key variable of concern could be increasing flood risk, which negatively influences a performance indicator (e.g. maximum acceptable flood damages). This key performance indicator can be translated to a limit value (maximum flood level or probability exceedance level) that acts as performance threshold value. The performance indicators are usually determined by norms or design standards but can also be derived from general policy objectives or societal values (Jeuken & te Linde, 2011). Once these ATPs and associated performance indicators and limit values are defined, they can be related to scenarios to find the moment in time that a system

reaches its ATP and adaptation is necessary. This moment in time is, most likely, more of a bandwidth depending on the amount of uncertainty of change and will change when scenarios are updated. Finally, adaptation actions are selected based on the effectiveness to influence the ATP or reduce the vulnerability (Fig. 3.5) and other criteria, such as opportunities for creating co-benefits and added values.

**EXAMPLE OBJECTIVES, INDICATORS AND THRESHOLDS APPLIED TO PLUVIAL FLOODING, BASED ON THE ROTTERDAM CLIMATE CHANGE ADAPTATION STRATEGY (ROTTERDAM, 2013)**

<b>A – Policy objectives:</b>
'The city and its inhabitants experience minimal disruption from too much or too little rainfall (Rotterdam Adaptation Strategy)'
<b>B – Performance indicator:</b>
'no flooding of buildings or power outages that exceed 1/100 year cloud burst event is accepted'
<b>C – Performance requirements (limit value):</b>
'the threshold for this flooding is a 30 cm flood depth'

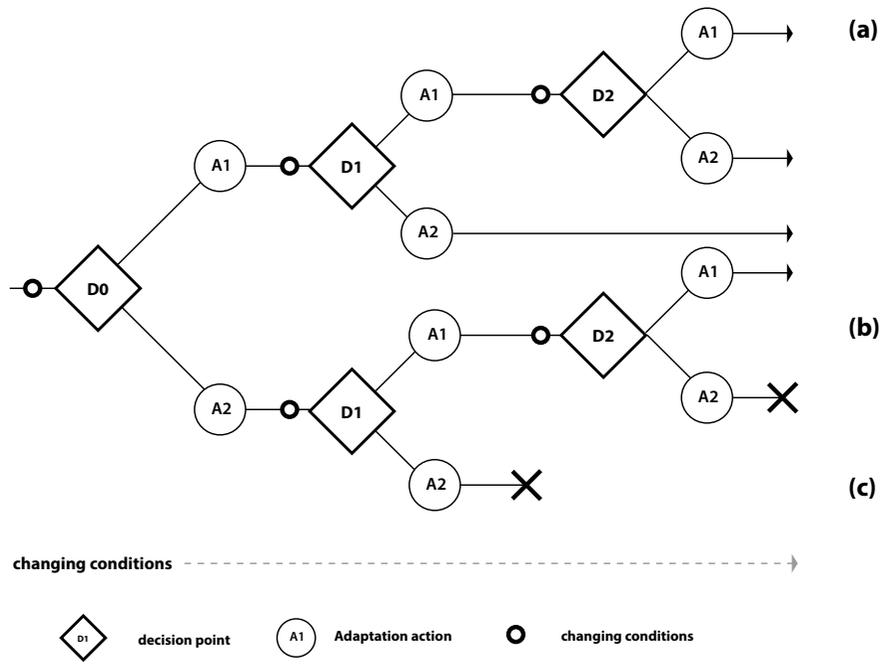


**FIGURE 3.5** Example of a depth/damage profile showing the existing thresholds and new thresholds based on two flood reduction interventions. Adaptation thresholds can be influenced by creating a larger buffer threshold (orange line), for example by enlarging a flood wall, or by reducing the sensitivity of the urban system (red line), for example by flood proofing urban assets making it more difficult for a system to reach the adaptation tipping point.

### § 3.3.4 Developing adaptive strategies: Adaptation Pathway Method

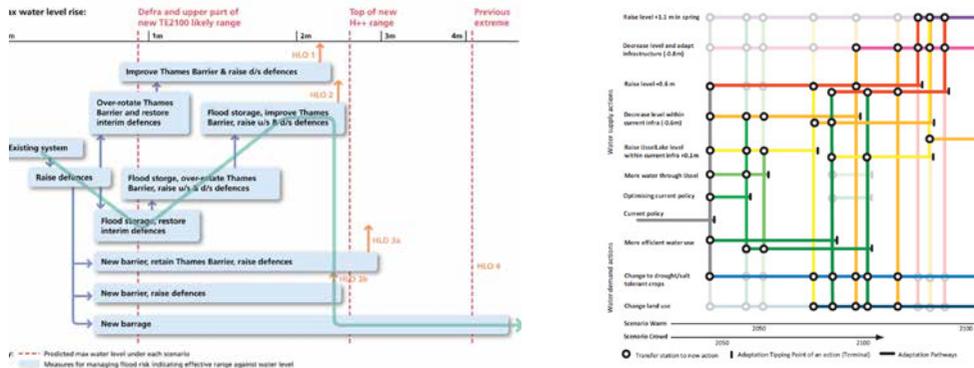
The adaptive pathway (AP) method is an analytical approach for exploring and sequencing a set of possible actions that enables policy makers to explore options for adapting to changing environmental and societal conditions in time (Haasnoot, 2013). The method builds

upon the ATP method but adds an element of flexibility by selecting sequences of actions (pathways) that allow for changing from one action to another or keeping options open. At the heart of the method is the selection of potential actions that are needed to craft pathways, consisting of sequences of actions. The AP method starts with assessing ATPs to understand the magnitude of change that a system is able to deal with and under what conditions it is necessary to move to other strategies. The moment the ATP is reached is scenario-dependent. By exploring the effects of multiple scenarios it is possible to find the bandwidths of time when ATPs are reached and action is required. Then adaptation measures are selected, including their 'sell-by dates' (Haasnoot, 2013), which is the time after which an adaptation action is no longer desirable or effective, and assembled in sequences of adaptation actions or measures. These sequences of actions or measures are called pathways. By developing several adaptation pathways, decision-makers are provided insight into the effectiveness of different flood risk management strategies over time, and potential lock-in situations, or irreversible decisions that should be avoided. After a selection of adaptive pathways, so-called contingency actions are selected that are to anticipate and prepare for one or more preferred pathways.



**FIGURE 3.6** Hypothetical decision analysis tree consisting of decision points, adaptation actions and changing conditions. Note that path (a) consists of a single adaptation action (A1), whereas path (b) consists of a sequence of multiple adaptation actions (A2 and A1). Pathway (c) runs towards an unsustainable situation and should be avoided. A decision (D0) for A1 offers the highest flexibility to change pathways compared to a decision for A2, which only opens only one sustainable path.

Pathways can be assessed by techniques as a decision tree (Asselman et al., 2008), route-map decision analysis method (Reeder & Ranger, 2011) or adaptation pathway map (Haasnoot, 2013). A decision pipeline tool (**Fig. 3.6**) is a tool to assess the potential sequences of actions that can be adapted to change when it unfolds. The decision pipeline tool is mainly effective to evaluate the robustness of alternative strategies and to identify potential lock-in situations in which a change of adaptation runs into a non-sustainable situation. Haasnoot (2013) introduces a subway map as a graphical representation indicating potential “routes” and “transfer stations” under what conditions and (depending of the bandwidth of change within scenarios at what moment) it is necessary to switch from strategy (**Fig. 3.7**). The route map or adaptation map introduces the time component by confronting potential strategies (pathways) with points in time when adaptation is needed. These pathways are assessed with the help of a Multi Criteria Analysis, in which criteria as spatial quality, flexibility and cost-effectiveness are used to weigh the different measures and combinations of measures. The adaptation pathway map can be used to assess different pathways on *decision robustness* (see section 3.2.2), which is the ability to deal with a wide range of possible futures and external changes), flexibility, the ability to keep options open and switch from one measure to another, and identifies possible lock-in situations, which are unsustainable situations in which there are no options left to switch between measures. In addition, the sequences of adaptation responses can be assessed according the irreversibility of the investment (e.g. once realized, the system adapts in accordance to the new situation), path dependency (e.g. an investment rules out other adaptation options in the future), sensitivity for uncertainty (e.g. high sunk costs in combination with long useful life of investments), and long lead and planning times. Particularly path dependence is an important challenge in adaptation planning. Path dependency is a situation where earlier decisions rule out options and sets a path that cannot be left without costs and eventually leads to outcomes that are regrettable and costly to change (Liebowitz & Margolis, 1995).



**FIGURE 3.7** Two graphical representations of adaptive pathways. Left: pathways developed within the TE2100 project. The adaptation responses (blue boxes) are grouped according to the effectiveness to move critical threshold levels (increase in extreme water level on the x-axis). The blue arrowed line illustrates a possible path based on the assumption that sea level-rise accelerates in the future. Picture: Reeder & Ranger (2011). Right: subway map assessing several pathways for fresh water supply in the lake IJssel (Haasnoot, 2013).

The method is appropriate for both high – level analysis and for more detailed assessments focussing on clarifying options and more detailed cost-effective assessments (Reeder & ranger, 2011). The Adaptive Pathway (AP) method is developed and tested in several strategic decision-making processes on at the Thames Estuary 2100 project (Reeder & Ranger, 2011) and Delta Programme Rijnmond-Drechtsteden (2014), river basin management (Haasnoot, 2013) and sewer system planning (Gersonius, 2012). However, the method has not yet been applied to local adaptation planning.

Although there are multiple variations, the adaptive pathway method consist of the following steps:

**Structuring the problem:**

- 1 Define key elements of the system that affects the locality (water system, urban, economic, infrastructural systems);
- 2 Explore changing conditions (climate change, urbanization, changing hydraulic conditions);
- 3 Understand current vulnerability of the system.

**Define the limits of resilience:**

- 4 Define the Adaptation Tipping Point based on an assessment of policy objectives and performance indicators (no flood is accepted that exceeds... the areas should recover within x hours...electricity remains function during a xx flood);
- 5 Define measurable critical thresholds under which the performance indicators cannot be met anymore (flood levels/return periods) for each indicator;
- 6 Assess when and where these critical thresholds are reached, regarding current and future conditions;

#### Appraise adaptation options and assemble path ways:

- 7 Select possible adaptation response options to cope with thresholds;
- 8 Evaluate adaptation measures on performance criteria (flood reduction, cost-effectiveness, social equity, spatial quality, additional benefits, negative side effects on other levels of the system);
- 9 Assemble high-level pathways of response options that will tackle the thresholds;
- 10 Compare the effectiveness of different pathways in terms of (cost) effectiveness, potential benefits and other relevant criteria.

#### Develop final adaptation strategy:

- 11 Start implementation;
- 12 Develop monitoring framework. Select key variables, which should be monitored to assess if a switch of route will be needed in the future.

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## § 3.4 Discussion and conclusions

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### § 3.4.1 Critics on the adaptive pathway method

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A general criticism that often is made is that the adaptation pathway concept remains rather conceptual and is difficult to operationalize in the complex reality of adaptation planning. In addition, some of the key presumptions underlying the method are challenged. The method presumes that:

- 1 Goals of adaptation are clear and not ambivalent (Wise et al., 2014) and the 'boundaries of resilience' (or tipping points) can be defined with any given certainty;
- 2 The impacts of adaptation interventions are known;
- 3 Decision-makers have the power and agency to make decisions and influence the system towards optimal pathways and there is political and social consensus on the decision-making moments (Wise et al., 2014);
- 4 Finally, that moving between alternative interventions (and thus developing alternative pathways) is straightforward.

In local adaptation planning, however, precisely these four conditions are problematic. In many cases, goals of adaptation are not well defined and identifying the boundaries of resilience seems to be very difficult. Related to this issue is the question whether we can define "sufficiently resilient". Particularly the concept of adaptive paths has been criticised for the inability to define the "maladaptive", "unsustainable" or less resilience space of which the system should be managed away from. Resilience in itself

does not include preferences about which system state is more preferable; the question remaining is how to define successful adaptation. Moreover, the adaptive pathway method assumes that there is a rational decision maker who is able to make decisions based on long-term assessment of options. In contrast, adaptation is often the result of many, often conflicting interests and interventions that are led by opportunistic rather than strategic motives. Considering this, Wise et al. (2014) concluded that the APM is mostly effective in well-understood, well-governed socio-technical systems that are under threat of slow environmental change. The following two sections reflect on the main question of whether we can find the 'boundaries of resilience' and how to define successful adaptation.

### § 3.4.2 Can we find tipping points with any precision?

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Is it possible to define or predict the position of tipping points within socio-ecological systems with any precision? Some researchers (Davidson, 2010, Pelling, 2011, Walker & Salt 2012) challenge the idea that identifying tipping points in a complex socio-ecological context are difficult to find with any objective confidence. Particularly, in urbanised deltas several factors contribute to reaching a tipping point, such as subsidence, coastal erosion, salinity intrusion, rapid urbanisation, or changes in socio-economic conditions (Renaud, et al., 2013). This implies that there are multiple changing variables and thresholds that in many cases are linked. Furthermore, in complex social systems there is often a hierarchy of ATPs, with local ATPs embedded in or influencing higher-scale ATPs (Walker & Salt, 2012). As an illustration, reaching several local ATPs for flood risk may cumulate to a higher level ATP that triggers a policy change. In this respect, it is useful to point to the complex situation in which multiple lower and higher level ATPs with different dominances, together trigger a policy change. This is for example the case in complex flood management systems, such as the Rotterdam-Rijnmond region and the London Estuary, in which a decision on the future of the storm surge barrier depends on several sometimes competing factors, such as risks of local flooding, improvement of the primary flood defence system and other tipping points related to ecological and economical values. Given the multi-faceted and interacting tipping points, many researchers (Walker & Salt, 2012, Pelling 2011) argued that social system recovery tipping points are difficult, if not impossible to identify, or at least need to be understood as an area of recovery, rather than a fixed identifiable point (Mens et al., 2011). Renaud et al. (2013) claim that critical systems tipping points can only be found in ex-post evaluation.

Again, issues of scale trouble this discussion. Reaching a recovery tipping point at lower levels within the system (e.g. at the level of individual households or the intermediate scale of communities) may be less difficult to define empirically and may serve as an

important indicator for the loss of resilience of the system as a whole (Walker et al., 2004). To measure resilience and identifying the recovery tipping point it is therefore essential to clearly define the level on which resilience is assessed (Adger et al., 2005b). Additionally, solving the difficulties of defining the recovery tipping point is precisely what the ATP aims at: defining the limit values of policy objectives creates information that can be used for adaptation planning and decision making. Without losing sight of the difficulties faced when defining tipping points and developing pathways, the value of the concept of ATPs and the APM is that its main purpose is to systematically explore the effects of potential futures and develop adaptive strategies to deal with these futures, thus bridging the gap between vulnerability assessments and adaptation strategies. In this sense, the concept of ATP is can be understood as an artifice for dealing with complex system behaviour.

### § 3.4.3 What is successful adaptation?

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The question that remains is how to determine successful adaptation. Or, to be more precise, how do we know what adaptation responses, strategies and planning methods are more or less successful in moving coastal waterfront areas to a more resilient future? To answer this question it is necessary to define the criteria of successful adaptation. Adger et al. (2005a) were one of the first who paid attention to this matter. Following a more developed literature on policy appraisal he argues for using generic principles as *effectiveness, efficiency, equity and legitimacy* as criteria for evaluating adaptation. *Effectiveness* of adaptation actions or strategies relates to ‘the capacity of an adaptation action to achieve its expressed objectives’ (Adger et al., 2005a: 81). When translating this definition to flood risk resilience, effectiveness can be expressed as the extent to which an adaptation action – for example a floodwall –, or a sequence of adaptation actions, result in a significant reduction in flood risk. Flood risk reduction can be both translated into quantitative terms (e.g. the amount of buildings exposed to flooding), monetary terms (e.g. the annual costs of flooding), time (e.g. return periods of flooding or duration of power outages), and risk of casualties (e.g. individual mortality). Effectiveness also relates to the response time that is needed for reaching a preferred state. Adaptation strategies that require incremental change may proceed too slowly to anticipate on quickly changing conditions, while other, transformational strategies are more effective in achieving a timely change. *Efficiency* relates to the balance between public and private costs and potential benefits (economic efficiency) and the extent to which adaptation action can be implemented easily. In its simplest form, the economic efficiency of adaptation actions is defined as the ratio between implementation and maintenance costs and the expected cumulative reduction in flood risk during the lifetime of the investment (Mens et al., 2011). A more complex assessment should also include costs of inaccurate prediction,

adversely effects of the investment to other elements, or enhanced opportunities that arise from an adaptation action.

*Equity*, in its sociological meaning refers to the extent to which all stakeholders benefit from an adaptation strategy equally. *Legitimacy* refers to both the lawfulness as to the fairness and acceptability of decision-making as perceived by participants that are affected by those decisions (Adger et al., 2005a, Kokx, 2013, Driessen et al, 2010). Lawfulness related to the extent to which adaptation actions are consistent with current legislation and responsibilities between public and private actors in flood risk management. Fairness and acceptability of adaptation actions are mainly determined by the distribution of costs and benefits, or, as stated by Adger et al. (2005a): 'who wins and loses from the adaptation' (p. 82). Particularly, the issue of equity in adaptation planning is considered a key principle as the most vulnerable groups in society usually felt the effects of environmental change the hardest.

In addition to these criteria, the synergistic values of multifunctional or integrated adaptation responses for urban development are important positive effects that are used to evaluate adaptation. Usually, the concept of spatial quality is used to describe the co-beneficial effects of adaptation actions. A commonly used definition following the Vitruvius Virtues of Spatial Quality by Hooimeijer et al., (2001), distinguishes between user value, experience value and future value. These still generic values can be translated into more precise criteria; however, the concept of spatial quality runs a risk of a catchall concept that refers to all elements of sustainable urban planning in general, supplemented with an assessment of aesthetic values. This thesis prefers to use the more neutral concept of *added value*. Added value is defined here as the total of direct benefits (e.g. improved waterfront accessibility) and indirect co-benefits (e.g. increasing real estate prices) that are produced, or released as a result of an adaptation intervention. Co-benefits may include it opens up opportunities for residential development, environmental improvements and improvements of the spatial quality of the public realm and cityscape (quality of street scape, accessibility of the waterfront, etc.).

To conclude, criteria as effectiveness, efficiency, legitimacy, equity and added value provide adequate starting points for evaluating successful adaptation paths. In the next sections the concept of ATP and APM is applied to the local level of adaptation planning in two case study areas in Rotterdam (Chapter 6) and New York City (chapter 7) to test its applicability in the complex reality of adaptation planning of coastal urban waterfronts.



# 4 Adaptive design of urban coastal waterfronts: typologies and strategies

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## § 4.1 Typologies of coastal adaptation

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This chapter focuses on the question what adaptive measures and design strategies are effective to reduce risk of coastal urban waterfronts as a consequence of climate change and add value when improving flood resilience of urban waterfront areas. The purpose of this chapter is to provide an overview of practices and strategies and the development of several Guiding Models that may serve as a toolbox for application in the following chapters.

Designing for flood risk requires understanding of causes and character of several types of flooding in terms of probabilities, duration, depths, water quality (i.e. salinity) and velocities (Jha et al., 2012), as well as an understanding of the effectiveness of measures related to urban typologies, such as typology, size, age and construction of the building, and urban density (NYCDCP, 2013b). Within this context, this chapter starts with an elaboration on several types of flooding of coastal areas. It then continues with an assessment of adaptation responses on effectiveness to reduce flooding, cost-effectiveness and opportunities for creating co-benefits, following the definition of successful adaptation as introduced in section 3.5.3. The final section addresses design strategies to improve flexibility and introduces several guiding models for combinations of coastal resilience measures.

### § 4.1.1 Method

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The information in this chapter is derived from literature review, supplemented with information from expert interviews in Rotterdam and New York City. Additionally, the information on costs and technical aspects of local flood protection measures and property level protection measures is developed in close collaboration with city officials of the engineering department of the City Rotterdam and an independent consultancy firm (Wareco) that conducted a detailed flood risk assessment of 9 existing buildings located at the Noordereiland in Rotterdam and the historical waterfront of

Dordrecht. Finally, information on the cost-benefit ratio of several adaptation actions was developed in collaboration with a Rotterdam based firm specialised in financial engineering (Rebel Group). Because for preventive solutions, such as flood walls or storm surge barriers the cost-efficiency strongly depends on hydraulic conditions and potential for risk reduction, the cost efficiency can only be described in general terms. Given the specific urban conditions in the two case studies, only adaptation measures that are effective in mid and high urban density conditions are assessed. Solutions that are only effective in low-density conditions, such as building houses on mounds, are not reviewed extensively. Based on the information on effectiveness, cost-efficiency and potential added value of individual measures, potential combinations of measures (guiding models) were developed, using conceptual and sketch design. These combinations of measures were assessed quantitatively on additional potentials for co-benefits on district or regional level.

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## § 4.2 Understanding flood risk

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### § 4.2.1 Flood characteristics of coastal urban waterfronts

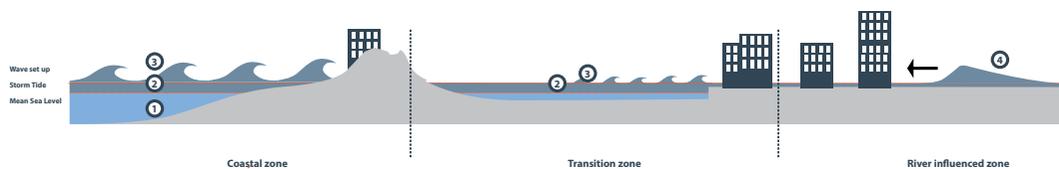
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To understand the risks of flooding of coastal intertidal landscapes it is necessary to distinguish between several causes and characteristics of flooding. In coastal areas, flooding may be tidal, storm surge induced (coastal), river flooding (fluvial) and storm water related (pluvial).

*Tidal flooding* is a recurrent flooding caused by the daily, or seasonally rise of seawater. This kind of flooding is usually short-lived. Coastal flooding is caused by rare events of high tides (also known as King tide) or astronomically high tides coinciding with a storm surge, which forces water levels up to the coast and into inland river basins, usually accompanied with high-energy waves and winds (Bowman et al., 2005). Floodwater that is pushed up into inland water basins or tidal inlets may cause local inundations of low-lying waterfront areas, which may flood streets and buildings. This type of inland surge flooding is characterised by comparatively low flood depths, low energy waves and is usually short-lived because flood water drains back to the river at low tide, although the duration depends on the storm duration and funnelling effect of estuary or tidal inlets. In addition, urban areas exposed to large open bodies of water, such as a harbour or lake, need to take into account the effect of rising of water levels locally caused by storms and strong winds over long distances (fetches) and effects of local wave setup caused by gusts (Chbab, 2012). Additionally, storm depressions may

cause wind oscillations, which are large long distance waves that increases the level of storm surges and penetrates into tidal inlets, rivers and bays.

*Fluvial*, or riverine flooding is caused by extreme river discharges following heavy rainfall in the upstream catchment areas that exceed the normal discharge capacity of a river channel (Merz et al., 2006). Typically, river floods are characterised by high velocities, and relative deep, quickly rising water levels, resulting in risks of casualties as well as considerable structural damages to buildings. However, fluvial flooding, particularly in large river basins can be predicted well in advance. Because of the generally short fetches, local wind and wave setup is not significant (Chbab, 2012).



**FIGURE 4.1** Coastal flooding in the coastal zone is caused by the cumulative effect of (1) astronomical high tide, (2) storm surge and (3) wave set up. In the transition zone between coast and river dominated areas extreme water levels are caused by an accumulation of (1) astronomically high tides, (2) storm surge, (3) localised wind and wave setup effects, amplified by the effect of (4) extreme river discharges. In the river-dominated areas the effects of the storm surge are not felt significantly.

Particularly urban areas that are located in the transitional zone at the confluence of rivers and the sea or ocean, are faced with a potential combination of tidal, coastal, and fluvial flooding, as well as local wind and wave setup effects (**Fig. 4.1**). Flooding occurs when flood levels exceed the design level of coastal defences, both surge related as fluvial flooding could result in flooding of low-lying waterfront areas and, at worst, a breach or failure of the flood defence system. This type of flooding caused by a failure of the flood defence system is characterised by high vertical velocities, deep water levels and a limited preparation time.

Finally, flooding can be *pluvial*. Hurricanes and storms are usually accompanied by heavy rainfall both before and after the arrival of the surge (Bowman et al., 2005). Major rainfall events (pluvial flooding) might cause local runoff (flash floods) or storm water that accumulates in lowest areas, causing additional damage to buildings and infrastructures in areas that are located outside the coastal flood zone. Particularly coastal areas that discharge storm water under gravity to the river are vulnerable for combinations of storm surges flooding blocking the discharge capacity of the storm water system.

## § 4.2.2 Probability of extreme water levels

Water level probabilities in the intertidal transition zone are determined by the likelihood of coinciding of high river discharge, astronomically high tides and storm surges conditions. The probability of each single event is determined by the frequency of exceedance of observed flood events and an extrapolation of long-term historical data series of river discharges, storm and wind conditions, astronomical tides and long-term effects, such as sea level rise and subsidence (Bowman et al., 2005, Orton et al., 2015, TAW, 1998). The annual probability that a certain water level is exceeded can be found by combining a large set of potential water levels and their corresponding likelihood of occurrence (return periods). This annual probability is usually displayed in a water level – probability graph (Fig. 4.2). Flood level probability assessment should take into account a certain degree of uncertainty, particularly for low probability (rare) flood events. High probability flood events can be predicted with more accuracy particularly when historical data on observed extreme flood events is available. Low probability flood events, however, are based on extrapolations of observed water levels, trends and model-based calculations, and, consequently, come with higher uncertainties (Orton et al., 2015). In addition, the potential failure probability of storm surge barrier systems and man-made changes in the natural conditions (e.g. dredging riverbed for navigational purposes) may impact the probability of occurrence of extreme high water events. Additionally, this uncertainty is amplified by uncertainties on future variations caused by changing climatic conditions.

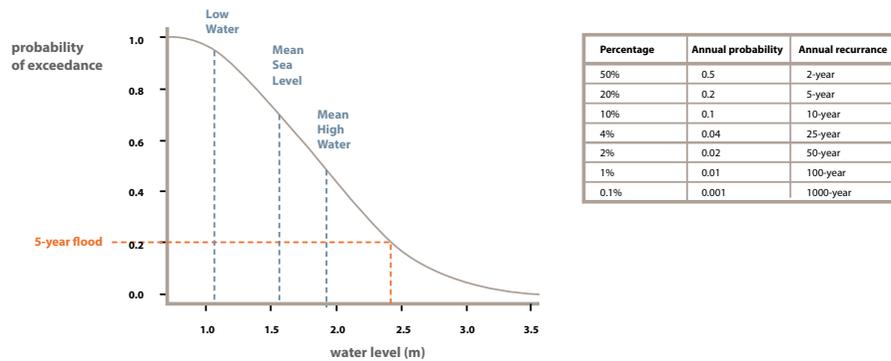


FIGURE 4.2 Conceptual annual probability of exceedance curve showing the Mean Low Water (MLW), Mean Sea Level (MSL) and Mean High Water (MHW) range. The orange line shows the probability of exceedance and corresponding water level of a flood event. Right table: probability of exceedance as percentage, annual probability and annual recurrence rate. Based on Orton, et al. (2015).

An important difference between coastal flooding and fluvial flooding is the predictability of both the timing of extreme water and the expected maximum water level. Based on assessing precipitation patterns and discharge levels in the upstream catchment areas, flood waves in large rainwater-influenced river basins can be predicted well in advance and with a relative precision on the expected maximum water levels. Coastal flooding is more difficult to forecast accurately because the expected water levels strongly depend on the intensity and direction of a storm. Moreover, local waves and wind set-up effects influence the expected local water levels considerably, which creates a relative large uncertainty on the expected maximum water level. The relative large uncertainty both in predicting the annual exceedance probability, climate change effects and short-term effects of storms and local wave set-up is of major challenge for long-term adaptation planning and requires incorporating flexibility into the design of adaptation measures. Section 4.3 explores some flexibility based design principles in more detail.

### § 4.2.3 Assessing flood risk

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As explained in more detail in section 3.3.1 flood risk can be defined as the function of hazard probability, exposure and sensitivity of assets that are affected, in which exposure is the size and characteristics of the exposed population and sensitivity the potential for loss. The exposure is usually expressed in terms of flood depths, velocities and duration of a flood. Sensitivity for flooding can be translated to quantitative terms (e.g. the amount of buildings exposed to flooding), monetary terms (e.g. the annual costs of flooding), time (e.g. return periods of flooding or duration of power outages), and risk of casualties (e.g. individual mortality) (Jonkman, 2007). However, the most common way to express flood risk is to describe the risk in terms of expected annual damage and displayed in an exceedance probability-loss curve (**Fig. 4.3**), in which the area under the curve represents the total annual damage risk (Ward, et al., 2011). The expected damage costs per flood event are calculated by combining data on the probability and characteristics of an event (e.g. flood depths) with data on the amount of assets and an estimation of the susceptibility of the exposed assets (Ward et al., 2011).

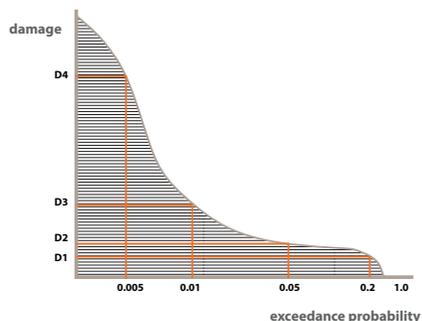


FIGURE 4.3 Exceedance probability-loss curve showing the damage curve relative to the exceedance probability of flood events. The dashed area represents the cumulative annual damage costs of low and high probability flood events.

## § 4.3 Toolbox of adaptation measures

### § 4.3.1 Building a classification of adaptation responses

A large variety of responses of flood adaptive measures, ranging from large-scale interventions, such as closing off distributaries, to small-scale locally implemented interventions on property and estate level, and behavioural measures such as risk communication can be applied to enhance the resilience of an urbanized delta or coastal system as a whole (Nabielek-Kronberger et al., 2013). Adaptation responses are commonly categorized as either ‘hard’ or ‘soft’ (Hallegatte, 2009) or structural or non-structural (Jha et al., 2012). “Hard” or structural adaptation responses are physical and engineered adaptations to future flood risk. “Soft” or non-structural responses are changes in regulatory instruments, financial incentives or recovery and disaster management that improve the coping and recovery capacities. Other classifications subdivide actions on the effect of the intervention, for example by distinguish between measures that focus on protect, accommodate or retreat from risks (Nicholls et al., 2007), or reduce hazard, reduce exposure, or reduce vulnerability for flooding. De Graaf (2009) distinguishes between several capacities: a threshold, coping, recovery and adaptive capacity. Other classifications differentiate between design principles. For example, the British Department of Environment, Food and Rural Affairs (DEFRA) developed four strategic coastal defence options based on *hold*, *advance*, *retreat* the

*first line of defence and no intervention* (Cooper et al, 2002). Following Walker et al. (2004) and Walker & Salt (2012) strategies to improve resilience focus on avoiding crossing a threshold (by creating a larger buffer capacity), influencing the system away from its tipping point (e.g. by improving flood resistance of buildings), or to make the threshold more difficult to reach (e.g. by reducing local water levels by upstream interventions), and actors can manage cross-scale interactions to avoid loss of resilience at the largest scales. Table 4.1 summarizes some of these classifications of adaptation responses and shows how these categorizations are related.

RISK-BASED	CAPACITY-BASED (de Graaf, 2009)	RESILIENCE-BASED (Walker & Salt, 2012)	DESIGN PRINCIPLE-BASED (Nicholls et al., 2007, Cooper et al., 2002)
Reduce hazard probability		Move tipping point away from the system	Protect (higher level)
Reduce exposure	Threshold capacity	Move the system away from the tipping point	Protect (lower level) / hold or advance the line
Reduce sensitivity	Coping and recovery capacity	Make the tipping point more difficult to reach	Accommodate and retreat

TABLE 4.1 Several classifications of adaptation responses.

As introduced earlier in this thesis (3.3.1) resilience can be defined as the inverse vulnerability, in which vulnerability is defined as the exposure and sensitivity of assets to hazards. Following this definition a risk-based classification (reduce hazard, exposure and sensitivity) classification offer an effective frame to assess the effectiveness of physical adaptation responses for enhancing flood resilience. The adaptation response options are described in terms of economic effectiveness, type of flooding and flood depths, technical limitations, implementation lead-time, costs and opportunities for multifunctional use, or other synergetic benefits.

### § 4.3.2 Reduce hazard probability

Measures that affects hazard probability aims to reduce the probabilities of occurring of high water levels and reduce flood depths, waves and velocities of a flood. There are three main types of flood defence systems that effects hazard probability, storms surge protections, reduce river flooding and lower the impact of wind and waves.

## Storm surge protection

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Storm surge protection is a family of hydraulic constructions in rivers and estuaries designed to prevent urbanized areas with high economic value from flooding from storm surges or exceptionally high tides. Storm surge protection systems could consist of closure dams that permanently close off a river mouth or estuary, or storm surge barriers with partly moveable gates (Aerts et al., 2013). Best-known examples of moveable storm surge barrier systems are the Maeslantkering at Rotterdam and the London Thames Barrier that protects large urbanized areas from being flooded from high tides and storm surges at the North Sea. Storm surge protection systems reduce flood probabilities of extreme events considerably, although, there is still a risk of increasing flood levels caused by river water runoff accumulating behind the closed barriers (Bowman et al., 2005). Moreover, due to the complex operating system and mechanical nature of its components, moveable storm surge flood protection systems come with a relative high probability of default (RWS, 2009). This relative large failure probability also affects local flood probabilities, making additional flood protection at lower level of the system necessary.

As storm surge barriers are usually applied as part of a larger flood protection system most storm surge barriers not only aim at the reducing the flood probabilities of urban areas but also to prevent high costs for improvement of local floodwalls and levees. The Maeslant Barrier's main purposes, for example, are to ensure a high level of flood protection of the port area and to minimize extensive dike improvement of a large part of the Rotterdam region (RWS, 2009). These interdependencies between higher level and local level flood protection systems create complex governance arrangements, which may lead to conflicting expectations and interest among several layers of authority (van Buuren et al., 2014). Secondly, storm surge barriers are known to generate a sense of security leading to a reduction of flood awareness and precaution and consequently to increased accumulation of assets in the protected hinterland (Tobin & Montz, 1997, Merz et al., 2010). This "levee-effect" (Tobin & Montz, 1997) results in the paradoxical situation in which flood losses continue to increase even when more investments in flood protection are made. As a result, an investment in storm surge barriers may create an irreversible situation that reduces flexibility and adaptability of local level systems (Zevenbergen et al., 2010).

## Reduce peak discharges

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To attenuate peak discharges there are basically three options: adding discharge capacity, increase (upstream and downstream) storage capacity and upstream water retention. As the focus of this research is on adapting coastal urban waterfront areas, measures that influence river runoff are not assessed in depth.

## Forelands, breakwaters, and living shorelines

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Forelands, breakwaters and living shorelines form a family of “soft influencers” that are intended to break waves and reduce the impact of wind set-up, as well as protect shorelines from erosion, high velocities and ice drift but not to reduce storm surge or peak discharge induced flooding (NYCDCP, 2013a). There are two main types of influencers: breakwaters and living shorelines, and many variations of these. Breakwaters are engineered or natural structures intended to break waves and reduce the impact of wave run-up (NYCDCP, 2013a). Breakwaters can be either engineered structures made of sand, rock or stone, such as harbour protection facilities, or, coming up more recently, soft and multifunctional used structures such as artificial islands, reefs and floating facilities. The effectiveness of a breakwater largely depends on the shape and design and local flood characteristics. Generally, breakwaters are most beneficial at shallow water levels and areas that suffer from strong wave forces. Breakwaters, particularly when creating areas with low wave energy, offer many opportunities for ecological and recreational uses (see for example Nordenson et al., 2010).



**FIGURE 4.4** Left picture: Building with nature project in Rotterdam. A revetment is designed to capture silt over time so to create natural conditions for intertidal shoreline vegetation. Picture: City of Rotterdam. Right: artificial reefs functioning as living breakwaters as part of the coastal defense strategy for Cheapside, Virginia, US. Photo by author.

A living shoreline is a coastal protection technique based on using natural vegetation and natural silted-up sand or soil in a foreshore to reduce wave and surge impact and control erosion, while maintaining valuable ecological shoreline conditions (NYCDCP, 2013a). In urban context, living shorelines are usually combinations of hard infrastructures, such as bulkheads and revetments with softened, natural edges that provide some wave attenuation and reduce erosion caused by high velocities. Particularly when raising the bulkhead or floodwall is difficult or expensive, living

shorelines may be a cost-effective strategy that improves the functional life and performance range of structural flood defence infrastructure. Additionally, the co-benefits of living shorelines, such as improved ecological and recreational values, as well as improving the esthetical attractiveness of coasts and waterfronts are expected to be large.

### § 4.3.3 Reduce exposure

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#### Local flood defences: floodwalls and levees

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To reduce the exposure of urban areas to flooding typically levees, dikes, floodwalls or land elevations are used.

Dikes and levees are earthen embankments that provide flood protection from coastal or fluvial flooding. Most levees consists of a sand or earthen fill core covered by a layer of clay, and a stone or asphalt finishing to prevent erosion from waves or from flood water overtopping the structure (Veelen et al., 2015). An important consideration of fixed flood barriers constructions, such as flood walls and levees is that these construction, by nature, create physical and visual barriers that impede spatial development and block spatial relations with the waterfront. At the same time, when well designed, the development of a flood protection scheme offers opportunities for integration flood protection into the design of waterfront parks and buildings, multifunctional use and waterfront redevelopment.

Flood defences reduce the probability of flooding but they are not designed to eliminate all risk. Flood defences may fail – the structure collapses when design conditions are exceeded – or floodwater may overtop the structure when the flood level exceeds the flood defence threshold. In both cases the results can be catastrophic because of the sudden inflow of floodwater and short warning and evacuation time.



**FIGURE 4.5** Floodwall along the Jingmei river in Taipei, Taiwan. Right picture: floodgate providing access to the waterfront park of one of Taipei’s urban rivers. Photos by author.

### Temporary flood barriers

Given the considerable amount of land that is needed, many levees and dikes in urban context are temporarily deployed during flood events. Temporary flood barriers are freestanding demountable or deployable flood barriers made of panellised constructions or inflatable or fillable tubes that are put in place at the event of a flood. Most systems are able to withstand considerable flood levels up to 2.5 m, although they are not suitable for areas that experience wave action during a storm (NYCDP, 2013a). The advantage of temporal flood protection is that they do not need structural interventions and allow the waterfront assessable during normal conditions (NYC, 2013). However, this system still requires open space and access for their deployment and most systems need separate storage. In addition, substantial manpower is needed to deploy and the systems require regular testing and drills (Dhonau, et al., 2014, NYC, 2013). The total costs, including the costs for open space, storage, maintenance and regular testing are expected to be considerably high. Also, these systems are particularly sensitive for human errors or incorrect installation. In addition, these systems provide minimal opportunities for urban development or yielding additional benefits.

### Integrated flood protection solutions

Integrated flood protection solutions (IFPs) are flood protection systems that combine active protection based on mechanical gates and deployable floodwalls that are closed or put in place in advance of expected high water conditions, with passive flood protection elements such as landscaped features, buildings walls, infrastructures and esplanades serving as flood protection (NYC, 2013). IFPs can be implemented relatively quickly, requires minimal site preparation and are relative inexpensive in operating costs. Although IFPs offer many opportunities for redesigning waterfront areas, they

require detailed urban and landscape design to ensure high quality integration into the public realm, making these solutions more expensive. Additionally, when combined with active elements (e.g. flood doors or temporarily deployed flood walls), the level of reliability and protection is lower than the reliability levels of passive alternatives (NYCEDC, 2014).

### Multifunctional flood defences

Multifunctional flood defences (MFDs) are river or coastal flood protection infrastructures that are designed to integrate flood protection with functions like infrastructure, housing, recreation and ecology (Veelen et al., 2015). MFD is a collective term covering a number of solutions that aim at optimisation of land use and differ in the degree to which non-water retaining functions are integrated with the flood defence infrastructures. MFDs can consist of a vertical retaining wall which replaces a dike slope or berm, leaving space for commercial or residential real estate development, or they consist of oversized flood protection landscapes that function as a basement for development. Special situations consist of a functional integration, in which a build object functions as flood protection (Veelen et al., 2015).

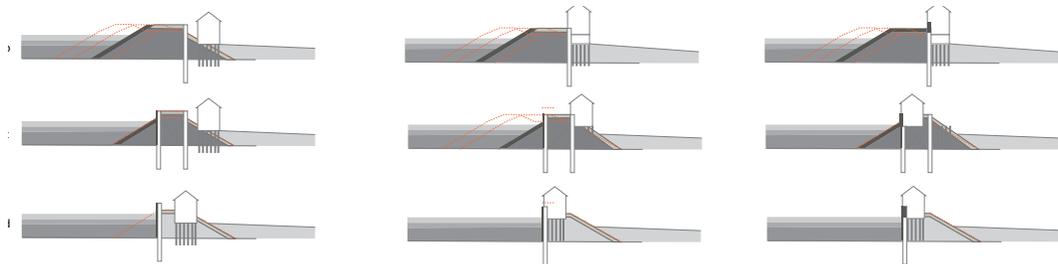
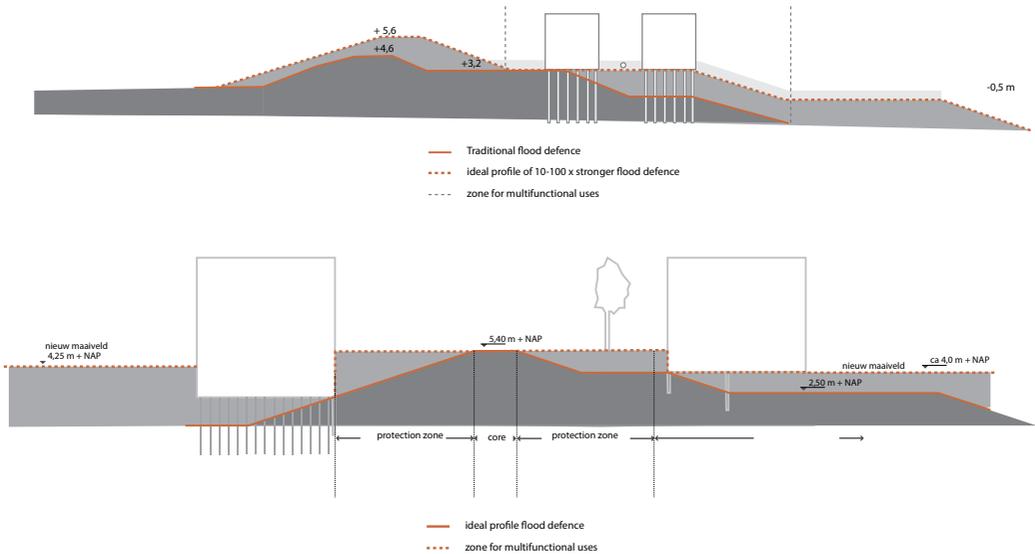


FIGURE 4.6 Various examples of MFDs with different degrees of spatial and structural integration, based on (b) a sheet pile wall, (c) cofferdam and (d) a floodwall construction.

Conceptually, a multipurpose levee (MPL) is a flood protection infrastructure consisting of a landscaped berm, sloped open space or landscaped edge, which is designed to reduce flooding and provide recreation space, real estate development opportunities, and improve the accessibility of the waterfront. MPLs are passive, earthen levees that are usually 30 times as wide as they are high, providing a 10 to 100 times stronger flood protection structure that is unlikely to breach during extreme conditions (NYCEDC, 2014). In the Netherlands, MPLs are usually referred to as *unbreakable dykes* or *climate dykes* (Veelen et al., 2015). In Tokyo, Japan these kinds of levees are known

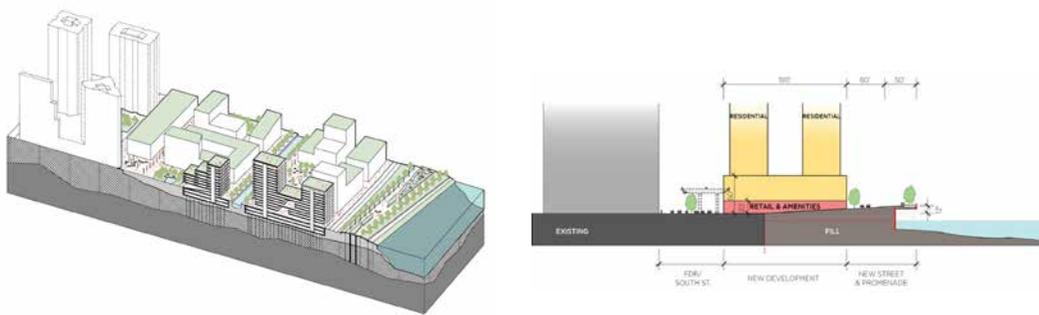
as *super levees*. MPLs are usually constructed of elevated landfills, over-sized levees or elevated land reclamation sites. The main advantages of MPLs are the high reliability, low maintenance costs and opportunities to integrate into the existing urban fabric (NYCEDC, 2014).

While MPLs offer high flood protection reliability, compared to alternatives they are also far more expensive and require extensive space for redevelopment or land elevation. Particularly in dense urban waterfronts space is scarce, or only accessible to high costs for land purchase and land reclamation. Additionally, costs of a large landfill highly depend on the availability of fill material (de Graaf et al., 2012). More importantly, a major drawback of a MPL is its limited phasing ability and lack of flexibility over time. This creates large financial risk caused by the high up-front investments needed for a full build-out of the flood protection infrastructure and the potential long time before real estate sales generate revenues. In general, due the lack of phasing opportunities MPLs require massive public support, which can be justified when the solution creates large public benefits such as enhanced flood protection for a wider urban region, or when it triggers the redevelopment of other parts of the city that otherwise would remain underdeveloped. This is primarily the case in the Netherlands and Japan where single flood protection infrastructures protect large parts of the urbanized flood plains.



**FIGURE 4.7** Cross-section of a multipurpose flood protection: in dark grey profile of a mono-functional river levee, in light grey a 10 times stronger levee and additional landfill zone for multi-functional use. Lower picture: multipurpose levee in Rotterdam providing opportunities for urban development. Source: Veelen et al. (2015)

Two recent research studies evaluating the technical and financial feasibility of a MPL for the Southern Manhattan (NYCEDC, 2014) and New Jersey City (Marchetto, 2015) showed that an MPL is technically feasible and an effective approach to substantially reduce flooding of a larger urban area. However, it requires a substantial riverward landfill and urban development programme to become beneficial or self-funding. Particularly the extensive urban development that is needed to self-fund the MPL, requires a phased and long-lasting development ranging from 30 to 60 years the minimum.



**FIGURE 4.8** Left: design for a multi-purpose flood protection and landfill serving as future urban extension for the Jersey City Waterfront. Picture from Marchetto (2015). Right: conceptual design for a multipurpose levee for Southern Manhattan consisting of a landfill and floodwall in the East River (source: NYCEDC, 2014).

### Land elevation

Land elevation is probably the oldest form of man's attempt to protect itself against rising sea levels (Meyer et al., 2010). Man-made elevation of building plots, roads, and public space above flood elevation levels is an effective approach to reduce flood levels and reduce flood probabilities. In general, land elevation is a relative inexpensive when integrated into large-scale redevelopment or land reclamation projects as can be found at projects as the Kop van Zuid in Rotterdam and Battery Park City in New York City. Land elevation is effective for large-scale redevelopment projects, provided sufficient amount of cheap fill material is available, which is, particularly in highly dynamic urban areas, easily available from the supply of excess soil resulting from the development of underground constructions and parking garages. Land elevation, however, is expensive when applied in existing urban areas due to the high costs of retrofitting the existing sewer and drainage systems and may negatively influence the streetscape's viability. Alternative to land elevation is to elevate the building site to above the flood level. On site

elevation is effective at low depth, high probability flooding, but, particularly for small infill sites more expensive than alternative building level protection strategies (NYC DCP, 2013b). In addition, land elevation runs into issues concerning a fair distribution of costs and benefits. Land elevation costs are borne by the landowner or project developer and charged to the property buyer, while elevation costs of streets and public areas usually are borne by public authorities. Land elevation, as flood protection strategy requires long-term agreements between public and private stakeholders.



**FIGURE 4.9** Left picture: land elevation at an urban development of the former port area in Rotterdam (Müllerpier). Note that the land elevation keeps a distance from the bulkhead to avoid structural integrity problems of the historical quay construction. Middle picture: elevation of an infill building (Feijenoord, Rotterdam). Photos by author.

### On-site flood protection

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When flood levels or high flood velocities may jeopardise the structural integrity or stability of buildings on-site flood protection may be effective to avoid floodwater reaching the outer walls of a building. An on-site flood barrier is a flood protection construction that is placed around the property to prevent floodwater entering the building. The construction can be a fixed construction, such as an earth berm or elevation, a concrete floodwall, or be temporal, such as a demountable panellised floodwall that is put in place in case of a flood event (NYC DCP, 2013a). Small flood protection constructions consist of vertical precast concrete slabs on a small foundation or larger reinforced concrete floodwalls (VMM, 2015). To reduce risks of sewage back flow or ground water or storm water flooding, on-site protection need to be equipped with drainage pumps and sewer valves. When applied to larger buildings, on-site flood protection equipment also needs to consider accessibility, for example by an elevated access ramp or automatically closing floodgates. A point of concern is that on-site flood protection may adversely increase flood levels and velocities of adjacent properties (NYC DCP, 2013a).

Depending on the construction, a plot-based flood protection is effective to retain flood levels that range 20 to 45 cm (VMM, 2015). To provide protection to higher flood levels a more robust design of flood protection is required, including measures to prevent underground water flows to undermine the construction. Brick-stone floodwalls are usually applied to flood levels up to 50-60 cm. Reinforced concrete floodwalls usually are applied to a maximum of 1.20 m height. However, preserving visual relations from the building or site to the surrounding landscape is probably a more decisive argument for not building taller floodwalls.

Due to site restrictions and costs of additional measures to prevent underground seepage and withstand hydrostatic forces, the cost-effective height of on-site protection is usually limited to about 1.8 m for levees and 1.2 m for concrete floodwalls (FEMA, 2014b). As a rule of thumbs, reinforced concrete floodwalls are only cost-effective from flood levels that reaches 70 cm or higher (VMM, 2015). In higher-density conditions, integrating on-site protection may be challenging and require detailed landscape design (NYCDP, 2013a). Because of the relative large required space, high costs and remaining risks of flooding due to overtopping floodwater or seepage of groundwater, this solution is considered only effective when deployed in low-density suburban areas, or large building complexes such as residential estates, hospitals and schools in high-density environments.

#### § 4.3.4 Reduce sensitivity for flooding

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##### Property level Protection

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Property-level flood protection (PLP) is the installation and deployment of a range of flood resistance and flood resilience measures to reduce flood damages (DEFRA, 2014). There is basically two techniques that allow buildings to be better prepared for flood events: dry flood proofing and wet flood proofing. Dry proofing aims to reduce flood vulnerability by keeping water out of a building and wet proofing aims to reduce damages by applying water resilient interiors and materials. In the UK, both techniques are also referred to as household flood *resistance* and *resilience* respectively (DEFRA, 2014).

##### Dry flood proofing

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Dry proofing is a flood proofing technique aiming at preventing water from entering individual properties up to a certain level (DEFRA, 2014, NYCDP, 2014b). Dry flood proofing is based on making exterior walls and basement slabs impermeable, closing

off windows, ventilation holes or air bricks, and utility hatches with temporarily (sand bags or flood panels) or permanent measures, such as flood resistant windows that are designed to resist flood loads. In addition, dry flood proofing requires sealing off all pipe and cable entry points, the installation of back flow valves in the sewer to protect building from flooding from the sewer system and measures to prevent water seeping through the walls (DEFRA, 2014, VMM, 2015). In literature, a distinction is usually made between two types of dry proofing: active dry proofing and passive dry proofing. Active (or manually or temporarily) dry-proofing is based on manually installed and activated measures to prevent flood water entering building openings such as sandbags, door guards and air brick covers. Passive (or automatic or permanent) dry proofing uses permanently placed or automatically operated measures, such as flood proofed windows and doors, impermeable wall coatings, airbrick covers and sump pumps (Thurston et al., 2008). Generally, passive dry proofing is expected to have relative high reliability factors compared to active dry proofing because of higher human risks (JBA Consulting, 2012).

### Effectiveness to reduce flood

A major concern is that dry flood proofing requires walls that are substantially impermeable to the passage of water and structural components having the capacity to resist hydrostatic loads and buoyant forces (NYCCDC, 2014b). As a general principle brick-stone and concrete walls are able to resist hydrostatic loads of flood levels up to 60 – 90 cm, depending on the building age and positions towards the water flow (VMM, 2015), although brick walls are only watertight for a relative short period of 20 – 60 minutes (EA, 2015). Because of structural integrity problems and the increasing risks of a sudden failure of the dry-proofing measures the maximum level to which dry proofing is still effective is usually set to about 50-60 cm (Thurston et al., 2008, FEMA 2014b, DEFRA, 2014). Particularly when temporarily deployed or manually operated techniques are used and when applied to older buildings, particularly brick stone constructions, the maximum level is more likely lower than 50 cm. When higher flood levels are expected permanent measures as flood doors can be installed, although they are usually only cost-effective when applied to larger buildings (FEMA2014b). Another challenge is that dry proofing needs to address the risk of ground water pressure through the basement floor and walls and the potential for floodwater to rise up through the walls (DEFRA, 2014). Particularly in older buildings, the options to prevent ground water flooding are limited and usually requires the replacement of wooden or brickstone flooring with concrete flooring, which is expensive and technically challenging as it requires a structural retrofit (NYCCDC, 2014b). It can be concluded that dry proofing only provides an effective solution to mitigate flood risk when a sufficiently watertight basement construction can be ensured. However, it still needs to be recognised that dry-flood proofing does not provide full safety. Especially for existing buildings, to provide sufficient impermeability of walls and foundation require large investments. The residual risk of floodwater seeping through brickwork

and ground water rising up through the walls and floors still results in flood levels of several cm indoors. Particularly the humid conditions caused by flooding or high ground water levels may lead to severe structural damages and health risks. To reduce the damage, dry proofing is usually deployed in combination with sump pumps that are located at the lowest point, usually the basement or crawl space. The New York Flood resistant building codes define impermeability as no more than 4 inches of incoming water accumulating during a 24-hour period (NYCDCP, 2014b).



**FIGURE 4.10** Example of retrofitting dry proofing to an existing office building in Manhattan, New York (left) and an historical building in Kampen, The Netherlands (right). Both dry proofing solutions are based on installing panelised flood protection during high water conditions. Photos by author.

Because of the hydrostatic forces, dry-flood proofing is only effective for homes with masonry or concrete walls and only in shallower and short-lived flood events. The longer the duration of a flood – usually defined as no more than 24 hours – the risk of failure of dry-proofing measures and the risk of groundwater seepage increases considerably (FEMA, 2014b). Another consideration is that in densely urban typologies dry flood-proofing is the most effective when applied to all ground floor spaces of one building block, to avoid structural integrity problems through water pressure building up in adjacent non-protected or wet flood-proofed properties. Dry proofing a complete building block does require the readiness to cooperate and the capacity to agree on a common strategy, which is not always an attainable situation. Dry proofing is therefore the most effective for detached or semi-detached properties (Thurston et al., 2008) and is not recommended for homes with basements (FEMA 2014b). However, dry-proofed architecture has been criticized on the negative visual effect of blank walls on the streetscape (**Fig. 4.11**).



**FIGURE 4.11** Dry-proofed architecture in Feijenoord, Rotterdam. The blank walls of dry-proofed buildings may have a negative visual effect on the streetscape and require careful design. Photos by author.

In the Netherlands, the majority of buildings is built on a below grade crawlspace-foundation. Because of all heating, sewer and power infrastructures enters the building through the crawlspace and concrete floor slab, it is extremely difficult to make the crawlspace and concrete floor sufficient watertight to withstand underground water pressure. Dry proofing seems to be most effective when integrated into the design of new buildings in which the dry-proofed zone becomes part of the building's structure, for example when used as a parking garage. Incorporating property-level adaptation measures into the design of buildings offers more options for low-impact, high value solutions. A major disadvantage of incorporating a watertight zone in the design of buildings is that it may have a negative effect on the streetscape and the limited adaptability of these solutions.

Dry proofing large building complexes, such as hospitals or commercial buildings is usually more complex. Dry proofing large buildings require connected permanent and removable floodwalls and floodgates. Usually, additional measures such as on-site storm water management must be provided to prevent storm water flooding of the area during a storm event. This can be achieved by on site storm water retention or by installing a pumping system that discards storm water over the flood protection.

#### MEASURES TO DRY-PROOF RESIDENTIAL BUILDINGS

- making walls impermeable
- closing off or extending building openings or ventilation vents.
- installing sunk pump
- sewer one-way valves to prevent sewer overflows
- sealing the ground floor and closing off all entry points for gas and telecom

### Cost effectiveness

There is evidence that dry proofing is cost-effective although it highly depends on type of flood, and the typology, size, age and construction of the building. The British Environmental Agency (EA, 2015) reported that the costs of implementing a complete package of dry proofing measures consisting of door gates and air brick covers to protect a residential building up to a 60 cm (2 ft.) flood would range between €3,000 – €6,000 (2008 prices). When including flood valves and external wall treatments the costs are more likely between €14,000 and €20,000 (ABI, 2009). Aerts, et al. (2013) estimate costs of dry proofing €7,500 - €12,500 based on 2009 FEMA index numbers and a 2 ft. wet proofing level. A 2008 study (Thurston et al., 2008) on the effectiveness of dry-proofing and wet-proofing measures in reducing flood risk found that dry proofing is only economic worthwhile for properties at high probability flooding with an annual chance of flooding of 2% or more (50 year return period). Another study (JBA Consulting, 2012) found that active dry proofing of residential buildings is only cost beneficial with an annual change of flooding of 2,5% or higher (40 year return period) and passive dry proofing at an annual probability of 4% (25 year return period). In other words, for households that flood more than once in every 50 years, the benefits outweigh the up-front investments. The cost-effectiveness ratio of active dry-proofing measures is even higher than passive dry-proofing measures, but the damages are only reduced to an average 50% per building, while passive measures may reduce damages to 65% and 84% (Thurston et al., 2008). These studies, however, focussed on the costs of retrofitting dry proofing. Incorporating passive dry proofing measures in new buildings is way less expensive.

### Wet flood proofing

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Wet-flood proofing is a flood-proofing technique based on allowing parts of the structure to intentionally flood by equalizing hydrostatic pressures on the building and by using flood damage-resistant materials (NYCDCP, 2014b). Wet-flood proofing includes measures aimed to limit the damage caused once it has entered and allow quick recovery (Defra, 2014). This can be achieved by raising all mechanical and electrical systems, such as electrical panels, boilers and fuel tanks to above the expected flood level, the use of flood resistant materials such as waterproof plaster, tiles or other flood resistant flooring, and provide sufficient openings for water influx and exit points to avoid hydrostatic pressures to be built up and cause structural failure (FEMA, 2014b, NYCDCP, 2014b). Elevating electrical, mechanical and heating systems to above the expected flood levels reduces the flood damages considerably and increases the speed of recovery after a flood. Relocating critical systems can be relatively easily implemented, however, adapting an existing electrical network is challenging and requires a large-scale renovation. Particularly, in the US oil spills due to fuel tanks that are located in basements cause long-term and expensive renovation works (FEMA, 2014b) and need to be relocated to less vulnerable locations.

Wet proofing is effective to considerable flood levels, however is not suitable for high velocity conditions or quickly rising water levels due to hydrostatic pressures being built up because of unevenly rising water level outside of the building (DEFRA, 2014). The British Environmental Agency (EA, 2015) concluded that wet proofing is mostly effective for high probability flooding where the depth of flooding exceeds 0.60 m (3 ft).



**FIGURE 4.12** Left: wet-proofed two-family homes in Red Hook, New York City, US. Photo by author. Right: wet-proofed buildings at the Oranjeboomstraat, Feijenoord Rotterdam during construction. The hall is located at street level, while the ground floor is elevated above expected flood levels Photo by Eric Offereins on Skyscrapercity.com.

### Costs-effectiveness

Although wet flood proofing is less expensive than alternative measures, such as elevating a building (FEMA, 2014b), the evaluation of costs of wet proofing varies considerably depending on the intensity of the interventions and building typology. Some sources report that wet flood proofing may be inexpensive (Aerts et al., 2013, NYCDPC, 2014b). Others sources (ABI, 2009, Finlan, et al., 2014, City of Rotterdam, 2014) show that wet proofing, particularly of mid and high-density urban typologies, prove to be extremely expensive because of the costs of relocating building systems and reduced usability of wet proofed spaces. However, wet proofing can be inexpensive when deployed in combination with a rebuilding or extensively repairing of buildings after a flood. The indicative costs estimations of retrofitting wet proofing measures to residential building ranges between € 4.000 – 10.000 (Aerts et al., 2013), €15.000 – €20.000 (EA, 2015) to €50.000 (ABI, 2009) per building. These different numbers can be explained by differences in packages of wet proofing measures and differences in building typologies, but more importantly, it reflects that wet proofing can be based on low impact and low-costs measures, such as using flood resistant flooring, which can have a positive effect on the risk of flood damage to a building or its contents. Additionally, wet proofing is only effective when the flood-proofed spaces are less

intensively used or when interiors can be easily relocated prior to a flood. This requires a change of use or, in some cases, giving up habitable spaces, which, particularly in higher density conditions may lead to a depreciation of the real estate value. Although cost-effectiveness is an important factor, the preparedness to invest in wet or dry proofing measures is also conditioned by a range of other factors, including the perception of the risk and social-economic position of households (Thurston et al., 2008) and the requirements from the insurance industry.

A 2008 DEFRA report (Thurston et al., 2008) concluded that wet proofing is only cost-effective when installed in a building that has a greater than 4 % annual risk of flooding (a 25 year return period). Also a recent study (JBA consulting, 2012), based on a survey of 34 building types of several ages, found that wet proofing is only cost beneficial at high frequency flooding with an annual flood risk of 20% (a 5-year return period) or more. When wet proofing measures are installed in combination with a large overall renovation the investment is becoming worthwhile at a 2 % annual risk of flooding (a 50 year return period) (Thurston et al., 2008). Again, the cost beneficial ratio depends greatly on the type of flood and building size, age and structure and may vary considerable, however, an interesting finding is that wet proofing is most effective under high probability flooding with considerable flood levels that exceed the threshold of dry proofing measures.



**FIGURE 4.13** Left: elevating of an existing wood frame building above flood elevation level, Jersey Coast, New Jersey, US. Picture right: new constructed waterfront property on Galveston Island, Texas, US. Photos by author.

### Elevating buildings

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Elevating a construction is an effective way to improve the flood resilience of buildings without losing habitable space within the building. In the United States elevating homes is one of the common retrofitting methods (FEMA, 2014b). There are

basically two options to elevate buildings. The common approach is to lift the existing structure to a new level and install a new or improved foundation. Another option is to constructing an elevated floor to above the flood level inside the building (NYCDCP, 2014b). Especially nineteenth-century buildings provide enough room in floor-to-ceiling heights to allow for an elevation of the ground floor of 10-30 cm (1 foot). An alternative of this in-build elevation technique, which is applied to typical US wood-framed houses is to leave the house on its original foundation, extend the walls and roof and add a new elevated floor inside the building (FEMA, 2014b). In the Netherlands, a widely practiced building method is to elevate the building plot to above the expected flood level. Ground level elevation by filling it with silt or sand is economic beneficial between flood probabilities ranging between 1/10 and 1/250 a year (Asselman & Slager, 2013) although it must be recognized that the economic feasibility of this method highly depends of the availability of fill material and specific site conditions. Additionally, elevating land within existing urban conditions is challenging because of the required adjustments to overcome height differences with lower streets and plots. Elevating buildings, particularly in high-density conditions is extremely expensive and challenged because of structural integrity limitations and the need of collaboration with several neighbouring property-owners (NYC, 2013). Depending on size and building quality of the building, elevating a residential building in the US ranges between \$ 30.000 (€ 27.000) and \$ 90.000 (€ 82.000) per building (Aerts et al., 2013), or, in the Netherlands, between € 20.000 to € 120.000 per building (RWS/CURNET, 2008).

### Managed retreat

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For extremely high-risk areas and areas that are under constant environmental pressure such as coastal erosion, a managed retreat strategy could be considered as a long-term option. Managed retreat is 'the process of removing development from areas vulnerable to flooding and the prevention of future development (NYCDP, 2013a: 72)'. Generally, a managed retreat strategy requires a buy-out programme, in which the state or local government purchases and demolishes the property, and changes land use to open space, recreation or nature but it may also consist of proactively changing land use to avoid future developments in flood exposed areas (NYCDCP, 2013a). A managed retreat is only effective when the costs of maintaining flood risk management exceed the value of the property that it protects, which is mostly the case in extreme low-density, isolated coastal waterfront areas. Additionally, a buy-out programme relies on full participation of the community to be effective, making this approach expensive and politically sensitive, as it requires a long-lasting funding and strong commitment from both the community and decision makers. In high-density urban waterfront conditions a managed retreat strategy is the most expensive adaptation option and not regarded as a viable option (NYC, 2013, NYCCDP, 2013a). However, a managed retreat or realignment of the flood-protected area can

be an effective approach as part of a post-disaster rebuilding strategy, for example in Japan after the 2011 tsunami, or when the intervention has a more widespread impact on reducing flood probabilities of adjacent sites, for example when it is part of increasing the storage capacity of a river.

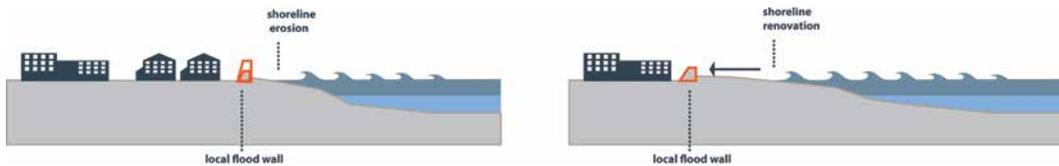


FIGURE 4.14 Adaptation responses “hold the line” (left picture) or a “managed realignment” of the first line of defence. Pictures adapted from Cooper, et al. (2002).

On a lower scale, a managed retreat strategy can be operationalized by a change in building requirements that regulate the use of ground floor spaces for buildings in the flood zone. Rezoning is another effective instrument to incentivize the development of flood resilient buildings and relocation of flood sensitive functions.



FIGURE 4.15 Elevated shore power supply facility in Dordrecht, The Netherlands (left) and flood protected power distribution station at the Noordereiland, The Netherlands. Photos by author.

### Flood-proofing critical infrastructure

An important element in vulnerability-focused adaptation entails adapting infrastructure such as power, heat and sewer systems, and underground infrastructure to enhance the recovery capacity after, and provide adequate performance during, a

flood. For example, flooding may cause temporarily failure of power systems or reduced accessibility of certain locations. However, when the impact of these failures is large, trigger other system failures, or is crucial for a smooth recovery, the infrastructure is critical. Critical infrastructure is broadly defined as those infrastructures of key public interest whose failure could cause extensive disturbances or impacts (Hellström, 2007). Applied to coastal flood risk, critical infrastructure is defined as the infrastructure that is needed for maintaining a system's performance during, or support recovery after, a disaster (Zimmerman & Faris, 2010). Particularly energy infrastructure is critical as most other urban facilities and infrastructures rely on its service and a failure of the power infrastructure may have widespread impacts. These system interdependencies of infrastructures is a particularly important factor in assessing flood risk because cascading effects may occur in which one failure triggers another infrastructure failure. Thus, assessing climate sensitivity of critical infrastructure demands a careful assessment of all system components and their interdependencies (Zimmerman & Faris, 2010). Chapter 5.1 elaborates in more detail on critical infrastructure vulnerability of the cases in Rotterdam and New York. Adaptation actions for reducing the sensitivity of power infrastructure are elevating or dry-proofing the distribution stations and transmitting stations to above the expected extreme flood level (Fig. 4.15) or protect existing infrastructures through temporarily or fixed flood protection (De Graaf et al., 2012). An alternative approach is to design a power infrastructure network that operates independently of other not flooded parts of the system, or that allows for a temporarily and local shut down during a flood.

### Behavioral responses: evacuation and flood insurance

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Behavioral responses that influence the coping and recovery capacity of coastal communities, such as moving a household's inventory prior to a flood to higher levels, or an early evacuation of vulnerable groups, significantly reduce flood damages and risk of casualties, or help to recover quickly after a flood. To stimulate these behavioral responses, measures such as an early warning system, improvements of disaster management procedures, or broaden insurance conditions are effective adaptation responses. However, as already mentioned in the introduction of the chapter, these soft measures have not been assessed in this elaboration in depth and will not be included in the development of adaptation paths.

## § 4.3.5 Conclusions

### Building level adaptation is only effective for high frequency flooding and low depth, low energy flooding

Fig. 4.16 shows the (indicative) cost effectiveness range relative to the maximum flood depths and annual probabilities of flooding of several property level protection measures. The graph shows that the majority of property level protection measures is only generally only beneficial from an economic point of view for high frequency floods with an annual probability of 1% (100 year return period) and higher. Dry proofing existing buildings is cost effective under a larger range of flood probabilities compared to wet proofing but only provides robust flood protection in situations of low depth flooding. Wet proofing is only cost effective for extremely high frequency flooding, although the cost-effectiveness strongly depends on the flood depths and probabilities. Wet proofing is a more effective approach to reduce costs of a larger range of flood depths.

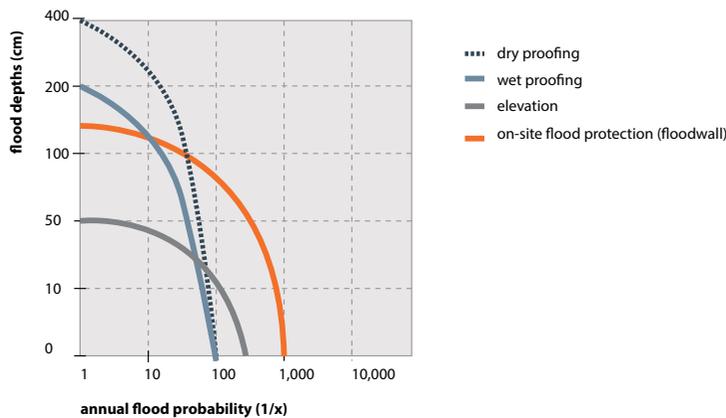


FIGURE 4.16 (Cost)effectiveness range relative to maximum flood depths and annual recurrence of several property level protection measures

In addition, wet proofing measures offer more potential to piggyback on planned maintenance and renovations cycles of building systems and interiors that considerably may reduce costs but also allow for a step-by-step adaptation process. Dry-proofing measures offer fewer opportunities to align with other investments. However, property level protection may raise ethical and societal objections as it may result in socio-economic inequalities or unacceptable societal costs for recovery and disaster management. Additionally, an important consideration is that property

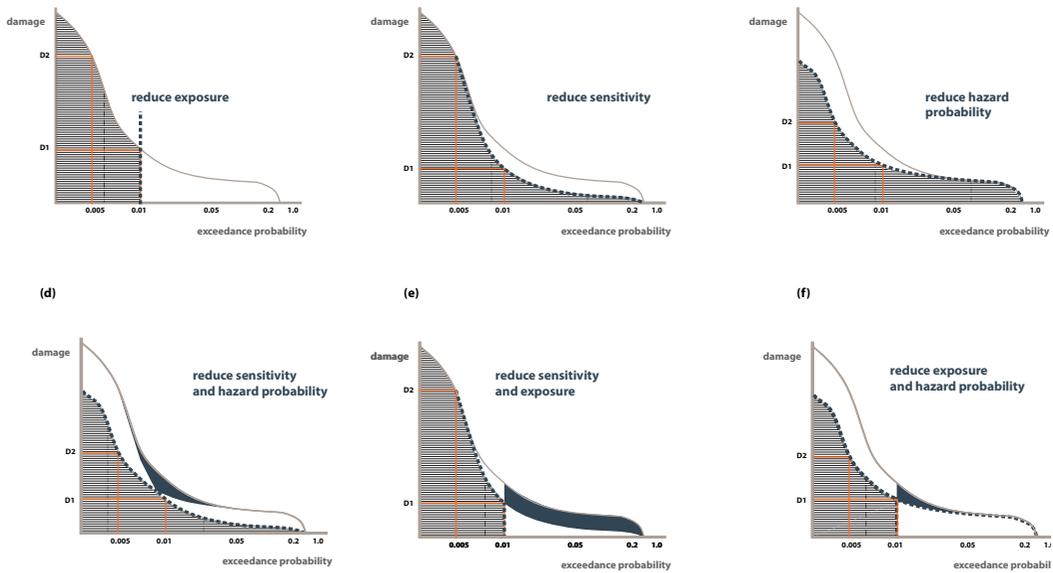
level protection does not offer the same level of protection compared to a district-wide flood defence infrastructure. However, it is an effective method to manage the consequences of flooding when a district wide flood defence would be too expensive or in combination with measures that reduces the flood depths such as storm surge barriers or land elevations.

A major concern is that building codes or building regulations may impose limitations for wet proofing or dry proofing. For example, the Dutch National Building Code requires a maximum distance of 3 meters between the entrance of a residential building and the meter. This restriction limits the opportunities to relocate the meter to spaces above the flood level. Also accessibility regulations run counter to adaptation strategies that are based on elevated lower floors. Flood protection measures such as a floodwall, raised quay sections, and temporary flood retaining measures are effective under a wider range of flood levels and probabilities, depending on the protected area and local flood characteristics. Flood protection measures, such as levees, floodwalls and barriers are effective to reduce the risk of high probability range flood events and more extreme high-energy conditions, such as high velocities or strong waves. Additionally, flood protection offer opportunities for a high level integration in urban design of waterfront areas, if well designed and planned.

### Guiding models for coastal flood resilience

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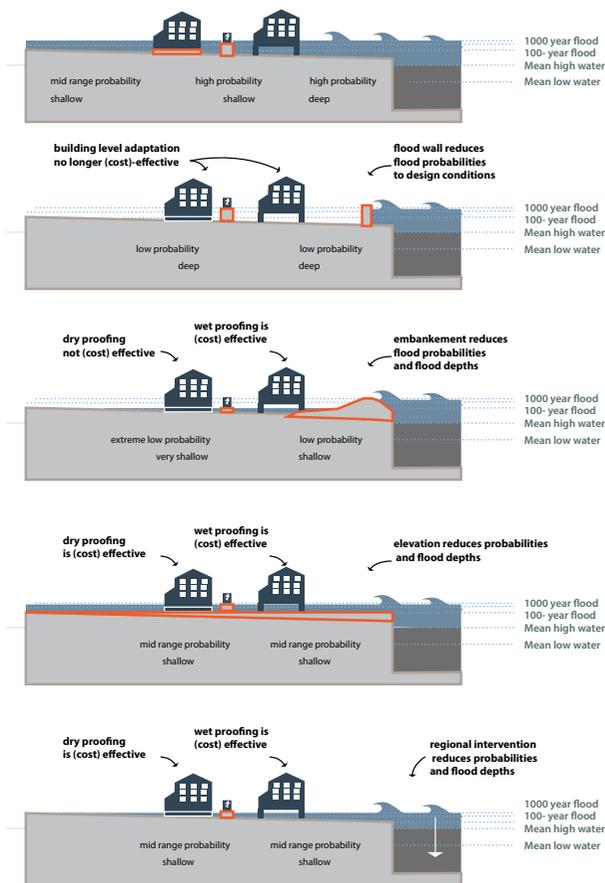
The question is what combinations of above introduced options that reduce hazard, exposure or vulnerability are complementary and most effective to reduce risks of coastal flooding? There are only a few combinations of adaptive measures that are complementary (see **Fig. 4.17** and **4.18**). A major challenge is that the development of flood protection negatively influences the cost benefit ratio of property level protection. This can be explained as follows: a local flood protection infrastructure, such as an embankment or floodwall reduces the probabilities of a flood to the level of the flood to which it was designed, which is usually more than the 100 year flood. The residual probability of flooding due to a risk of overtopping or a failure of the flood protection comes with low probabilities but high flood levels and velocities, making dry proofing ineffective and wet proofing not beneficial. This is particularly true for flood defence measures that reduce the residual flood risk to probabilities that exceed the cost-effectiveness range of property level protection measures as illustrated in **Fig. 4.16**. In other words, district-wide flood protection designed to the 100-year or higher flood level and property level protection are, from an economic point of view, not complementary to one other.



**FIGURE 4.17** Damage reducing effect of several adaptation actions (a, b and c) and combinations of these adaptation responses (d, e and f). The dashed zone indicated the residual risks and dark blue area indicates the extent of overlap. A combination of (e) a local flood protection (e.g. a floodwall) and reduced building sensitivity (e.g. dry proofing or wet proofing) has broadly the same impact range on flood damage reduction and is therefore as combination less effective.

**Fig. 4.17** shows the loss reducing effect of several adaptation actions relative to the exceedance probability of flood defences and the combined effect of these adaptation responses (d, e and f). The dark blue area indicates the extent of overlap. A combination of local flood protection (e.g. a floodwall) and reduced building sensitivity (e.g. dry proofing or wet proofing) has broadly the same impact range on flood damage reduction and is less effective. More effective combinations include combinations of measures that have different impacts on the probability-loss curve. For example, measures that reduce the hazard probability or lower the inundation level of a flood are complementary to measures that reduce sensitivity. For example, elevating a waterfront area reduces the local inundation levels and flood probabilities to the range within which property level adaptation – in this case dry proofing— becomes effective and beneficial. This is for example, the design principle of Hamburg’s Hafencity. Also, nature based solutions, such as breakwaters and living shorelines, that reduce wind and wave set-up may have a positive effect on the effectiveness of property level protection. For example, wet proofing becomes more effective under relative calm conditions. Additionally, flood protection structures designed so that they are unlikely to fail during extreme conditions (e.g. super levees) may increase the options for building level protections, as the reduce residual flood risk is reduced to relatively low inundation levels caused by overtopping or overflowing water. These moderated

inundation levels makes building level protection physically effective, although it may not be economic beneficial to invest in property protection due to the low probabilities.



#### Living with floods

Property level protection is cost-effective under high probability and low depth flood conditions

#### Floodwall

Local flood protection (e.g. a flood wall) reduces the probability of flooding, although a structural failure of the flood wall would still cause considerable flood depths and damages. This residual risk of low probability and high flood depths makes property level protection less effective or beneficial from an economic point of view.

#### Embankment

An embankment or levee, particularly when designed to be overflow resistant, reduces the probability of flooding to low probability and low depth flooding, making dry proofing less effective but wet proofing buildings optional. Flood proofing critical infrastructure could still be necessary, depending on the remaining risk of flooding.

#### Land elevation

Ground level elevation reduces the flood probabilities and flood depths. This creates potentially optimal conditions for wet- and dry proofing of buildings and assets. However, when the flood probability is reduced to extremely rare conditions building level protection would become less beneficial.

#### Storm surge barrier

A regional intervention that reduces the local flood probabilities or flood depths (e.g. a barrier) would have the same effect as a local land elevation and could potentially create optimal conditions for wet- and dry proofing of buildings and assets.

**FIGURE 4.18** Some illustrative examples of complementary “multiple lines of defense”. Best combinations include measures that influence the inundation level and probability of a flood with measures that reduce vulnerability of local waterfront communities. District wide flood protection combined with property level adaptation measures is generally not effective or beneficial, unless it reduces flooding to recurrent or seasonal flooding.

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## § 4.4 Improving designed adaptability of flood resilient urban landscapes

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### § 4.4.1 Designing for integrated and coupled systems

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A general assumption is that incorporating provisions in the design to allow for an easier adaptation to future conditions is more cost-effective than retrofit adaptation (Nicholls, 1995, Klein et al., 2004, Hallegatte, 2009, Hallegatte et al., 2013). One of the major challenges when integrating flood risk management measures into the built environment is the inequality of the two systems in terms of design parameters. Flood protection infrastructures, such as a floodwall, are major line infrastructures that operate as a networked system, in which the individual assets are functionally connected (Alegre et al., 2012), and which functions on the principle of system robustness (designed to work under a wide range of conditions). The built environment consists of a dynamic system of objects that function more or less independently and changes more incrementally. However, when the flood risk management infrastructure is incorporated in, or highly interconnected with other functions, which is the case in multipurpose flood levees the design of the flood risk management system is faced with a more dynamic context. The challenge is to design an integrated system that is able to move along with changing hydrological conditions, as well as changing urban conditions, requirements and uses. There are basically two strategies that improve the ability of designs to deal with evolving or changing conditions. The first is to incorporate expected future conditions in the design of large investments and infrastructures. This strategy is known as *robust* design. An alternative approach is to increase the flexibility or changeability of the adaptation option, to allow for a more co-evolutional development over time. In this section design strategies are reviewed and some examples of integrated or coupled waterfront areas highlighted.

### § 4.4.2 Robust design strategies

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Robustness is defined here as the ability of an adaptation option to perform under a wide range of possible futures (Ranger, 2011, Mens et al., 2011). Over-sizing is a commonly applied design strategy in the design of large infrastructure systems or structures that come with large life cycles or that cannot easily be modified. Over-sizing, also known as “safety margin” strategies (Hallegatte, 2009, Hallegatte et al., 2012) is often applied when uncertainties on performance requirements are high or when it is difficult to calculate strengths of a construction with any precision. This design strategy is cost-effective when building-in a safety-margin is relatively

inexpensive and manageable during the design and implementation phase compared to the overall investment costs and the expected retrofitting costs (Hallegatte et al., 2012). As an illustration, the Dutch primary flood defence design standards require a safety margin of 50 cm to be prepared for unforeseen changes (TAW, 1998).

Robust design strategies have proven to be particularly effective when the life cycle of the designed infrastructure is similar with the period of change.

Robust design strategies are faced with two key challenges. Firstly, robust design requires a future that is projected to be relatively stable. Secondly, over-sizing requires up-front investments, which is relatively expensive and may become redundant when change is not evolving as predicted. The new urban development of Hafencity, Hamburg in Germany clearly illustrates this challenge. This new city quarter under development in Hamburg is located outside of the protection of the primary flood defence system. To prevent flooding all new buildings in this area (Fig. 4.19) are built on elevated plinths, or earth mounds ranging up to 7.5 to 8.0 m above mean sea level ([www.hafencity.com](http://www.hafencity.com)). This level is well above the highest storm surge ever recorded (+ 6.45 m in Hamburg St Pauli in 1976) and takes into account the short-term expected flood levels due to climate change. However, it is expected that long term flood levels due to climate change and dredging works on the Elbe River may well reach up to the design level of Hafencity in 2085 (Grossmann et al., 2006). Due to the inflexibility of the architecture and urban design, Hafencity is not able to adapt to respond to more extreme flood conditions. Additionally, the higher costs of building on flood-proofed plinths and mounds are partly mitigated by the benefits of multifunctional uses and intensively land use (Mees et al., 2013).



**FIGURE 4.19** Hafencity in Hamburg (Germany) is an example of the robust design principle. In this new waterfront development flood protection is integrated into the architecture of buildings and urban design: all buildings are built on elevated flood proofed plinths that are used for parking and storage of 7.5 to 8.0 meter above mean sea level. This is 0.75 – 1.25 m above the highest storm surge ever recorded. Pictures by author.

### § 4.4.3 Adaptable design principles

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However, when over-sizing is too expensive, technically or socially unfeasible, or the uncertainty on long term change is great it is necessary to incorporate provisions in the design that increases the ability to adapt. In many fields of research, such as product design science, architecture, system engineering, computer science and information technology, changeability has been object of extensive research. Changeable systems are defined as ‘those systems whose configurations can be changed, altered, or modified with or without external influence after the system has been deployed (Ferguson et al., 2007: 2)’. Fricke and Schultz (2005) distinguish several aspects of strategies that permit flexible response to changing conditions, based on whether external or internal implementation of changes is needed. They distinguish between adaptability, flexibility and agility. Flexibility, here, is defined as a system’s ability to be changed easily by adding or changing external elements or conditions. In contrast, adaptability is defined as a system’s ability to adapt *itself* towards changing environments. Agility refers more to the process of adaptation and is defined as a system’s ability to be changed rapidly or easily.

In architecture design science, adaptation or flexible design has been intensively studied. Although it is referred to as wide range of definitions and terms, flexibility in design aims to respond more easily to a variety of potential changes. Douglas (2006) defines building adaptation as any intervention to adjust, reuse or upgrade a building to suit new conditions and requirements. Adaptability is defined as ‘the capacity of a building [or infrastructure] to absorb minor or major change’ (Grammenos & Russell, 1997, cited in: Douglas, 2006). Schmidt et al. (2010) add to this definition the element of value maximization. Adaptability is ‘the capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing value through life (idem: 3)’.

DESIGN PRINCIPLE	PURPOSE
Adjustable	Change of task
Versatile	Change of place
Refitable	Change of performance
Convertible	Change of function
Scalable	Change of size
Moveable	Change of location

TABLE 4.2 Overview of adaptive design principles and corresponding purposes. Based on Schmidt et al. (2010)

Although above-mentioned design principles are not mutually exclusive, there is certainly some overlap and a risk of semantic confusion (see **Table 4.2** for an overview of adaptive design principles). In order to avoid a semantic discussion, here a simpler subdivision of designed adaptability principles is followed introduced by Douglas (2006), which is based on three design principles: adjustability (allowing for changes in use or performance), expandability (allowing for increase in volume or capacity), and convertibility (allowing for economic, legal or physical changes in use of space, buildings and infrastructure).

### Adjustability

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Adjustability is defined as incorporating modifications in the use or design of a building or infrastructure in anticipation of future conditions or requirements. Adjustability requires additional upfront costs but they may remain relatively small, particularly when the modifications to the design are beneficial to other functional requirements of the building or infrastructure. Adjustability can be enlarged through incorporating structural redundant capacity into the design of an object to allow a future expansion. As an example, in the Visschersbuurt in Papendrecht (NL) new one-family homes were built on a concrete flood slab resting on steel pillars to allow raising building to new required elevation level of the levee (**Fig. 4.20**).

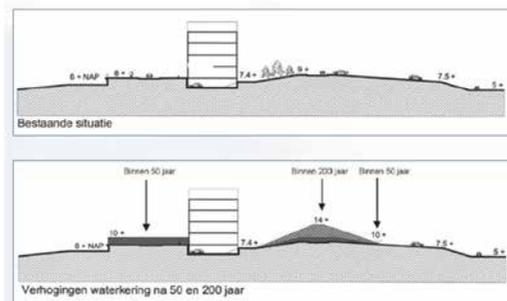


**FIGURE 4.20** Adjustability. One-family homes at the Visschersbuurt at Papendrecht. The design of this row of buildings includes structural provisions to allow for a future elevation of the levee. The houses are constructed on a concrete floor slab resting on steel cylindrical pillars that can be raised to required elevation levels. Photo left courtesy of Kingma Roorda Architects, right photo by author.

## Expandability

Expandability is a design principle allowing for an (low cost) extension of buildings or infrastructure in response to changing conditions. Expandability can be based on preserving space, over-sizing critical elements or built-in redundancies into the design to allow for a future expansion. For example, over-sizing the foundation of a floodwall allows for a future enlargement of the wall without the need to increase the bearing capacity of the foundation. This approach can be cost-effective because it allows for right-in-time responses to future conditions and it opens-up opportunities to mainstream investments with processes of urban renewal and maintenance. Note, however, that this approach also could lead to higher costs in the future because the future investment in improving the structure may be more expensive than the initial costs for a robust or over-sized design. In general, this strategy is effective when the costs of over-sizing or preservation of space are relatively small compared to potential costs of over-sizing or when retrofitting adjustments in the future is extremely expensive.

Expandability is at the heart of the Dutch flood defence system. The regulatory system protects flood defences from land uses that could limit its ability to expand to expected future design levels. However, in highly urbanized areas this strategy can be expensive and under constant societal pressure, or get lost over time.



**FIGURE 4.21** Convertibility. Providing high floor-to-ceiling height in the design of waterfront high-rise at the Vlissingen Boulevard (top picture) allows for a relative easy conversion of the first floor use in anticipation of an expected elevation of the boulevard in the future. Cross sections: Gemeente Vlissingen, 2012. Photo by author

## Convertibility

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Convertibility is defined as allowing economic, legal or physical changes in function of space, buildings and infrastructure in anticipation of changing conditions (Douglas, 2006). Convertibility is an effective design principle when the costs of change of use are relative small compared to the costs for future adaptation without provisions for conversion. Low costs convertibility can be achieved by incorporating provision in the design and the legal arrangements that keep large-scale alterations or structural modifications to a minimum (Douglas, 2006). The Vlissingen Boulevard nicely illustrates convertibility as adaptive design principle. In the architecture of new seaside residential apartment buildings an oversizing of the floor to ceiling space of the ground floor allows for convertible first floor uses to accommodate a future elevation of the primary flood defence and boulevard (Fig. 4.21).

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## § 4.5 Conclusions

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This chapter aimed to understand what adaptive measures and design strategies are most effective to reduce flood risk of coastal urban waterfronts and offer added value when improving flood resilience of urban waterfront areas. There is a wide range of adaptation actions available that allow for small-scale building-to-building adaptation to large-scale and long-term flood protection landscapes offering many opportunities for a complete redesign and rethinking of the position of urban waterfront. Building level adaptation is only effective for high frequency flooding and low depth, low energy flooding, whereas flood defence systems are effective within a larger range of flood probabilities and at more extreme conditions. Generally, flood defence, if well designed and planned, seems to offers more opportunities for integration into the urban realm and produce co-benefits. Resilience is enhances when there is a wider range of measures available that can be applied at multiple scales of intervention and addresses all elements of risk (hazard reduction, exposure and vulnerability). However, combining of adaptive measures across scales and elements of risk is challenged because of economic constraints and reduced effectiveness.

Finally, design strategies for integrated solutions were reviewed. Over-sizing is a commonly applied design strategy in the design of large infrastructure systems or structures that come with large life cycles or that cannot easily be modified. However, it requires high up-front investments, which is relatively expensive and may become redundant when change is not evolving as predicted. Designing for flexibility means minimizing interdependencies or providing measures that allow for an improvement or change without negative effects to other components. Flexible design strategies are based on improving adjustability, convertibility and expandability.

In the chapter 6 and 7 this toolbox of measures, strategies and design principles is applied to two case study areas in Rotterdam and New York City, as introduced in chapter 5.





*East River bikeway, Manhattan, New York, USA*



*Noordereiland, Rotterdam, The Netherlands*



*Brede Hilledijk, Rotterdam, The Netherlands*

PART 2 Cases





# 5 Cases

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## § 5.1 Introduction

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This section introduces two cases and compares the flood risk characteristics and vulnerabilities of the Rhine Estuary Region unembanked area (section 5.2) and the New York City- New Jersey waterfront (section 5.3), and discuss the effectiveness of the flood risk policies of both regions (5.4).

This chapter is based on literature review and interviews with city officials, planners, landscape architects and local community representatives in Rotterdam and New York during several site visits. Annex 3 provides an overview of names of persons interviewed.

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## § 5.2 Rotterdam-Rhine Estuary

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### § 5.2.1 A delta landscape in inverse

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The urbanized area of Rotterdam is one of the largest metropolitan areas of Europe that is located at the confluence of the rivers Meuse and Rhine into the North Sea making this area vulnerable for both coastal and fluvial floods (Delta Programme Rijnmond-Drechtsteden, 2014). A large network of dunes, primary dykes, walls and locks protects the low-lying urbanised polders of Rotterdam from flooding, including the lowest urbanised polder in the Netherlands, which lies as low as 6.67 metres below sea level (**Fig. 5.1**). A considerable part of the Rhine Estuary Region, including the port, is, however, located outside the levee protection system. The region has large unembanked alluvial areas that are almost entirely urbanized and not protected by the primary flood defence system. The former port areas and historic merchant districts of Rotterdam, Dordrecht and Vlaardingen are exposed to tidal and seasonal fluctuations in water levels. The majority of these unembanked areas are built on higher ground

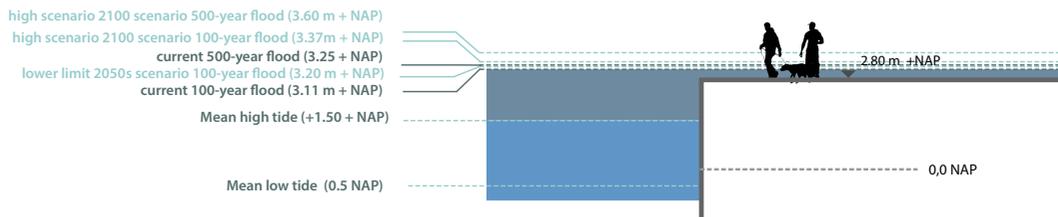
or have been elevated over time to a height above high tide. Approx. 65,000 people live in the unembanked area of some 200 ha, an area equivalent to that of a small provincial city, including the largest port-industrial cluster of Europe (Veerbeek et al., 2010a). In the larger metropolitan Rijnmond-Drechteden region more than 2.020 hectares of land is located in the 100-year flood zone between the North Sea and the city of Dordrecht (RWS, 2009), of which a large part is urbanized or in use for industrial activities (Veerbeek et al., 2010a).



**FIGURE 5.1** man-made landscape of elevated ports located outside of the primary flood protection system and deeply subsided polders (dark grey area) that are located several meters below sea level. Picture: City of Rotterdam/ TU Delft- Inge Bobbink.

The Rotterdam-Rhine estuary is protected from storm surges from the North Sea through a series of fixed and flexible storm surge barriers, part of a larger chain of barriers along the Dutch coast created in the aftermath of the disastrous floods of 1953. Being the most iconic barrier, built in 1997 as the final stage of the Delta Works programme, the Maeslantbarrier's main purpose is however, lowering the flood levels at the river during storm surges so to prevent a large dike improvement of the primary flood defence network. The Maeslant barrier closes when flood levels at Rotterdam reaches 3.0 m + NAP or 2.8 m at Dordrecht (RWS, 2009). Although a large part of the area is elevated above average storm surge levels and benefits from the protection of

the Maeslant storm surge barrier, a considerable part of the unembanked waterfront areas is still vulnerable for flooding (Veerbeek et al., 2010a, Veerbeek, 2013). The flood prone parts of the unembanked areas are faced with a flood probability that ranges between yearly to 100-year events. In the next decades the risk of flooding is expected to increase due to rising sea levels and subsidence, as well because of these port areas, due to their position close to the city and river are attractive places for urban development.



**FIGURE 5.2** Flood levels at the current and projected 100-year and 500-year flood levels at the Noordereiland. Although the expected flood levels are reduced considerable since the Maeslant barrier became operational, the area is still vulnerable for fluvial flooding.

The low-lying flood prone areas differ when it comes to flood characteristics such as flood frequency, water depth and flood duration (Veerbeek et al., 2013). The majority of the flood prone areas has a mound-shape or a gradually rising ground level, which makes flood duration limited to short-lived, low inundation events, since flood water is drained directly back in the river. Some areas are bath-tub-shaped because of land subsidence or because the quays have been raised in the course of time. Flooding of these areas happens more sudden and less predictable, and with relatively large vertical and horizontal velocities and water depths. These floods generally last longer, because water has to be pumped out. Flooding in these areas causes significant damages and severe social disruption because vital urban infrastructures, such as power supply and sewer system, will be disabled for at least several days. Flood velocities are expected to be relatively low, ranging between 0.1 to 0.25 m/s (Veerbeek et al., 2010a) although a sudden inflow of water into the lower located areas may be accompanied with higher flood velocities. Because of the tide and relative mild storm conditions it is expected that a flood is relatively short-lived and never last longer than 35 hours (Veerbeek & Gersonius, 2012).

## § 5.2.2 Changing conditions

### Sea level rise

Observed mean sea level rise along the Dutch North Sea Coast is 1.2 mm/year. During the last 2 decades the sea level rose 2 mm/year (KNMI, 2014). The Northeast part of the Atlantic Ocean follows the average sea level rise as observed globally, although compared to other coastal regions the increase in sea level is relatively small. It is not expected that storm surges will increase in power or frequency, making sea level rise the major driver of change (KNMI, 2014). Sea level rise has a significant effect on the expected water levels on the river. In the tidal dominated part of the estuary sea level rise is the dominant driver, whereas the upstream river dominated part of the river system is mainly affected by increase in river discharge (Slootjes et al., 2011). The impact of sea level rise on the tidal dominated river system is significant because of the high failure rate of the Maeslant barrier (Slootjes et al., 2011). This thesis uses KNMI 2006 sea level rise projections for the Dutch North Sea Coast (KNMI, 2014) that ranges between +0.15 m to + 0.35 m for the year 2050 and +0.35 to +0.85 m for the year 2100. Table 5.1 shows the effect of several KNMI '06 climate change scenarios for water levels at several return periods at Rotterdam and Dordrecht.

SEA LEVEL RISE	0	35	60	85
Climate scenario	Current situation	KNMI W/W+ 2050 KNMI G/G+ 2100 (lower limit)	KNMI G+ 2100 (upper limit)	KNMI W/W+ 2100
Frequency (1/x years) Rotterdam KM 999	Water levels in cm + NAP			
10	284	299	312	319
25	296	308	320	326
50	304	314	326	331
100	311	320	331	337
500	325	333	347	360
5000	346	368	396	415
10000	359	385	413	432
Frequency (1/x years) Dordrecht KM 976				
10	230		266	
100	257		294	
1000	281		322	

TABLE 5.1 Effect of sea level rise on water levels at different return periods for Rotterdam (km 999) based on KNMI '06 climate change scenario and Dordrecht (km 976). Source: Stone (2013) and Delta Programme Rijnmond-Drechtsteden (2014)

## Increase in peak discharge

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It is expected that changes in winter precipitation patterns (more intensive rainfall and less snow) have a substantial impact on the peak discharge of river water flowing down from Germany and France (KNMI, 2014). Although there are considerable differences in reported effects and uncertainties, the peak river discharge is expected to increase with 10 % for 2100 (KNMI, 2014). This increase in river discharge mainly affects flood probabilities of the river-dominated parts of the Netherlands and to a lesser extent the sea-dominated area of Rhine Estuary Region. However, the unembanked areas of the upstream-located city of Dordrecht are located in the intermediate zone in which both effects of increasing coastal as pluvial flooding are felt (see table 5.1).

## Subsidence

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Land subsidence can be natural and anthropogenic. In the Netherlands, the natural land subsidence due to geological processes is as low as a few centimetres. In deltas, the main causes of land subsidence is however mainly human-induced and caused by compaction of the shallow subsoil due to urbanisation and oxidation of organic soils caused by drainage (Lange & Gunnink, 2011). Land subsidence is not included in the KNMI '06 sea level rise scenarios because subsidence rates varies strongly along the Dutch coast (KNMI, 2014). Local subsidence due to land compaction may influence flood risks significantly. In Rotterdam the observed land subsidence rates range between 6 – 17 mm a year, depending on the sub soils (peat or clay) and age of urban development (Rotterdam, 2013). Detailed land subsidence measurements using INSAR data sets 2009 -2014 summarised in table 5.2 show relative moderate subsidence rates of 2-4 mm a year for the unembanked areas of Noordereiland and Feijenoord, although particularly the twenty-century port areas show considerably higher rates that locally exceed more than 8 mm per year (Heijplaat). In these areas, subsidence rates over a 50-year period exceed the expected increase in flood level due to sea level rise.

	SUBSIDENCE RATE (MM/YEAR)	SUBSIDENCE 50 YEARS (CM)
Noordereiland	2-4	10-20
Feijenoord	2-4	10-20
Heijplaat	2 – 8	10 – 40

TABLE 5.2 Average local land subsidence rates of three residential areas using INSAR data (2009 -2014). Note that in Heijplaat local land subsidence exceeds the expected sea level rise, particularly of mid and low-end scenarios.

## Changing urban conditions

The Rotterdam population is expected to grow with some 10 % in the year 2030. At the same time, it is expected that the composition of the building stock will change considerably, from a predominantly low-cost and affordable rental housing stock towards and more expensive housing and increasingly privately owned building stock (Rotterdam, 2015). Rotterdam's growth strategy is based on compacting the city centre and continuing the redevelopment of waterfront and former port areas. The Dutch Delta Programme developed long-term scenarios that reflect four possible future perspectives that differ in speed of climate change and socio-economic growth. These *delta scenarios* combine the KNMI 2006 G and W+ scenarios with the 2006 socio-economic development scenarios ('regional communities' and 'Global Economy') developed by the National Planning Agency. Either scenarios assume a population growth, particularly of the Randstad region, by over 10 % till the year 2050, and to double thereafter in the 'Global Economy' scenario, or, in Regional Communities scenario, a population decline from the year 2050 onwards (Deltaprogramma Rijnmond-Drechtsteden, 2014). Interestingly, both scenarios assume that the first phase of growth largely is accommodated in the unembanked, former industrial and port areas. Intensifying urban land use in these waterfront areas increases the consequences of a flood.

## Vulnerability

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### Buildings

The unembanked area of Rhine Estuary Region is home to about 64,000 inhabitants and 15,000 buildings (Veerbeek et al., 2010a). The building typology mainly consists of single-family low rise, historical waterfront buildings and mid-rise apartment buildings. Because of the relative shallow and short-lived flood characteristics it is expected that flooding of the residential waterfront areas mainly result in direct damages to the interior and buildings systems and infrastructure (Veerbeek & Gersonius, 2013). The expected increase in annual damages of the unembanked areas in the larger metropolitan region due to climate change is calculated at a € 34 to € 55 million and a € 87 to € 108 million at the year 2050 (W+) and 2100 respectively (Jeuken et al., 2012). In this risk calculations the future damages due to economic growth and urbanisation are not included and it is assumed that all future urban development is climate adaptive. Veerbeek and Gersonius (2013) found that the average damage to flood risk for the Rotterdam area is significant, but moderate. The total expected aggregate annual damage due to flooding to buildings in the unembanked areas is estimated at €77.000/year at the current situation. This number is expected to increase to an annual damage of €222.000/year at a 60 cm sea level rise scenario. Surprisingly, the majority of flood damages comprises for almost 50 % to damages to finishing and furnishing (Veerbeek & Gersonius, 2013). Although several

flood risk cost estimations methods vary considerably when it comes to valuing indirect damage costs making the costs estimations controversial (Deltaprogramma Rijnmond-Drechtsteden, 2014), it remains clear that, particularly under climate change the flood risks of the unembanked area increases substantially.



FIGURE 5.3 Typical low voltage (left pictures) and medium voltage distribution stations (right picture) at Rotterdam. Critical threshold of these cabinets is an inundation that reaches depths of 30 and 50 cm respectively. Photos: Robert de Kort (2012).

### Critical assets

Local power distribution stations, control cabinets and charging poles for electric transport appeared to be extremely vulnerable for flooding. A 30 cm inundation causes short-circuit which causes outages that last a considerable period of time and require extensive renovation (de Kort, 2012, Veerbeek & Gersonius, 2013). The critical inundation depth of low voltage cabinets and medium voltage distribution stations is about 30 cm and 50 cm respectively (Fig. 5.3). Street lanterns are vulnerable for flooding of about 35 cm. Inundation above this level will result in short circuiting since the cabling is not resistant to ingress of water (de Kort, 2012, Veerbeek & Gersonius, 2013). Based on information of the power supply company the power will be cut off already at a 20 cm inundation depth to avoid large-scale damages to the network and long-lasting recovery (de Kort, 2012). Due to the complexity and interconnectivity of the power supply network it is expected that a local cut off anticipating on expected flooding will affect a much larger area. In addition, it is expected that a power supply failure directly affect other critical systems in the area such as sewer pumping stations and district heating systems, which may lead to an increase in flood losses and recovery efforts. Although the potential cascading effects of power supply failure potentially contribute to an increase of flood risks, the extent to which this effect will occur is unknown.

The sewer system consists both of an old combined sewer and separated storm water and grey water systems. Wastewater from the unembanked areas is distributed to a wastewater treatment plant, located on both sides of the river embankments, using local pumping stations and pressurized sewerage transport pipelines. These local pumping stations are often located on the lower parts of the sewer system and are vulnerable for direct flooding but they will also be inactive during a power cut due to local flooding elsewhere. As many of the older residential areas in the unembanked areas have combined sewer systems, a flooding could lead to both outdoor and indoor sewer overflows and eventually result in environmental and water contamination and public health threats. Modern drinking water and gas distribution infrastructure is not vulnerable for flooding, although it is expected that older cast-iron gas pipes may breach at a flood level that exceeds more than 40 cm. Indirect effects of flooding, such as land sliding or settling after a flood may result in damages to the water and gas infrastructure, although experiences in pluvial flooding showed that this risk is small. Local gas distribution stations are vulnerable for flooding of more than 100 cm (de Kort, 2012). Parts of the area are connected to district heating. District heating consists of high-temperature distribution network and low-temperature transmitting stations for domestic hot water that are usually serving several building blocks. The high temperature distribution network uses several booster stations that distribute high temperature water and balance supply and demand on district level. As these booster stations are located in flood-protected areas or elevated land it is expected that the sensitivity of the heating infrastructure for flooding is mainly due to the vulnerability on block or household level. It is expected that the heat exchanging equipment that transmit hot water for domestic use on household level is severely damaged at a 40 cm flood level and fails at lower flood levels because of the interdependencies of power supply.

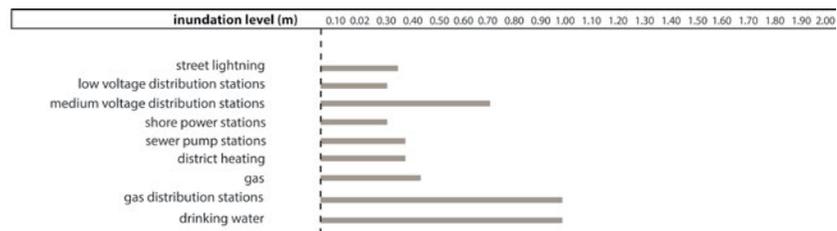


FIGURE 5.4 Vulnerability thresholds (maximum inundation level in m) of several critical infrastructure system elements.

### Infrastructure vulnerability

The local public transport infrastructure is well able to cope with small floods but at flood levels higher than 50 cm the area will not be accessible by mobile emergency services. Communication systems are less vulnerable for flooding. It is expected that the mobile phone network continue to function as the main transmission towers are located outside the flood zone. However, the fixed telephone network has a level of vulnerability similar to the power network. Two metro stations are located in the unembanked areas. Both stations are located well above the flood levels and the metro tunnel crossing the river Meuse is equipped with floodgates to both North and South sides (de Kort, 2012).

## § 5.2.3 Flood risk policy

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The Dutch national legislation on water and flood risk (Water Act 2009) distinguishes between areas that are protected by a primary flood defence system and areas that are located outside this system. From a legal point of view the unembanked areas are considered part of the river's flood plain. Consequently, the property owners do not enjoy flood protection and are bearing the full economic consequences of flood risk (van Buuren et al., 2014). This is in strong contrast to the areas that are located behind the primary flood defense that benefit from relative high levels of protection. The national government has redirected responsibility for flood risk of the areas that are not protected by the primary flood defence system to local and regional levels of authority. Municipalities are responsible for assessing flood risk, incorporating flood risk management in zoning regulations and provide information on flood risk (Water Act, article 5.26). The responsible for maintaining flood defence infrastructures and managing polder and river water systems rests with the regional water authorities (water boards) and river water managing authorities (Directorate-General for Public Works and Water Management (Rijkswaterstaat) and the Rotterdam Port Authority). As of 2012, the Province South-Holland requires a risk assessment as part of the reviewing procedure of zoning plans in flood prone areas. This risk assessment, however, is limited to an assessment of local individual risk (LIR), which is the annual probability that a person permanently present at a certain location dies due to flooding (Jonkman, 2007) and an assessment of social disruption caused by failure of critical infrastructure due to flooding. The LIR should not exceed an annual probability of 1/100.000 ( $10^{-5}$ ) a year. Finally, the regional Safety and Emergency Authority (Veiligheidsregio Rijnmond) is responsible for disaster response and crisis management during and after a flood (van Veelen & van der Linden, 2013).

Currently, the city of Rotterdam has no comprehensive flood risk policy for flood protection of existing buildings in the flood prone areas. The current flood risk policy of the City of Rotterdam regulates new developments to elevate the plot to the 1/10.000

storm surge flood level. The current storm surge flood level height is set to a level that fluctuates between NAP + 3.60m to NAP + 4.10m above sea level, depending on certain local conditions and vulnerability of the land use. In low-lying areas, this policy has a large effect on the design of streets and urban realm because new buildings needed to be built to a new level, sometimes more than one meter above average street level. For existing built-up areas there is no additional policy or regulation in effect to minimize the effects of a potential flood (van Buuren et al., 2014). Property-owners bear the full financial risks for possible damages caused by a flood event and are responsible to take precautionary measures, although at this moment they are poorly informed about local flood risks. Community disaster response and crisis management is limited to precautionary measures such as an early warning system and closing-off quay sections and public areas when high water levels are expected. There is no disaster management plan in effect. In addition, flood risk is not available in regular home insurance. Consequently, as many of the existing vulnerable waterfront communities comprise social housing, the current flood risk policy also can be questioned with respect to social equity (van Buuren et al., 2014).

Although the division of responsibilities between levels of government concerning flood risk is clear, the policy outcome so far did not result in a substantial decrease of flood risk, particularly of existing waterfront neighbourhoods (Veelen & van der Linden, 2013). The lack of managing flood risk of the unembanked areas is related to a number of factors. Firstly, the lack of formal responsibilities of the regional water board for managing flood risk of the unembanked area constitutes a major obstacle both for financing and managing local resilience planning. Secondly, the risk awareness of the potential flood risk and distribution of responsibilities is low. De Boer et al. (2012) found that only 50 % of residents in unembanked areas realized that they lived in flood prone, unprotected areas. A research conducted by students of the InHolland University of Applied Sciences<sup>1</sup> among residents of the Noordereiland found similar numbers. Although, in this case 72% of the respondents were aware of the unprotected position, only 9 % of the respondents was aware of the fact that they are bearing the full costs of flood damages. The low risk awareness can be explained by the strong public involvement of higher level authorities in the Dutch flood risk system and strong trust in government's interventions in the Netherlands in general, but is also related to the fact that the construction of the Delta Works, and particularly the Maeslant barrier, considerably reduced the frequency of flooding. This low risk perception is expected to enhance flood insensitive behaviour of residents and companies and compromises the readiness of stakeholders to undertake any investments in flood risk reduction. Secondly, integrating flood risk management in spatial planning and building codes proved to be problematic. Currently, coastal flood risk management is not included

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1 Unpublished bachelor thesis report.

in the formal requirements of a zoning plan, although, in some cases, flood risk is mentioned in the explanatory noted to the plan. In addition, it lacks regulatory instruments to enforce flood risk adaptation of existing buildings or critical assets (van Vliet, 2013). In the Netherlands, buildings must comply with the National Building Code (Housing Act, 2012) that sets technical standards for structural integrity, fire safety and health requirements of buildings and constructions. Given the more general nature of code, the National Building Code does not provide building regulations for buildings in flood zones. And, to complicate matters, by law, local authorities may not impose technical requirements additional to the building code.

Thirdly, the plot elevation policy has worked well in recent past when abandoned port areas were redeveloped within large-scale redevelopment projects, based on public land-development models and supported by large public investments in urban renewal and development. In large-scale redevelopment projects, such as the Kop van Zuid and the Wilhelminapier land elevation proved to be the most effective approach to reduce flood risk. It is expected that future urban development will be largely determined by small-scale incremental transformations of the built environment, with other stakeholders and limited public funding involved (Krabben & Jacobs, 2012). These changes also affect urban flood risk policies.

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## § 5.3 New York – New Jersey estuary

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### § 5.3.1 A large flood prone waterfront

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Although the major part of New York City is built on higher grounds, the city has a 520-mile-long low-lying waterfront area, which is vulnerable for flooding (NYC, 2013). A considerable part of the waterfront lies less than 2,5 m above mean sea level making these areas vulnerable to coastal flooding during major storm events, both from fluvial flooding as coastal storm surges (Rosenzweig et al., 2010). The most vulnerable areas for flooding is the waterfront of Lower Manhattan, including the financial and business district, but also parts of the Brooklyn waterfront, Long Island City in Queens and the coastal zones of Staten Island, Jersey City and Hoboken appear to be very vulnerable to floods. In fact, about 60,000 buildings with over 250,000 residential units are located in the 100-year floodplain and an additional 35,000 buildings with 145,000 residential units are located in the 500-year floodplain (Findlan et al., 2014). In these areas a considerable amount of vital assets, among which the La Guardia Airport, subway entrances, wastewater treatment plants and tunnels, are located in the 100-year flood zone (Aerts & Botzen 2011).

## Flood characteristics and vulnerabilities

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To understand the type of flooding of the East Coast it is necessary to distinguish between two main types of storms, hurricanes and 'Nor'easters', and two types of storm-related impacts, the surge and waves (Bowman et al., 2005, Strauss et al., 2014). Hurricanes are rare but extreme storm conditions that produce large storm surges, high waves and winds. Nor'easters are winter storms that produce smaller surges and winds but happen more frequently than hurricanes (Bowman, et al., 2005, NYCDCP, 2013b). Nor'easters' or hurricanes create high-energy waves that mainly impact the Atlantic-facing shorelines, resulting in severe coastal erosion and serious damages to buildings and infrastructure, and sometimes even casualties. In addition, both hurricanes and Nor'easters create low-energy flooding (storms surges) by pushing up water towards the coast. Storms surges, in contrast, result in slowly rising water levels that may cause considerable damages but do not result in structural damages or casualties. The NYC/NY coast is particularly vulnerable for storm-surge based flooding because of the orientation of Long Island Sound and the wedge-shaped entrance to the New York Harbor bay, which creates two natural funnels that drive sea water into the Western Sound and Upper East River, and up to the Battery in New York City during north eastern storms and north bound hurricanes (Bowman et al., 2005). Because Nor'easters generally last longer—sometimes a couple of days – the chance of a storm surge coincide with astronomically high tides is large, making Nor'easters the main source of flooding in NYC (Lin et al., 2010). Hurricane surges, in contrast, may rise very quickly, but last only a few hours. As a consequence, extreme hurricane-based flood levels are produced only when the surge and high tides coincides, which is rare (Bowman et al., 2005). This type of low-energy flooding is characterized by a relatively slow increase of water levels, resulting in an inundation of low-lying areas to flood levels that reaches to a maximum of 0.5 – 1.5 m above ground level.

Hurricane Sandy that hit NYC in October 29, 2012 was an extra-tropical storm that created high-energy winds and waves causing considerable damages to buildings and casualties. 17 per cent of the city land mass was flooded (NYC, 2013). The Jersey shores and the south-facing shores of the Far Rockaways experienced significant damage to buildings and casualties as a result of their direct exposure to high-energy waves (NYC, 2013). Manhattan, Brooklyn, Jersey City and Hoboken were particularly hit by low-energy flooding (the surge) caused by an accumulation of seawater due to the funnelling effect of the Raritan and New York Bay (NYC, 2013). The rising surge water, causing flooding of streets, basements and first floors, impacted many of the urbanized waterfront areas of Manhattan, Jersey City, Hoboken and Brooklyn along the Hudson and East River and parts of Queens around the Flushing Bay.

## Model uncertainties

Uncertainties in defining the 100-year flood for the New York metropolitan region are large (Orton et al., 2015). There are substantial differences between the flood prediction data and observed flood levels. **Table 5.3** shows the differences between the predicted current 100-year flood level of several sources. The confusion around these numbers is partly related to the complex system to which flood levels are measured and whether the effect of wave set-up is taken into account. For example, Sandy created a 14-ft. flood level at the Battery. This flood level is the sum of the tidal level and the storm surge, which reached to 2.74 m (8.99 ft.) at peak level and near high tide. It is important to understand that the surge level is measured relative to the high tide line or Mean Higher High Water (MHHW) level at the Battery (Strauss et al., 2014). The high tide line at the Battery is 1.54 m (5.06 ft.) above NAVD88 (NOAA, 2012). In comparison: the 1% annual chance flood (100-year flood) reaches 1.80 m (5.9 ft.) above the high tide line at the Battery (Strauss et al., 2014). However, the exact flood level associated with the 100-year flood is still under debate.

SOURCE	100 YEAR FLOOD (TO NAVD88)
NPCC, 2013	3.29 m
FEMA 2014	3.44 m
Rosenzweig & Solecki, 2009	2.62 m
NOAA, 2015	2.40 m
Linn, et al. 2012	1.97 m

**TABLE 5.3** 1% annual exceedance probability level (100 year flood) at the Battery according to several sources. Source: Bowman et al. 2005, Orton et al, 2015.

In addition, there is uncertainty about land elevations. Many of the shorelines along the New York Harbor are bulk-headed of which the exact elevation is not precisely known (Bowman et al., 2005). Also, inaccurate land elevation data on local elevation levels that show significant variation across short distances and missing information on potential connections via culverts or other underground infrastructures, jeopardizing predictions on local flood behaviour on the local level (Strauss et al., 2014). During Hurricane Sandy the differences between the FEMA indicated flood plain areas and the observed flooded areas caused by Sandy exceeded more than 50 per cent (NYC, 2013)

## § 5.3.2 Changing conditions

### Sea level rise

Already before super storm Sandy wrecked havoc on the shores of New York and New Jersey, several researchers (Bowman et al., 2005, Rosenzweig et al., 2010, Aerts & Botzen, 2011) have shown that NYC is vulnerable for sea level rise. Due to natural changes and global warming effects the average sea level has increased over the last century. Sea level has been raised along the East Coast of the US at rates of 0.9 cm (0.34in) – 1.1 cm (0.43in) per decade (Rosenzweig et al., 2010). Sea level rise along the East Coast shows an average increase of 3 cm (1.2 in) per decade since 1900<sup>2</sup>. Currently, observed rates of sea level rise in New York City range between 2.2 cm (0.86in) and 3.8 cm (1.5in) per decade (Rosenzweig et al., 2010). The New York City Panel on Climate Change (NPCC, 2013) expects that coastal flooding by the 2050s is very likely to increase in frequency, extent and height as a result of increased sea levels. In New York City at the Battery the sea level has risen with 0.34 m (1.1 ft.) since 1900. Sea level rise predictions based on middle range and high estimate climate change scenario's ranges between 0,10 m to 0,28 m (4 to 11 inches) in 2020 and 0.28 to 0.79 m (11 to 31 inches) in 2050 (NPCC, 2013).

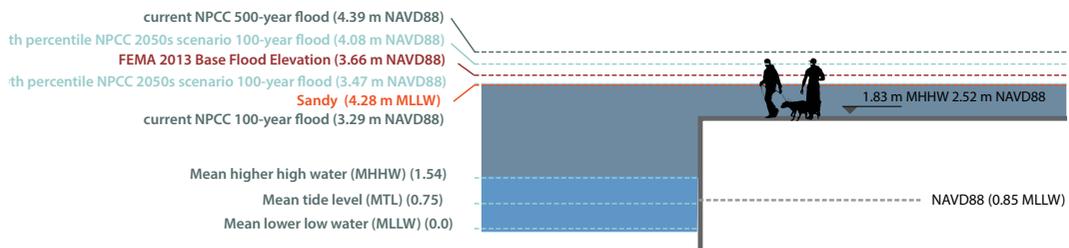


FIGURE 5.5 Flood levels at the current and projected 100-year and 500-year flood levels at Red Hook, New York.

The current 100-year flood is expected to occur more often to once in 19 to 68 year in 2050, and once in 4 to 60 years by the 2080s (Bowman et al., 2005). The recently updated flood maps showing the 100-year flood plain released in June 2013 by the Federal Emergency Management Authority (FEMA) show significant changes of urban areas that might suffer flooding (NYC, 2013).

### Increased storm and precipitation patterns

In addition to storm surge flooding, storm water flooding is a potential risk for New York City. Hurricanes and Nor'easters are accompanied by heavy rainfall both before and after the arrival of the surge (Bowman et al., 2005). Climate change is expected to increase the frequency and intensity of storms (NPCC, 2013). Major rainfall events might cause local runoff (flash floods) or storm water that accumulates in lowest areas, causing additional damage to buildings and infrastructures in areas that are located outside the 100-year flood zones. Given the fact that the majority of the sewer system network in New York City is reaching its functional life and the already limited capacity in the sewer system (NYC, 2011), an increase in storm events poses a major challenge, particularly in combination with storm surge. There is a trend towards more extreme precipitation events in New York City since 1900 and climate change projections point to increasing annual precipitation patterns, although these changes are small and not statistically significant (NPCC, 2013).

### Intensifying waterfront development

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New York City's population is growing and is expected to grow in the future (NYC, 2011). Demographic projections differ on the expected moment NYC is to reach a growth of 1,000,000 new residents – in 2030 (NYC, 2011) or in 2040 (Keenan & Chakrabarti, 2013) – but are unequivocal in expecting a steady, long-term influx of new residents. The city's housing strategy is encouraging growth within the existing city's boundaries by intensifying neighbourhoods; encourage transit-oriented development, and transforming underutilised formerly industrial zones (NYC, 2011). Particularly the formerly industrial sites along the East River, offer opportunities for large-scale, high-density, transit-oriented development, although it is recognized that even when these sites are developed the city does not have the capacity to house the 1,000,000 new residents (Keenan & Chakrabarti, 2013). The under-capacity of available sites for development and growing housing demands puts further pressure on the affordability of housing in NYC. A major concern is preserving affordable housing (NYC, 2011).

The trend towards intensifying waterfront land uses is further enhanced by the increase of net present value of buildings in the 100-year flood zone, which has approximately doubled over the last 30 years (Botzen et al., 2014).

### Vulnerabilities

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Contrary to what one would expect, the majority of the buildings in the 100-year flood zone in New York City consist of low-rise, 1- 4 family homes (Findlan et al., 2014). In New York, typical low-rise brown stone buildings are characterized by a below-grade space that is often rented out as a small apartment (NYCCDC, 2014).

Building systems, such as heating, are often placed sub-grade or at the lowest floor of the building. In addition, multi-family high-rise usually have their buildings systems and elevator equipment located in the basement (Findlan et al., 2014). Much of the damage experienced during Sandy was related to flooding of basements and first floors causing damage to systems and equipment, such as failures of oil tanks, shorting out of electrical systems, saturation of building materials such as sheet rock and insulation and damage to furniture (NYC, 2013). Although more than 70,000 homes reported damages, only some 800 homes were substantially damaged or destroyed (NYC, 2013). In addition, many critical infrastructures are located in the flood zone – including hospitals, power facilities, tunnels, the subway system and wastewater treatment plants (Bowman et al., 2005, NYC, 2013, Aerts & Botzen, 2011). The flooding caused by hurricane Sandy highlighted significant vulnerabilities, particularly due to the high level of interconnected systems, such as subway tunnels, telecommunication and power (NYC, 2013).

### § 5.3.3 Flood risk policy in the US and New York City

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#### Flood Insurance

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The US approach to flood risk is based on encouraging building level resilience combined with disaster management (short-term relief programmes and evacuation strategies) and recovery after a flood. An essential part of the US flood management strategy is the federally operated National Flood Insurance Program (NFIP). This programme enables property owners in flood prone areas to insure damage of flood risk, as long as they meet the basic requirements for constructions in flood prone areas. Buildings in flood zones are mandated to elevate above or flood proof below a certain flood elevation level, the Base Flood Elevation (BFE), which is determined by the classification of vulnerability and local flood characteristics (NYCDCP, 2013a). Only when buildings are completely brought up to the flood resistant construction standards they are eligible for a substantial reduced flood insurance premium (NYCDCP, 2014a). The NFIP flood insurance premiums are based on Flood Insurance Rate Maps (FIRMs) that identify areas at several levels of risks of flooding. The primary US design standard for coastal flooding is the 100-year flood. This flood is defined as the flood that has a 1 % change of being exceeded in any given year (Solecki et al., 2010). Also the 500-year flood (0.2 % annual change) is used to define building requirements and elevations for critical infrastructures and facilities (NPCC, 2013). By statutory requirements, the FIRMs are supposed to reflect the actual flood levels and do not take into account future flood levels due to climate change (interview NYCDCP, Oct 2014).

Homeowners with a federally backed mortgage in a high risks flood zone are required to purchase insurance (NYCDPC, 2013a). However, the take-up rate of flood insurance in New York is low<sup>3</sup>.



FIGURE 5.6 Left: FIRM flood zones based on inundation level and wave exposure (NYCDPC, 2013a). Right: The Design Flood Elevation (DFE) is the minimum elevation, based on the sum of the Base Flood Elevation (BFE) and a freeboard based on the building's structural category (NYCDPC, 2014b)

### Flood resistant constructions in building codes

Building resilience in the US is managed through several regulative instruments and guidelines at federal, state and local level that sometimes overlap or show minor inconsistencies (Aerts & Botzen, 2011). The Federal Emergency Management Agency (FEMA) sets buildings guidelines that regulate new structures in the 100-year flood zone. Buildings in the 100-year flood zone that fully comply with all FEMA guidelines are eligible for a reduction in its flood insurance premium. In general, this means that buildings in flood zones are mandated to elevate above or flood proof below a certain flood elevation level, the Base Flood Elevation (BFE), which is determined by the classification of vulnerability and local flood characteristics (FEMA, 2014a, ASCE, 2000). Municipalities that participate in the NFIP are obliged to incorporate FEMA's flood resistant construction standards into their Building Codes and Zoning Resolution (NYCDD, 2014b). The building codes regulate structural aspects of constructions related to structural integrity, safety and accessibility, whereas the Zoning Resolution regulates building size, location and use (Cullingworth & Caves, 1997). The New York City Buildings code's flood-resistant construction standards must meet FEMA required standards, as well as State Building code requirements (NYCDPC, 2014a). In addition to the FEMA standards for flood-resistant constructions, New York City sets higher standards. One of the principal requirements of the New York City Building

3 The RAND corporation estimated that only 55 per cent of the one- to four-family homes in the high-risk areas on the 2007 map had federal flood insurance (Dyxon, et al., 2013). A more recent survey showed that approximately 33 per cent did not have coverage (Botzen et al., 2014)

Code is a mandated additional “freeboard” of one or two feet (0.3 – 0.6 m) above the FEMA required BFE for additional safety, known as the Design Flood Elevation (DFE). Depending on building class the freeboard is one foot for commercial and multi-family buildings and two ft. for single and two-family buildings (Fig. 5.6). New structures that are built in the flood zone are required to elevate all residential used spaces to above the DFE or flood proof all spaces below this. Below this level, only non-habitual spaces such as storage, access or parking are allowed. Also all mechanical and electrical equipment of residential buildings are not allowed below the DFE (NYCDCP, 2014b). Following FEMA requirements, the New York City Building Code prohibited dry flood proofing (e.g making buildings impermeable for flood water) of residential buildings. However, dry flood proofing is permitted for non-residential buildings. Existing residential buildings that are substantially improved or substantially damaged are also required to fully comply the latest NFIP and NYC Buildings codes (NYCDCP, 2014b). A Substantial Improvement is defined as a rebuilding or repairing project where the costs of improvement or rebuilding surpasses 50% of the real estate value prior to improvement (NYC, 2013). In addition to building level resilience, FEMA allows the construction of flood walls and levees to protect buildings and assets, although it is difficult to get these infrastructures accredited and mostly flood walls do not affect NFIP flood insurance rates. Nonetheless, in New York City several locations are protected by structural measures especially at places where important assets are at risk. A network of seawalls and small levees, for example, protects the La Guardia Airport. Other vulnerable assets as metro entrances are sometimes protected by local protective measures and recovery management equipment (Rosenzweig et al., 2010).

## § 5.3.4 Challenges and changes

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### Deficits between the NYC building codes and NFIP regulations

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There are several conflicts between certain zoning provisions and the NFIP flood resilient standards. One of the most important instruments in the New York City Zoning Resolution is the regulation of maximum buildings envelopes. The NYC Department of City Planning defines “building envelopes” as ‘the maximum three dimensional space on a zoning lot within which a structure can be built, as permitted by applicable height, setback and yard controls’<sup>4</sup>. The regulation of building envelopes is an effective instrument to steer urban density and urban form. The maximum building envelopes

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<http://www1.nyc.gov/site/planning/zoning/glossary.page>

are, however, conflicting with the extra space that is needed to elevate the residential space up to the DFE. Particularly in areas where building envelopes are determined by the maximum building heights elevating buildings can be a problem (NYCDCP, 2014a). Other issues are related to the extra space that is needed to accommodate access to an elevated building in front yards or the lost of habitable space of elevated buildings when an enclosed entryway is needed. Also the relocation of mechanical systems from below-grade spaces need alternative locations in rear and side yards, which is currently not in compliance with the zoning regulations (NYCDCP, 2014a).

### Current regulatory framework does not promote overall resilience

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One of the most challenging deficits of the current flood risk policy is that it does not enhance the overall resilience of waterfront communities. One deficit in the current NFIP rules is that it does not offer insurance rate reductions for property owners who invest in flood protection measures that improve the resilience of building systems and equipment, such as raising all electrical equipment to above the flood elevation level (NYC, 2013). Measures like dry flood proofing of a residential building, or flood barriers (unless it is permanent and accredited) in the 1/100 flood zone are not compliant with NFIP guidelines and are prohibited by the New York City's Building Code (Findlan et al., 2014). This means that flood resilience measures are reduced to wet flood proofing (using flood resistant measures and elevate vital infrastructures above the DFE). This rule reduces the variety of measures thus reducing resilience (see definition at section 2.2.5). Although New York City updated several local laws to stimulate the adoption of building resilience measures (Goldstein et al., 2014), adapting buildings in dense urban typologies to meet the NFIP guidelines require substantial structural reinforcements that are subject to physical and financial limitations (NYCDCP, 2014b). In addition, building level resilience is only partly a solution to reduce the vulnerability of coastal waterfront communities. An essential part of the damages can be traced back to infrastructure vulnerability, such as sewer and electrical systems outages and flooded subway systems. The current FEMA regulations and City's building code do not require any adaptation of critical urban infrastructures and facilities, making waterfront communities vulnerable for flooding, regardless of any investment in building level resilience. This is particularly true for less affluent communities that lack resources to invest in adapting critical infrastructures.

### Negative socio-economic effects: affordable housing at risk

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Secondly, there is an issue of affordability. According to current rules, only when a building is completely brought up to the flood resistant construction standards it is eligible for a reduced flood insurance premium. Because the flood insurance premium is primarily determined by the position of the lowest occupied floor to the BFE, flood

insurance reductions are only substantial when the lowest occupied floor is located above the BFE (NYCDCP, 2014b). However, many buildings in the New York City's flood zones were constructed before the first FIRM was issued in 1983 and do not comply with the FEMA's standards (Findlan et al., 2014). This applies in particular for the one to four family dwellings of which almost 80 percent is built in the preFIRM period (Dyxon, 2013). Also the majority of rental buildings in the floodplain (more than two-thirds of the households in the flood plain are rental units) were not built according to current flood standards (Findlan et al., 2014). This means that buildings in the flood zone are faced with relative high flood insurance premiums.

Two recent changes negatively affect the affordability of flood insurance. An important change is the updating of the FEMA's Flood Insurance Rate Maps (FIRMs). The FIRMs were introduced in 1983, and have not been significantly changed since then. FEMA has recently started to update the 1983 flood risk maps and has issued new advisory flood maps, based on more accurate flood predictions. Although the newly issued Preliminary FIRM (PFIRM) for New York City is available, it has not yet been officially adopted. The PFIRM covers a substantially larger flood zone than the 2007 FIRM and projected flood elevation levels are higher, affecting roughly twice as many buildings (NYCUPD). In total, there are 67,400 structures and almost 250,000 housing units located in the new 1/100 flood zone (RAND, 2014). Almost 90 percent of the structures that are now located within the new flood zones do not comply with the FEMA's standards and will be confronted with full risks premiums (Findlan et al., 2014). Also buildings that were already within the existing flood zones are faced with higher BFEs that in average increased with 2 and in some cases more than 1.5 m (Dixon, 2013).

The NFIP is also under reform to update premiums to reflect actual risks. The Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12), which was approved by the Congress already before Sandy, limits federal subsidies to reduce the insurance premiums. Another important change is that it phases out the "grandfathering rule" that allowed owners of buildings that are confronted with a change in flood risk zones after an flood zone map update, to be eligible for the previous (lower) insurance rate (Findlan et al., 2014). Under the new act flood insurance premiums will increase every year within a 5-year period till they are brought up to the new full rates that reflect the risks of the new effective FIRM. As a result of this reform, it is expected that the flood insurance premiums will sharply increase for properties that are out of compliance. As results of federal legislative change, flood insurance premiums have sharply increased and many flood-prone communities are faced with new economic challenges if they do not meet the flood resistant design standards (Findlan et al., 2014, NYC, 2013).

The sharply increasing flood insurance premiums and high costs of retrofitting resilience will result in a loss of affordable houses in coastal waterfront areas. Particularly for buildings that are subject to rent stabilization and subsidy programmes, retrofitting adaptation measures, such as relocation of vital equipment to units above

the DFE or convert ground floor spaces into non-residential uses is probably not an economic viable option because the costs of adaptation cannot be passed on to the renters (Findlan et al, 2014). This might speed up the already on-going process of waterfront gentrification and, in other cases, decay. In attractive waterfront areas homeowners of cheap and middle-priced houses will be forced to sell their property to higher income communities who are able to cover the costs of adaptation or insurance premium. For privately owned housing stock in less attractive neighbourhoods, an increase in flood insurance premiums could result in lower property values and buildings that are vacant for some period of time (Dyxon, et al., 2013). This will accelerate processes of urban decay and degradation, or result in a stagnating process of enhancing building level resilience and lower property values.

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## § 5.4 Conclusion: differences and similarities

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Although cross-country comparisons of flood risks of urban areas requires precaution, some general conclusions on differences and similarities of the sources of risk and the role of the government and structure of governance can be drawn. For the Dutch case, this comparison is limited to the specific situation of the urbanized unembanked areas, located outside of the protection of the primary flood defense system.

### § 5.4.1 Flood risks

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Both cities show comparable flood characteristics. The North Sea storm surges are characterized by a moderate flood level and wave-impact, compared to the hurricane-impacted storm surge flood levels at the East Coast. However, the majority of the urbanized waterfront areas in New York City and Rotterdam are mostly exposed to slow rising storm surge flooding that causes relatively shallow and short-lived inundations. Disregarding differences in size and accumulated values of the areas at risk in New York, the vulnerability of waterfront communities for flooding in both cities displays remarkable similarities.

The effects of climate change are, however, felt more intensively at the New York City-New Jersey coast. This is not only because of differences in storms intensity and higher expected sea level rise, but also because New York City lacks storm surge protection that reduces the impact of high-energy waves and extreme water levels before it reaches the urbanised coasts. This contrast with Rotterdam, where the effects of sea level rise and river discharge are mainly related to an increased probability of flooding due to the

increased probability of failure associated with more often closures of the Maeslant barrier. Consequently, adapting coastal urban waterfront to the future 100-year flood level will have a significant larger spatial impact and probably be more expensive in New York, than it is in Rotterdam. Additionally, although adaptation action is immediately required, given the larger bandwidth of change and uncertainty compared to Rhine Estuary Region flood risk adaptation in New York requires even more flexible strategies allowing to respond to future conditions when they unfold.

## § 5.4.2 Uncertainties

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Uncertainties in projected flood level both in the US and The Netherlands is large and poses a challenge for adaptation planning. There are many uncertainties about the exact effects of sea level rise and climate change on local flood probabilities (NPCC, 2013). Also in the Netherlands, the statistical uncertainty, particularly of low probability flood events, is large. The standard deviation of flood probability uncertainty of the tidal river area amounts to 0.5 meter and reaches levels of 1.5 – 2.0 m at some coastal areas (Deltaprogramma Rijnmond-Drechteden, 2014). In addition, local flooding model uncertainties caused by local morphological differences, wind set-up and local area characteristics such as small-scale land elevations, underground infrastructures and drainage systems are not yet integrated into flood modelling. Although flood risk modelling in the Netherlands is more advanced, the down side is that among decision-makers there is little concern for uncertainties in modelling, which may lead to a false sense of precisely. Designing for flood risk requires detailed, and probably more importantly, accurate information on local flood levels as precise as decimetres, not just meters. Again, high uncertainty calls for a flexible, adaptive approach.

## § 5.4.3 Governance

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The US approach to flood risk is mainly focused on improving building resilience and recovery, less on disaster avoidance and prevention, as is the case in the Netherlands. Despite almost opposing approaches, both flood risk management policies share some crucial deficits. Both regulatory frameworks are highly prescriptive in a limited number of fields and not focussed on improving the overall flood resilience of waterfront communities. Both policies rule out alternative adaptation measures such as dry-proofing or district-wide flood protection, making the portfolio of available adaptive response rather small. This reduces the adaptive capacity of waterfront communities and consequently, reduces long-term resilience. Both frameworks lack

a comprehensive risk approach, covering all aspects of local flood risk protection to disaster management and, for example, ignore the flood risks arising from critical systems vulnerability.



# 6 Planning resilient urban waterfronts in Rotterdam using adaptive pathways

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## § 6.1 Introduction

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To effectively incorporate adaptation into the processes of urban development and change it is necessary to understand when in time adaptation is necessary and what (combinations) of measures are the most effective.

This section provides the empirical base for answering the research question what pathways to resilience are most effective, provide flexibility and deliver added value in the long run. Additionally this chapter aims to reflect on the applicability of the APM, as introduced in the theoretical section, for adaptive planning of urban waterfronts areas under stress of climate change. In the next section the AP method is applied to develop adaptive strategies for the Rotterdam flood prone waterfront area. This section is previously published as: van Veelen et al. (2013).

### § 6.1.1 Research method

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As a first step during the research, a detailed analysis of the vulnerability of the unembanked area was performed. This part of the research benefited from earlier research on flood risk assessment of the unembanked areas (Veerbeek et al, 2010a and Veerbeek & Gersonius, 2013). These reports provided information on flood levels, velocities and expected damages to households and infrastructure of several flood prone unembanked areas in the Rotterdam region. This research was used to make a selection of the cases. To gain more detailed information on the relative vulnerability and adaptive capacity of buildings in the flood zone, a detailed 1 m elevation model was used to map all buildings in the current and expected 100-year flood zone. In addition, based on a visual inspection using *Google Streetview* the height of the first floor level of the buildings relative to the ground floor was estimated. In addition to this GIS-based research, a consultancy firm specialised in construction assessments carried out an assessment of the direct and indirect effects of flooding of 5 typical buildings in the flood zone. Based on visual inspections of the building construction, finish

materials and interior and position of the building systems and measuring the position of potential flood entry points, the specific vulnerability of the buildings has been assessed. This research not only provided information on the relative vulnerability of the different building typologies in the area, but also information on the effectiveness and costs of adaptation measures. The vulnerability assessment was supplemented with interviews with representatives of the power network managing company, project developers and city officials of the Planning Department and Water Management Department of the City of Rotterdam and representatives of the local community, the social housing corporation and a project developer. In addition, two community meetings were attended.

During two workshops potential adaptation response options were appraised on legal, financial and technical feasibility, spatial integration and potential co-benefits. Furthermore, an in-depth analysis of the acceptability of these measures among stakeholders (Kokx, 2013) and an assessment of legal aspects (van Vliet, 2013) was executed, resulting in a short-list of most preferred options for the two locations in the Rotterdam. Based on this overview, a selection of measures that could potentially be applied in the case study areas Noordereiland and Feijenoord was short-listed, according to the vulnerability analysis of existing buildings and infrastructures, cost-effectiveness, and opportunities to link-up with urban development in the area. In addition, of all of these selected options the critical threshold (flood level) at which the option loses effectiveness, or at which the options reaches physical or spatial limitations, were identified. The spatial and visual effects were identified using research by design techniques (**Fig. 6.1**). For example, the position of building openings such as vent holes and window sills appeared to determine important physical and visual boundaries for retrofitting dry-proofing measures. Additionally, local flood barriers were tested to the extent of interference with existing spatial qualities and visual relationships. For example maintaining the open view towards the river, or preserving the accessibility of the quays as urban promenade, proved to establish important limitations for the height of the floodwall option. The identified critical thresholds based on an assessment of technical and spatial limitations of the adaptation measures, the effectiveness of the adaptation measures to prevent damage at a 1/100 return period at different climate change scenarios could be estimated. This overview can be used to identify at what sea level rise event (5, 10 or 15 cm, etc.) an adaptive measure fails to meet the previous set ATP.

By confronting adaptation actions with sea level rise scenarios, the most effective sequences of adaptation options could be selected. The pathways were evaluated on criteria for successful adaptation, as introduced in more detail in section 3.5.3: (1) effectiveness, (2) efficiency, (3) equity and legitimacy (4) added value. These more general criteria were translated to empirical evaluation criteria:

- Does the pathway result in a significant reduction of flood risk
- Is the pathway cost-effective?
- Does the pathway enhance flexibility?
- Is the strategy just? (Leading to more equity? Few adverse effects to other communities)
- Does the pathway produce synergistic advantages or added value for multi purpose uses?

To determine the cost-effectiveness of the adaptation pathways a cost estimate of the adaptation pathways was performed. For this research, collaboration with the Engineering Department of the City of Rotterdam and a consultancy firm (Rebel Group) was established (Pohl et al., 2014). The equity and legitimacy assessment was performed by a research coalition of the Erasmus University and Deltares (van Buuren, et al., 2014).

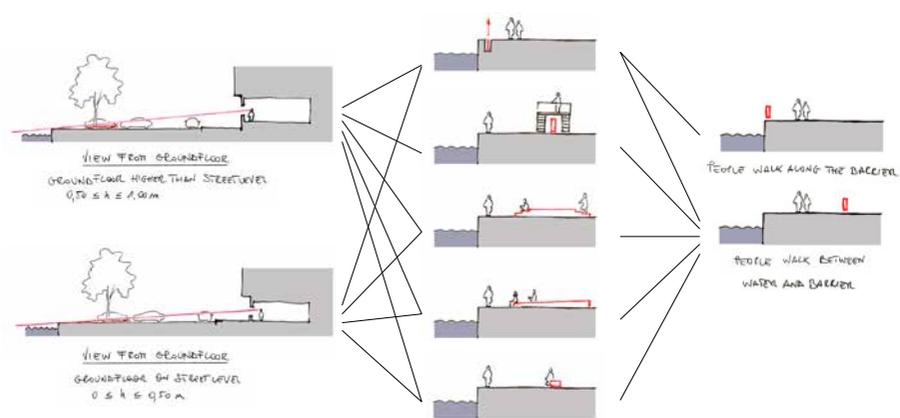


FIGURE 6.1 Research by design to define spatial and visual effects and potential co-benefits of proposed flood protection options (Nabielek-Kronberger et al., 2013)

## § 6.2 Developing adaptive pathways for Noordereiland and Feijenoord

### § 6.2.1 Situation

The case study area (**Fig. 6.2**) comprises two separate residential areas that differ in flood characteristics, building typology and socio-economic positions of its residents: the Noordereiland, which is a residential island with a predominantly privately-owned historical building stock and the Kop van Feijenoord, which predominantly consists of poorly maintained social housing apartment blocks. The Feijenoord area is struggling with several interacting social-economic problems, including one of the highest unemployment rates of Rotterdam. The area mainly consists of social housing and host several companies, including a factory of Unilever and an aluminium foundry. The general condition of the social housing stock is poor. Despite the socio-economic problems, the position of de Kop van Feijenoord as a waterfront location close to the city centre and neighbouring the prestigious high-rise district of de Kop van Zuid makes the area highly attractive for redevelopment. In 2008 a new master plan was developed to attract investors. This master plan includes a redevelopment of brownfield areas and a large-scale transformation of the existing social housing stock. A new tramline and a bridge are planned to improve the accessibility of the area. Many existing social housing buildings will be renovated or redeveloped. Although the area is a focal area for redevelopment and renewal within the cities strategic vision, many of the planned developments are currently on hold or being reconsidered due to the economic crisis that hit particularly the housing market between 2008-2015. The Noordereiland is a more affluent area, developed as part of the nineteenth-century expansions of the port on the South banks of the river Meuse. The area's building stock consists of multifamily 4 or 5 story historical buildings that are predominantly privately owned, and apartment buildings owned by the social housing corporation.

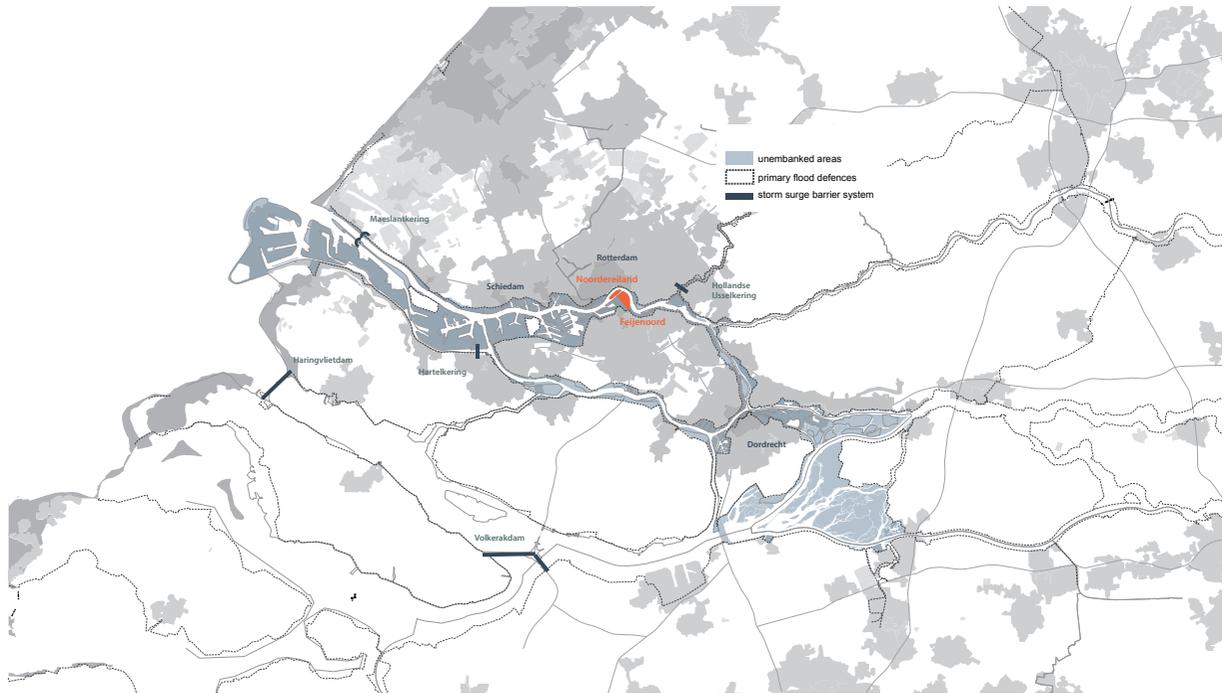


FIGURE 6.2 Positioning of case study locations within the Rhine estuary

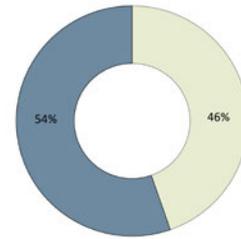
## § 6.2.2 Defining the boundaries of resilience: risk assessment using ATPs

### Kop van Feijenoord

The Kop van Feijenoord is a local basin with a relatively high flood probability (Fig. 6.3). At a 50-year flood event (3.04 m +NAP) water enters the area causing flooding of the low-lying area to a depth of about 0.5 m. Water will enter the ground floors of more than half of the buildings in this area, causing direct damages of about 30 million Euros (Veerbeek & Gersonius, 2013). At more extreme flood events the flooded area hardly increases in size, but water depths may rise to 0.8 – 1 m and more damage to the building structure and the interior of buildings can be expected. More than 90 % of the housing stock in the flooded area comprises social housing. This includes both renovated nineteenth-century building blocks and modern 4-story apartment buildings built between 1975 and 1985. Following the zoning codes applicable at that time these buildings have an elevated first floor to above NAP + 3,90 m. It is expected that these buildings are less vulnerable for flooding. Fig. 6.3 shows that based on an assessment of the position of the first floor relative to the surface level more than 50 % of the buildings in the area have their first floor elevated between 50 and 100 cm.



■ buildings elevated between >50 and < 100 cm  
■ buildings elevated < 50 cm



**FIGURE 6.3** More than half of the buildings in Feijenoord have a ground floor that is elevated above the expected 100 year flood level. Photo by author.

### Critical infrastructure

The sewer system in the Feijenoord area primarily consists of a combined sewer system. The system uses a pumping station to transport sewage to the sewage treatment plant. During a flood, this pumping station will be seriously damaged and be inoperative for several days. Due to the bath tub-like shape of the area floodwater cannot drain to the river under gravity and floodwater needs to be pumped out by emergency pumps. The combination of stagnant floodwater and overflowing sewer water will most likely cause considerable environmental problems and health risks. Additionally, as many low voltage and medium voltage power stations are flooded, power will be off, and, because of the relative long period that is needed to drain the area, it is expected that the recovery of the power network in this area also will take days, if not weeks. Besides, although the exact impact and magnitude of several simultaneously occurring local power outages caused by an extreme flood event is still unknown, but it is expected that the power network is vulnerable for cascading effects (Agten, 2016). The area is home of several large companies, including a Unilever plant and an aluminium foundry. Although detailed information on the direct effects of flooding to the companies operations cannot be made public due to confidentiality reasons, based on verbal information provided by the operational plant managers it could be concluded that both companies are highly vulnerable for the direct and indirect effects of flooding. Both companies rely on the local power infrastructure making them vulnerable for a power outage caused by flooding. Also, the high-speed railway tunnel to Antwerp and Paris submerges in the flood zone. Although the tunnel is equipped with floodgates and the train track is protected by a flood retaining wall, the railway connection power supply facilities and signal control system may be vulnerable for flooding (de Kort, 2012).

## Noordereiland

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Contrary to the Kop van Feijenoord area, the Noordereiland is mound shaped, making floods generally short-lived since floodwater is drained directly back into river. Given its waterfront position and the long-history of adapting to flood events, many historical buildings are built on semi-basements, which originally were used for storage. However, in recent years many basements are transformed into habitable spaces, adding to an increase in flood risk. During the urban renewal phase (1975 – 1985) also many nineteen-century buildings were transformed into social housing apartment buildings, in which cases the first floor often is converted to room for access, storage or building systems. During the post-war reconstruction period multi-story apartment buildings were developed that usually have shops and offices and access to higher floors on ground level.



**FIGURE 6.4** A substantial part of the costs of flooding of residential buildings is due to the vulnerability of building systems, interior and storage of sensitive goods in basements. Photos: Kuijk & Boer (2015).

A detailed assessment of 5 typical buildings at the Noordereiland (Kuijk & Boer, 2015) showed that the expected flood damages of the nineteen-century buildings that are built on a semi-below surface basement (souterrain) are relatively low (ranging from € 895 - € 3,350) because floodwater does not reach the ground floor at the 100-year flood event. The expected damages, however, are largely determined by the use of, and stored goods in, the basement and position of buildings systems (**Fig. 6.4**). It is expected that the flood damages will increase considerably when flood levels exceed the level of the ground floor. This is in line with the findings of Veerbeek and Gersonius (2013) who found similar numbers and found a sharp increase in flood damages after assessment of damages at the 85-cm sea level rise scenario (G+ 2100).

	BUILDINGS IN 100 YEAR FLOOD ZONE	BUILDINGS IN 100 YEAR FLOOD ZONE AT 85 CM SLR	EXPECTED ANNUAL DAMAGE CURRENT SITUATION (€ PRICES 2011)	EXPECTED ANNUAL DAMAGE AT 85 CM SLR (€ PRICES 2011)
Noordereiland	208	296	6,791 €/year	28,272 €/year
Feijenoord	176	226	20,462 €/year	45,473 €/year

TABLE 6.1 Number of buildings in the current 100-year flood zone and expected 100-year flood zone at a 85 cm sea level rise (SLR) scenario and expected annual damages (EAD) in euro at the current and 85 cm SLR based on Veerbeek & Gersonius (2013). Note that these risk numbers also include damages to infrastructure.

A most remarkable finding of this investigation is that the expected flood damages of a shop and office space located on the ground floor appeared to be extremely high, with direct flood damages ranging up to more than € 200.000. This is largely due to the high costs of lost working hours (Kuijk & Boer, 2015). Although the case described is an isolated example, in general, it may be presumed that offices and shops located on the ground floor are more vulnerable for flooding than residential uses.



FIGURE 6.5 Spatial and percentage distribution of building typologies in the 100-year flood zone at the Noordereiland. Note that more than a third of the buildings has a ground floor at, or just above street level.

### Critical systems

Sewage from the combined sewerage system is pumped to a sewage treatment plant located on the North embankments. During storm surges the local sewer pumping station will be turned off to avoid inflow of river water into the sewer system. It is expected that during an extreme flood event that reaches up to +NAP 3.40 m the sewer pumping station will be damaged (Fig. 6.6 and 6.7). The area is equipped with several

combined sewer overflows that allow for a discharge of untreated sewage into the river when the pumping station is turned off or damaged. These overflows, however, only function during low tide. The area also contains a number of shore power stations used by inland carriers and electrical transport charging poles. It is expected that short-circuiting of these facilities due to ingress of floodwater will trigger a larger power outage of the area. Due to the risks of short-circuiting the grid operator company's policy is to turn off the power already when flood levels reach several decimetres (Agten, 2016).

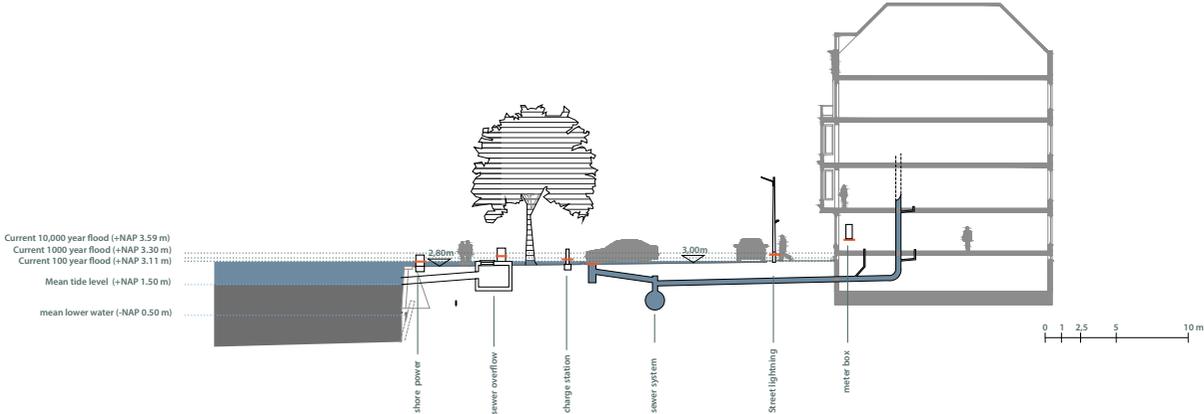
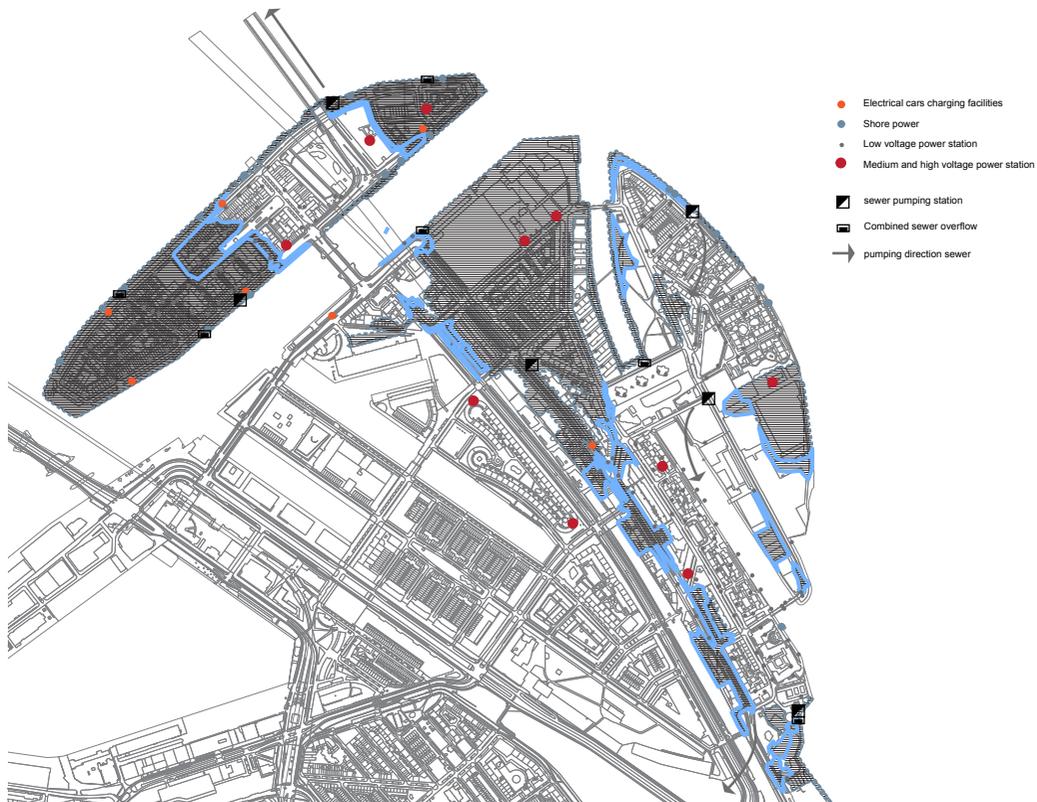


FIGURE 6.6 Critical thresholds (indicated as red lines) of vital infrastructure and buildings of the Noordereiland.

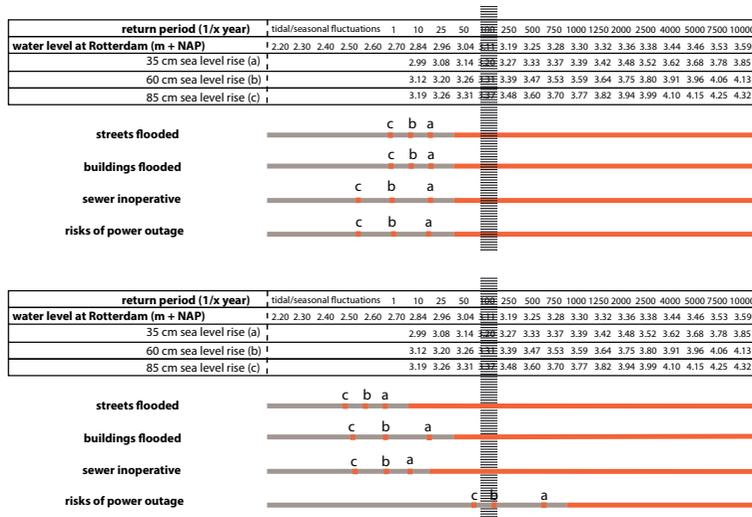


**FIGURE 6.7** Location of critical infrastructure (power and sewer) of the Noordereiland and Feijenoord areas and the 100 year and 500 year flood zones.

### § 6.2.3 Define policy objectives, performance indicators and limit values

As a second step in finding the ATP it is necessary to define policy objectives and translate these into critical performance limit values for several indicator values. The current flood risk policy of Rotterdam, however, only provides limited clues to develop a set of clear performance indicators (see also section 5.2.3). The flood risk policy of the City of Rotterdam requires the elevation of the building lots to the 1/10.000 storm surge flood level. The current storm surge flood level height is set to a level that fluctuates between 3,90 to 4,10 m above mean sea level, depending on certain local hydraulic conditions, such as wind direction and wave upset. There are no regulations to promote flood proof architecture. Moreover, for existing urban waterfront areas there is no flood risk management policy. Based on interviews with stakeholders in the area (Kokx, 2013) and a comparative research on flood risk management policies of

other delta cities, it became clear that effective performance indicators are inundation of streets, direct economic damage to buildings, risk of social disruption due to power outages and sewerage blockage and risks of individual mortality (see for an overview Merz et al., 2006). However, it proved to be extremely difficult to translate these performance indicators to clear policy objectives. Besides, working with multiple performance indicators requires defining multiple functional statements for indicators such as inundated streets, social disruption, damages and individual mortality risk. This proved to be confusing (Stone, 2013). For example, recurrent flooding of streets and properties was found socially unacceptable only at relative high return period (more than a couple times a year), whereas social disruption or casualties due to flooding is usually unacceptable at relative low probabilities (1% or lower). To avoid using multiple functional requirements and limit values it was decided to convert the policy objectives to more generic targets. Following the EU Flood directive and internationally accepted flood risk standards, the functional statement and limit value was set to no economic damages to buildings and social disruption due to failure of critical infrastructure at a probability of more than 1 in 100 year (Table 6.2)



**TABLE 6.2** The orange line indicates the position of thresholds of several indicator values related to the functional criterion of a 100-year flood (dashed column) at the current situation for Noordereiland (upper picture) and Feijenoord (lower picture). The orange 'dots' indicate the position of thresholds for flood levels associated with (a) 35, (b) 60 and (c) 85 cm-sea level rise scenario. Note that in Feijenoord all thresholds are crossed under current conditions and immediate adaptation is needed to meet the requirements of the stated policy objectives. The Noordereiland shows a more diverse landscape, in which all thresholds are crossed with the exception of the threshold for power outages that only is crossed at a 35 cm sea level rise scenario.

By confronting the flood depths at several return periods, both in the current situation and at a range of moderate and extreme sea level rise scenarios with a cross-section of the waterfront and a typical building block (**Fig. 6.6**), the position of thresholds of several indicator values can be found. This assessment showed that in Feijenoord all thresholds are crossed and immediate adaptation is needed. The Noordereiland shows a more diverse landscape with the threshold for risk of power outage only crossed at a 35 cm sea level rise scenario.

## § 6.2.4 Explore moments in time when adaptation is needed

A next step is to analyse the moments in time when the thresholds associated with the ATP are reached. For the case Noordereiland it was found that, although the area runs a risk of flooding at a yearly or 1/10-event, due to the mound-shape of the area floodwater only reaches the buildings at a 1/50 event. When flood levels at the river reaches more than 3,0 m + NAP the area will experience flooding of the first buildings. Because of the 30 cm threshold of electrical infrastructure, power outages may be expected at a flood level of 3.30 m + NAP (1000-year event) and the ATP for this

specific criterion is not yet reached. It is expected, however, that the ATP for power infrastructure will be reached within a couple of decades, depending on the speed of sea level rise. For the case Feijenoord it was found that, although the probability of flooding is lower than the Noordereiland, the ATP is already reached for all performance criteria in the current situation, since a large part of the built-up area is susceptible to flooding of about 2,90 m + NAP with a probability of 1/50 – 1/100 a year. This means that immediate adaptation is needed.

## § 6.2.5 Explore adaptation responses

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As introduced in chapter 4, there are three main strategies to reduce coastal flood risk: reduce hazard probability, exposure, or sensitivity of assets to flooding. A first strategy that is considered is to reduce the sensitivity (or improve the flood resilience) of the built environment. This can be achieved by a combination of flood proofing new buildings and retrofit flood resilience into existing buildings, wet-proof utilities and infrastructures, or change use of the ground floor spaces from residential to storage or access. A second strategy is based on reducing exposure to flooding by keeping water out of the area by gradually raising the low-lying quay areas to flood design level. Finally, reducing the probability of flooding by improving the performance of the existing storm surge system is considered.

### Reduce sensitivity

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#### Noordereiland

Dry-proofing buildings is an effective approach to reduce flood damages of relatively shallow and high probability flooding (see for an overview chapter 4). Dry proofing includes the installation of water resistant windows, closing off buildings openings, sealing brick-stone walls and the installation of provisions to prevent inflow of sewer water. As the nineteenth-century buildings typology generally has an elevated doorstep level to 50 cm above street level, dry proofing is an effective strategy to reduce inflow of floodwater. An assessment of 9 historical buildings at the Noordereiland and Dordrecht showed that the average costs for dry proofing is considerably smaller than the annual expected flood damage at a 100-year flood event (**Table 6.3**) cumulative over an assumed lifespan of the investment of 20 years.

Due to the risk of losing structural integrity caused by hydrostatic loads and buoyant forces building up during a flood, dry proofing is not a preferable adaptation strategy for buildings with a (semi) basement. Moreover, many of the historical waterfront building

with basements already suffer from ground water ingress during astronomically high tides. For these buildings wet proofing the underground spaces is an option, which means effectively giving up the residential use of the basement and relocating critical building systems.

	AVERAGE DAMAGE COSTS PER BUILDING* AT A 100 YEAR FLOOD (€ 2015)	COSTS DRY PROOFING (€ 2015)
Rotterdam	1,865	523
Dordrecht	6,811	2,807

TABLE 6.3 Average damage costs and costs of dry proofing per building at a 100-year flood based on 4 residential buildings in Rotterdam and 5 residential buildings in Dordrecht. Source: Kuijk & Boer (2015)

### Feijenoord

Because of the considerable flood depths and duration of the flood, in the Feijenoord area dry proofing of existing buildings is physically not a feasible adaptation option. For these buildings wet proofing is the better option. Because retrofitting wet-flood proofing requires substantial structural modifications wet proofing of nineteenth century buildings is, however, expensive and is estimated to amount up to more than €50.000 per building (Peters, 2014c). This cost estimation corresponds with general cost estimations of wet proofing found in international literature (see section 4.2.4). Measures examined included raising all electrical equipment to reference level, the use of flood resistant finishing and replacement of the wooden floor and joists with a concrete floor. This cost estimations excluded costs for water resistant interior, such as water resistant kitchens.



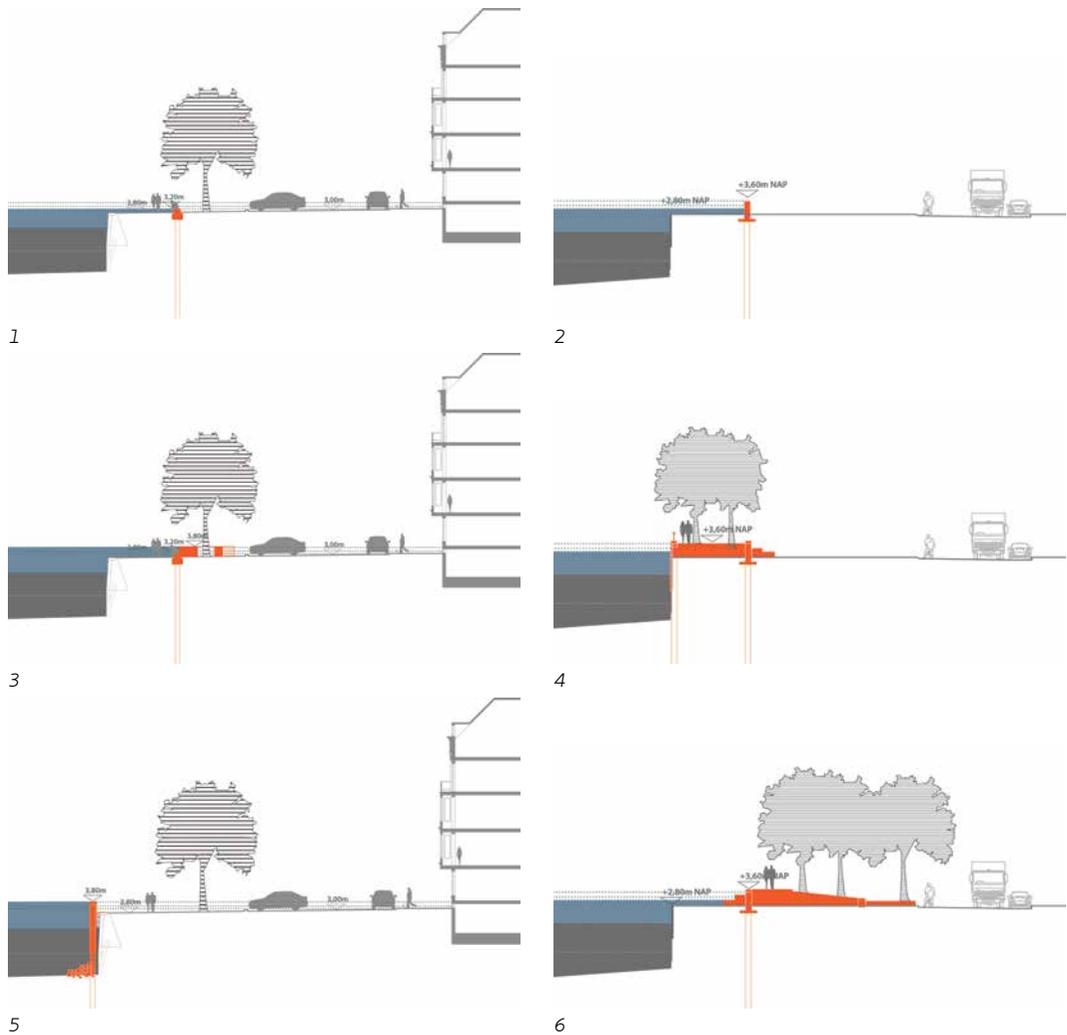
FIGURE 6.8 Left: retrofitting flood resilience to a charging post for electrical transport at the Noordereiland. Right: apartment building in Dordrecht built on a wet proofed semi below surface parking garage. Photo left: Gemeente Rotterdam, photo right by author.

Dry proofing of new residential buildings is, particularly when applied to large-scale redevelopment projects, an effective adaptation option. The extra costs for a dry-proofed design of an average single family-home is estimated to be €37,000 per building (€540/m<sup>2</sup>). Dry proofing includes building on a water resistant basement foundation with watertight entry points for heating and utilities instead of the traditional crawl space building technique (Peters, 2014c). A less expensive alternative is to elevate the building on an earthen or sand elevation (see **Fig. 6.9**) and wet proof the entrance hall to avoid flood damages. Dry proofing a large apartment building by elevating the building with 0.6 m is estimated to range between €0,8 – 1,5m (€15-30/m<sup>2</sup>) (Peters, 2012c). Note that the cost differences between retrofitting dry proofing to existing buildings and dry proofed design of new buildings does not vary significantly.

### Reduce exposure: district wide protection

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As a large part of the bulk headed quays is elevated during the initial construction or previous urban renewal phases, preventing floodwater to enter the area can relatively easy be achieved by raising some of the bulkheads and by constructing small floodwalls. For the Noordereiland and Feijenoord area several flood protection options were considered ranging from a small water retaining wall to an integrated floodwall combined with an elevated boulevard construction (**Fig. 6.9**). The dimensions for flood protection for the 100-year and 10,000-year flood (respectively 40 cm and 100 cm) provide ample opportunities for incorporating flood protection into a redesign of the waterfront areas. To guarantee sufficient strength and prevent ground water flows eroding the structure a sheet pile and concrete foundation need to be applied (Peters, 2012b). Particularly in areas with a historical quay construction, as is the case at the Noordereiland and some parts of Feijenoord, the construction of a sheet pile foundation may jeopardise the existing bulkhead construction creating significant cost increases (Peters, 2012b). The relative high costs for flood protection also means that, from an economic point of view, built-in expandability (such as shown in **Fig. 6.9** and discussed in chapter 4) is not beneficial, as the additional costs of constructing a larger flood-retaining boulevard are minimal compared to the large upfront costs for creating a foundation. In addition, the relatively high costs attributable to the construction of the flood retaining components of a multifunctional used flood defence also means that reducing costs by coupling investments with a redevelopment of the public space is limited. After all, the bulk of the costs for flood protection is attributable to the initial investment in flood protection. An option that might provide a substantial cost reduction is to couple the investment with the renewal of the bulkhead construction. The additional costs of expanding a sheet pile and concrete quay wall construction to new flood levels is relative small compared to the initial investment in quay wall renovation. However, from the viewpoint of benefit maximization these multifunctional options may be more attractive.



**FIGURE 6.9** Examples of some district-wide flood protection options for the Noordereiland (left row) and Feijenoord (right row). A small bench (upper picture) and wall allow for a future expansion to a larger elevated boulevard (middle picture) or a floodwall that can be combined with a future bulkhead renovation and enlargement. Cross-sections based on Nabielek-Kronberger et al. (2013).

As summarized by **Table 6.4**, all options considered for the Noordereiland and Feijenoord area require a relative moderate investment ranging from €1.5m to €5m. However, in the Noordereiland case none of these investments is beneficial compared to the cumulative annual cost savings of individual households that benefit from flood protection over the lifetime of the investment. However, potential economic benefits, such as effects on real estate value and co-benefits such as where not included in the CBA. However, the Noordereiland case also showed that the potential (co) benefits are limited. For example, due to the low flood risk awareness (see Boer et al., 2012) the real estate value in Rotterdam does not reflect the actual flood risks, and, consequently,

an increase in real estate value cannot be attributed to the benefits of improved flood protection.

The Feijenoord case shows that a floodwall is effective and beneficial, meaning that the avoided cumulative annual expected flood damage costs exceed the investment in flood protection.

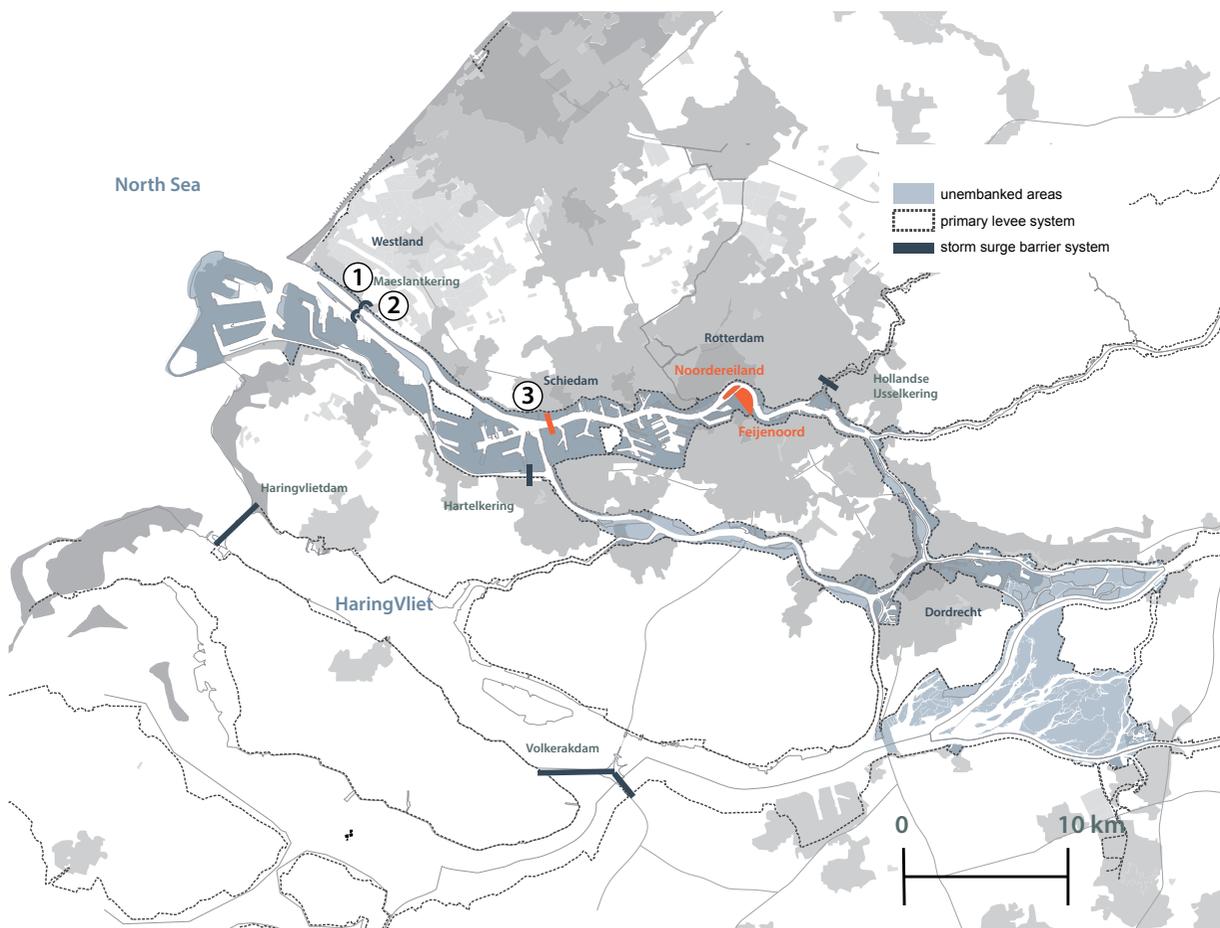
OPTIONS	COSTS PER M	TOTAL COSTS IN €M FEIJENOORD	TOTAL COSTS €M NOORDEREILAND
Flood wall with sheet pile foundation NAP + 3.40m	€ 740 – 900	1,5-1,8	1,4 – 1,7
Flood wall with sheet pile foundation NAP + 3.60m	€ 810 – 970	1,6 – 2,0	1,5 – 1,8
Flood wall ‘bench option’ NAP + 3.20m	€ 1,480– 2,750	n.a.	2,8 – 5,2
Flood wall ‘boulevard’ NAP + 3.60m Nassau- kade	€ 2,132– 3,960	4,3– 7,9	n.a.
Flood wall on new quay construction NAP + 3.80m. (Additional costs for 1 m flood wall)	€175 – 1,667	0,4 – 3,3	0,3 – 3,0
Flood wall ‘bench option large’ NAP + 3.80m	€ 1,590– 2,910	n.a.	3,0 – 5,5
Deployable dam NAP + 3.80m	€ 2,800 – 5,185	5,6 – 10,3	5,3 – 9,8

TABLE 6.4 Overview of costs of district-wide flood prevention options for the Noordereiland. Table based on cost calculations of Peters (2012a and b), prices (prices 2012), excluding costs for refurbishing the public space and based on a flood protection with a length of 1,850 m at the Noordereiland and 2,000 m at Feijenoord.

### Reduce hazard probability: improved storm surge protection

Because of the dominance of storm surge flooding in this part of the river, the most effective options to reduce flood hazard is to improve the storm surge barrier system. The Maeslant barrier is a moveable barrier at the mouth of the Nieuwe Waterweg that protects the tidal river of the Rhine-Meuse estuary from flooding during a storm surge at sea (Fig. 6.10). The barrier is composed of two moveable flood-retaining doors, which sink to the bottom of the canal and almost completely close the river mouth when submerged. The barrier is designed to close when water level reaches a level of + NAP 3.0m at Rotterdam or NAP + 2.9m at Dordrecht (Kallen et al., 2012). This level is defined as an optimal balance between the risks and the costs of high water levels in the river and the costs of a limited accessibility of the Rotterdam Port (RWS, 2009).

However, even in closed position the water levels behind the barrier may still rise due to river water discharge and wind set-up to an expected level of NAP + 3.6 m. This flood level still causes local floods of the unembanked areas (RWS, 2009). Due to the complex operating system and mechanical nature of the barrier the failure probability of the barrier is considerably high and estimated to a 1/100 change per closing session during storm conditions. In other words, the barrier's reliability is assumed to be 99% (Kallen et al., 2012). To reduce flood probability of the unembanked areas the Maeslant barrier can be improved by (1) improving the reliability factor by reducing the failure rate, (2) lowering the threshold at which the barrier closes and (3) replace the barrier by a dam and lock complex.



**FIGURE 6.10** Opportunities for improvement the existing storm surge barrier system include: (1) improving the reliability factor by reducing the failure rate, (2) lowering the threshold at which the barrier closes and (3) replace the barrier by a dam and lock complex.

### Improve reliability of the Maeslantbarrier

The reliability of the Maeslant barrier can be improved to a 1/1000-failure rate per closing session by replacing the moveable barrier structures by a more reliable system or to develop a second barrier upstream (Deltaprogramma Rijnmond-Drechtsteden, 2014). Options to substantially improve the reliability of the barrier are technically and economically limited (Kallen et al., 2012). Slootjes et al. (2011) concluded that improving the failure rate of the Maeslant barrier to 1/1000 per closing session significantly effects the low probability flood levels, however, the effect is minimal for high probability flood events (10 and 100 year flood), and fades away for upstream river dominated areas, such as Dordrecht. This means that, given the fact that the unembanked areas flood at high probability flooding, improving the reliability of the storm surge barrier is not effective to reduce the flood probability of the unembanked areas on the short term. On the long term, however, this adaptation option has a positive effect on reducing the mid and low probability flood levels associated with extreme sea level rise.

### Partial closure

The same applies for a partially closure of the barrier (e.g. only one of the doors closes properly). Although a partial closure of the barrier has a significant effect on reducing the more extreme flood levels at Rotterdam, it has no effect on the high probability flood events (10, 100 and 1000 year flood). Particularly, at low probability flood events (10,000 year flood) a partial closure of the barrier would reduce the flood level with approx. 30 cm and compensate for the increase of flood levels due to sea level rise. While this adaptation option has only minimal effects on reducing the flood probabilities of the unembanked areas it is potentially a “no regret” option because the costs of the investments are relatively low compared to alternative options to improve the reliability of the barrier (Jeuken et al., 2012) and is consistent with the current flood risk policy.

### Earlier closure

To reduce flooding, one of the adaptation options considered is to lower the threshold at which the Maeslant barrier closes automatically to NAP + 2,80 m at Rotterdam, instead of the current NAP + 3.0 m. The effect of an earlier closing on flood probabilities of the unembanked areas in the tidal dominated part of the river is small but still significant. At the 50-year to 1000-year return period range the effect is the largest but it reduces flood levels with not more than 12 cm in average (Rijkswaterstaat, 2009). Although the reducing effect is not large, it is however an interesting adaptation option to reduce flood probabilities of the unembanked areas in the short and midterm. Technically, it can be implemented relatively quickly but it requires new arrangements with the Port Authorities and the Rijkswaterstaat. Changing the closure level increases the amount of expected closure session and negatively affects the accessibility of the harbour. Based on a study (Rijkswaterstaat, 2009) an increase of annual closures costs as much as 10, 6 M€ (2008 prices) for a period of 10 year.

## Replace the barrier with locks

The Maeslantbarrier is designed to reach the end of its functional lifespan in 2070 (Rijkswaterstaat, 2009). One of the options considered is to replace the open barrier system with a barrier and locks system. The main advantage of this solution is that it reduces the relatively high failure mechanisms of the mechanically operated flood barrier to almost null and reduces the flood return periods at the river considerably with reductions of sometimes more than a meter (Slootjes et al., 2011, Vos et al., 2014). Additionally, this option can mitigate the effects of climate change completely. A seaside barrier, however, has a major impact on the accessibility of the Rotterdam harbour and has large ecological consequences (Jeuken et al., 2012). Moreover, closing-off the river with a barrier and lock system is an irreversible intervention that requires extensive governance reform and need to be considered as a long-term intervention option.

	Flood probability (1/x)	Flood level m + NAP	0.35 m SLR	0.85 m SLR	Partially closure at		Improve reliability of the barrier to 1/1000 per closing session		Earlier Closing Mae-slantbarrier at 2.80 m + NAP		Permanent Barrier with locks option		
Rotterdam	10	2.84	3.01	3.20	-1	0	-1	0	-10			-128	-100
	100	3.12	3.22	3.39	-1	-3	-1	-3	-13			-107	-72
	1000	3.31	3.41	3.79	-5	-24	-4	-29	-11			-87	-72

**TABLE 6.5** flood level reducing effects in cm of several interventions at Rotterdam (km 1000) relative to the current flood levels and the 0.35 m and 0.85 m sea level-rise scenarios. Data is based on Kallen et al. (2012), Slootjes et al (2011), and Rijkswaterstaat (2009). Options to improve the reliability of the existing Maeslant barrier are only effective at low probability flood events under extreme sea level rise conditions.

## § 6.2.6 Develop adaptation pathways

Based on an assessment of technical and spatial limitations of the adaptation measures (Nabielek-Kronberger et al., 2013), the effectiveness of the adaptation measures to prevent damage at a 1/100 return period at different climate change scenarios has been estimated. This overview can be used to identify at what sea level rise event (5, 10 or 15 cm, etc.) an adaptive measure fails to meet the previous set ATP. For example, dry flood proofing of existing historical buildings at the Noordereiland (e.g. closing off all openings in the façade) proved only to be effective at flood levels that are smaller than 50 cm, due to technical and architectural limitations. Other measures,

such as raising the quays or creating a floodwall proved to be effective within a larger range of flood levels. By doing so, it is possible to find the “sell-by-date” (Haasnoot, 2013) of actions and create several pathways. These pathways may consist of a single measure (such as a large flood wall) or of combinations of measures (flood proofing buildings combined with a temporary flood construction).

For the Kop van Feijenoord area it appeared that only a limited amount of combinations of measures is effective (**Fig. 6.11**). This has to do with the specific geographical situation of the case study area where only a small section of the quays is low-lying and responsible for the relatively high flood risk of the whole area. It appears to be an obvious choice to raise the low-lying Nassau quay (measure 3b) or a larger section of the waterfront development plot (3c), which allows for better flood protection for the low-lying area located behind it. Due to technical limitations and increasingly high costs when raising a historical bulkhead construction, a more cost-effective pathway could start with developing a low retaining wall (3a) and extending this wall in the future to a raised boulevard (3b) or with a temporary flood defence structure (3e) that can be put in place when necessary. An alternative strategy is to allow floodwater to enter the area. Because of the bath tube-shape of the area, water levels of more than a meter are expected, making dry-proofing of existing buildings difficult to integrate in the architecture and extremely expensive. Wet proofing measures (2a) of new constructed buildings and urban assets as well as (or in combination with) elevation of building sites (2c) for new developments could be effective for at least the next 100 years. Finally, a hybrid pathway consisting of elevating the embankment to NAP 3,40 m (3b), flood proofing critical infrastructure (2e) and developing crisis management, such as early warning system, better communication and training (4b).

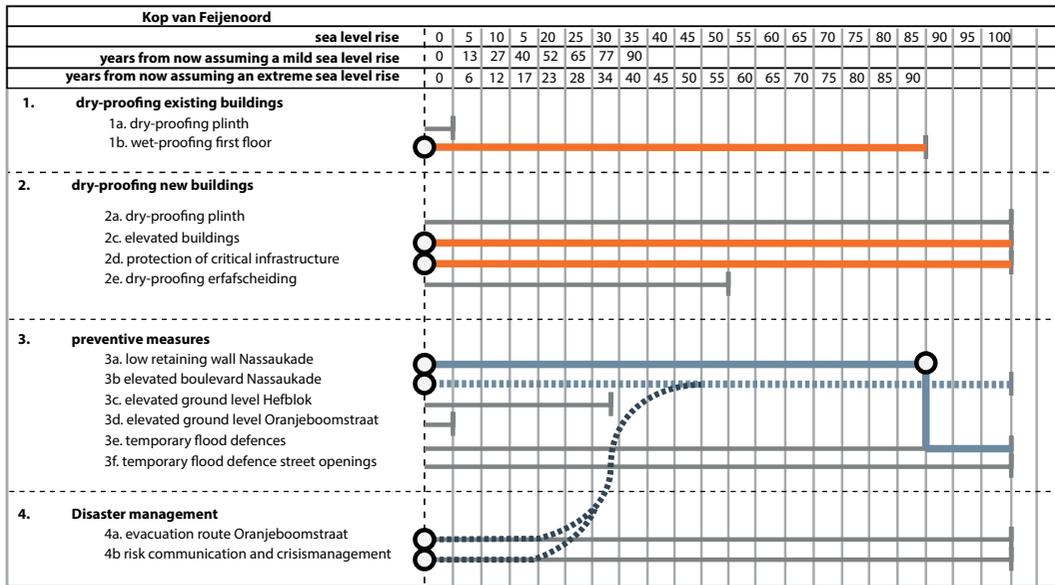


FIGURE 6.11 Assessment of effectiveness of adaptation measures (grey lines) to reduce a 100-year flooding relative to the current, moderate and extreme sea level rise scenarios for the Feijenoord area. The blue lines indicate an potential pathways (“water out”) consisting of a low retaining wall and/or elavated waterfront boulevard Nassaukade (dashed blue line). An alternative would be an combination of wet-proofing existing and new buildings and assets (“living with water”). Finally, an hybrid solution would combine disaster management with a future elavation of the quays or a low retaining wall (dashes black lines).

The Noordereiland case (Fig. 6.12) shows that a pathways based on dry-proofing the existing buildings and closing of the street openings by temporary flood defences is effective, but, because of architectural and technical limitations, only within a time frame of approximately 20 - 40 years. After this period the strategy might change to preventive measures, such as a local retaining wall or a raised quay embankment, which provides an acceptable situation for at least the coming 30-65 years. By expanding the embankment with a small retaining wall or a temporary flood defence, the strategy will be effective for the next 100 years. This solution is attractive because the embankment could easily be combined with a redesign of the public realm and be designed in a way that anticipates changing conditions and creates added value. An alternative pathway consists of dry-proofing as a short term adaptation action, and continuing this ‘living with water’ approach with giving up the residential use of ground floor spaces, as water levels increases. This, however, leads to a substantial loss of habitable space (more than a third of the ground floor apartments).

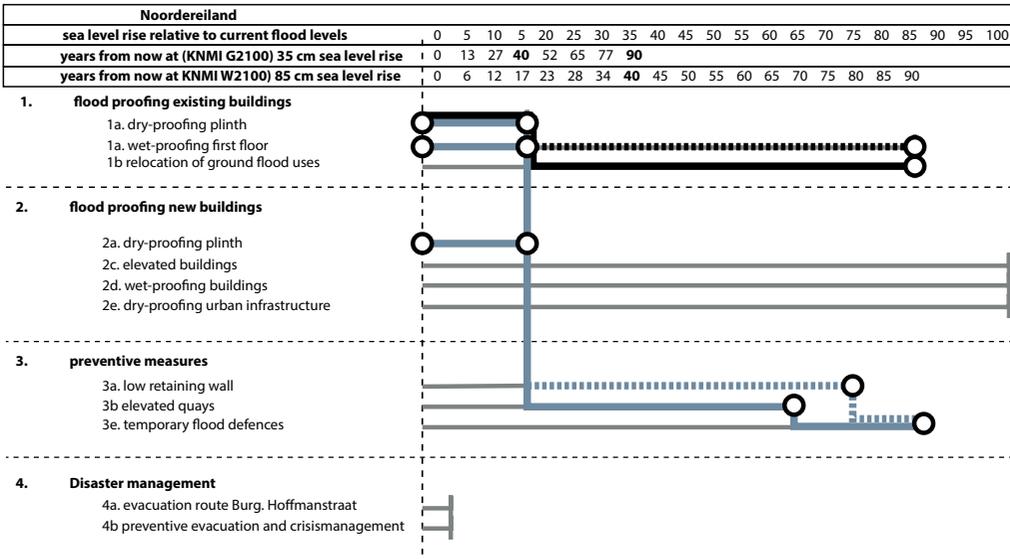


FIGURE 6.12 Assessment of effectiveness of adaptation measures (grey lines) to reduce a 100-year flooding relative to the current, moderate and extreme sea level rise scenarios at the Noordereiland. The blue lines indicate a potential pathway based on dry proofing existing and new buildings and an elevated quay and/or a deployable flood defence options (dashed blue line). An alternative path would consist of dry and wetproofing and a relocation of the ground floor uses (black lines)

### § 6.2.7 Evaluate pathways

Based on the assessment of potential combinations of measures a selection of the most promising pathways was made (Table 6.6). Two alternative pathways to reduce flood risk in the area are assessed. The first pathway is based on keeping water out of the area by gradually raising the low-lying quay shorelines to flood design level. A second pathway is to improve the flood resilience of the urban area. This “living with water” strategy can be achieved by a combination of flood proofing new buildings and retrofit flood resilience into existing buildings, wet-proof utilities and infrastructures. A third pathway “basic safety” is a hybrid of these two and is based on elevating the perimeter to provide basic safety in combination with building level protection and flood proofed infrastructure. As introduced in section 3.5.3, the potential adaptation pathways are appraised on the effectiveness in reducing floods, cost-effectiveness, and opportunities to create added value or synergistic benefits.

PATHWAY	ADAPTATION ACTIONS
Business as usual	2c. Elevation of new buildings and outdoor spaces to NAP +3,90 m 4b. Risk communication, training and crisis management
Water out	3a./3b. Low retaining wall or elevated boulevard to a level of NAP +3,60 m / NAP +3,90 m along the perimeter of the Feijenoord district.
Living with water	2a. Dry-proofed new residential buildings to elevation level of NAP +3,60 m / NAP +3,90 m 1b. Wet proofing existing buildings during renovation, including: Elevation of electrical and heating system to above the flood level Deployment of water resistant flooring and wall cover Closing off building openings and vent holes Measures to prevent inflow of water from the sewer 2d. Protection of critical to NAP+ 4,10 m 4a. Development of elevated evacuation route along the Oranjeboomstraat and Rosestraat to NAP+ 4,10 m
Basic safety	3a./3b. Low retaining wall or elevated boulevard to a level of NAP +3,40 m / NAP m along the perimeter of the Feijenoord district (to provide basic safety) 2d. Protection of critical to NAP+ 4,10 m 4b. Risk communication, training and crisis management 4a. Development of elevated evacuation route along the Oranjeboomstraat and Rosestraat to NAP+ 4,10 m

TABLE 6.6 Table overview of paths and measures

### Effective in reducing floods

All considered pathways for the Feijenoord and Noordereiland case reduce flood damages considerably. Pathways based on exposure reduction (options “water out” 1a and b) reduces flood damages to (almost) 100 %; whereas pathways based on flood sensitivity reduction (options “living with water” 2A and 2B) reduce expected flood damages to 92-93 % for the Feijenoord case and 35% for the Noordereiland case (Veerbeek and Gersonius (2013). All pathways perform significantly better than continuing the current strategy that would reduce flood damages to only 66% for the Feijenoord case (Pohl et al., 2014). The Noordereiland cases shows that building level protection (dry-proofing or wet-proofing) reduces the amount of flooded units to an average of 45 % of the total building stock. Dry-flood proofing is an effective strategy for almost one third of the Noordereiland building stock because many of the historical buildings have their ground floor elevated above the flood level and can be dry proofed relatively easily. However, dry proofing is only effective within a time frame of 20 - 40 years. Wet proofing is effective under a wider range of flood levels, but require large-scale refurbishment of the below flood level space and is therefor expensive.

## Cost-efficiency

Table 6.7 shows the cost effectiveness of various pathways for the Feijenoord area based on a Net Present Value (NPV). Pathways with a positive result are beneficial from an economic point of view. As opposed to the living with water pathways (alternatives 2a and 2b) the prevention-based pathways (1a and b) show positive results. A striking outcome is that the hybrid pathway ('basic safety'), which consists of a small elevation of the bulkhead combined with adapting vital infrastructure, is most beneficial although the differences with alternatives 1a and c are not substantial. The positive outcome is mainly due to the relative high costs of property-level adaptation compared to the relatively low investments costs of flood protection<sup>5</sup>.

PATHWAYS	BUSINESS AS USUAL	WATER OUT	WATER OUT	LIVING WITH WATER	LIVING WITH WATER	BASIC SAFETY
Adaptation Measures	2c) elevating new buildings 4b) crisismanagement	3a./3b low retaining wall (+NAP 3.60 m) 3 e) temporary flood defenses	3a./3b. low retaining wall/ Boulevard (+NAP 3.90 m)	2a. Dry-proofed new buildings to NAP +3.60 m 1b. Wet proofing existing buildings 2d. Protection of critical infrastructure 4a. Evacuation route NAP+ 4,10 m	living with water 3.90m	2d. flood proofed critical infrastructure 3a. low retaining wall (3,40 + NAP) 4a. elevated evacuation route 4 b. crisis management
<b>Costs</b>						
Investment (minus residual value)	8.468	1.362	1.481	22.656	29.174	1.017
Maintenance	3.221	587	639	5.500	7.045	475
<b>Benefits</b>						
Flood prevention	6.754	8.080	8.080	8.386	8.251	8.080
<b>Total</b>						
Total costs	11.689	1.949	2.120	28.156	36.219	1.491
Total benefits	6.754	8.080	8.080	8.386	8.251	8.080
Result	-4.935	6.131	5.960	-19.770	-27.968	6.589

TABLE 6.7 Cost benefit assessment (CBA) of several potential pathways for Feijenoord based on a preventive pathway (1a and b), a living with water approach (2a and b) and a combination of prevention and living with water (3) at several maximum protection levels (m + NAP). Source: Pohl et al., 2014.

5

Assumptions on the discount rate and costs may affect the viability of the projects, particularly for long-term assessments. To test the robustness of the strategies for changes in discount rates and increase in costs, a sensitivity assessment has been performed assuming a 0% discount rate and an increase of 10% in costs. The sensitivity analysis showed that the outcome is not significantly affected (Pohl et al., 2014).

The individual risk assessment and cost estimation of dry-proofing buildings of 9 buildings in Dordrecht and Noordereiland showed that the average costs of dry-proofing ranges between €500 - €1000. Based on these numbers and the expected annual damage costs the return on investment of dry proofing is 10 to 15 years. In other words, dry proofing is a cost-effective adaptation response that falls within property-owners time frames for planned building maintenance. Considering the relatively low expected annual expected damage (EAD) to households (see section 6.2.2) and the relative high costs of a flood wall with sheet pile foundation, district-wide flood protection is only cost-beneficial after 35 -40 years or under extreme sea level rise scenario (85 cm). This timeframe fits well with the expected time frame under which building level protection is effective. Note again that these numbers do not include indirect damage such as costs of power outages and long-term effects such as decreasing real estate value. Assuming a 2 to 10 fold increase in EAD a simple sheet pile floodwall solution will reach its return on investment point within 30 and 15 years, respectively.

A critical stance towards the role of CBAs in the assessment of adaptation pathways is, however, needed. In the CBA the indirect costs and benefits accruing from enhanced flood protection are not considered and are difficult to assess with any accuracy (Tobin and Montz, 1997). For example, an increase in real estate values in the Feijenoord area could be attributed as a positive effect of enhanced flood protection. However, in view of the current low risk awareness among stakeholders it is also likely that the low property values in the area do not necessarily represent flood risk, or that an increase in property values will occur anyway. Unravelling the 'variables that influence property values independently from flood hazard' (Tobin and Montz, 1997) is extremely difficult, if not, impossible.

### Added value

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Retrofitting dry-proofing measures may require substantial modifications to the building's architecture. Particularly for historical waterfront buildings at the Noordereiland, of which listed monuments, these modifications may be in conflict with the need to preserve the monumental value of the buildings. Even though there are dry-proofing techniques on the market designed for high-level integration in existing buildings, dry-proofing itself does not offer additional benefits. The development of a flood protection scheme potentially offers opportunities for a redesign of the quays. However, considering the relatively long return on investment, from an economic perspective an investment in district-wide flood protection will rather be depending on an investment in public space redevelopment, than that it triggers new investments. In contrast, the Feijenoord case shows that flood protection not only provides the most beneficial solution for flood protection but actually drives investments in redevelopment of the public space as well. Although such benefits are hard to quantify, they ought to be included in making final decisions on the flood adaptation strategy.

## § 6.3 Results

Which pathways to resilience provide flexibility and deliver added value in the long run? The Feijenoord case shows that a district-wide flood protection strategy provides the most beneficial solution and opens up opportunities for incremental development by capitalising on investments in urban realm and improvements of the waterfront. The Noordereiland shows a more diverse portfolio of adaptation responses, although there are only a few combinations of adaptation responses that are complementary to deal with change in the long run. A potential adaptation strategy for the Noordereiland is based on sequencing property level protection (wet-proofing and dry-proofing adaptation measures), followed by the development of a permanent or temporary floodwall. An alternative pathway is composed of building-level protection and continuing this 'living with water' approach with giving up the residential use of ground floor spaces, as water levels increase. Constructing a floodwall is highly effective but expensive. It will take a considerable amount of time to realize this structure.

Interventions in the regional storm surge protection system, particularly lowering the closing threshold of the Maeslant barrier to + NAP 2,80 m is an effective adaptation option to reduce the flood probabilities of the unembanked areas in the short and midterm. Particularly when combined with property level protection, this intervention attenuates the effect of long-term sea level rise on the lower and mid probability flood levels. This creates a larger period of relative stability in terms of flood probabilities and, more importantly, it extends the time frame in which property level protection is effective and beneficial. In other words, a 'fine-tuning' of the regional flood levels by improving the Maeslant barrier improves the performance of local level adaptation responses. This effect also works in opposite direction: dry or wet proofing of existing buildings is a cost-effective adaptation response that 'buys time' to increase opportunities for a transfer to a regional intervention.

Both cases also illustrate that the specific morphological, and urban and building typologies strongly determine the most effective strategy. This underlines that strategies to enhance the resilience of urban waterfronts must be based on a detailed assessment of local vulnerabilities, stakeholder engagement and promoting site-specific adaptation measures, leading to a tailor-made portfolio of solutions on district and neighbourhood level.

The net present value (NPV) of the strategies appeared to be time-sensitive (Pohl et al., 2014). Delaying expensive adaptation measures such as a floodwall reduces the overall investment costs (in NPV) but increases costs in the short time because the potential value of enhanced flood protection comes available only once the floodwall is completely built. The most optimal combination of adaptation measures, in terms of economic viability, would consist of low-costs measures that reduce the consequences of a flood in the short

term (such as an early warning system and building level protection) and measures that reduce exposure to be realised in the long term. However, this combination of adaptation actions run a risk of a financial lock-in. Every investment in building level resilience reduces the overall flood risks and hence the benefits accruing to the floodwall option, making a 'transfer' to a district-level solution less feasible from an economic point of view. In addition, the potential loss of investments of individual homeowners associated with a change of strategy could lead to societal and political resistance to change. This problem of 'transfer costs' between several adaptation options also happens with a transfer between local level adaptation and a regional intervention. Any decision to improve the Maeslant barrier is not prompted by a balance between the economic losses of an increase in closure sessions for the port infrastructure and the increase in flood damages of the unembanked areas (Rijkswaterstaat, 2009). In other words, the cumulative damages of the unembanked areas are a decisive factor that triggers a policy review. However, any investment in local level resilience (both at building and district-level) reduces local flood damages and hence weakens the benefits of an improvement of the Maeslantbarrier. This problem of cross-scale interactions in adaptation planning is an area that requires further research (Zevenbergen et al., 2008a).

Co-benefits and added values arising from increased flood protection can have a positive effect on reducing the transfer costs, although the efficiency effects strongly depend on site conditions. For example, building level adaptation (wet or dry-proofing) can also be effective to deal with increasing pluvial flood risk, which is, particularly in Asian cities, a major source of flood risk. Additionally, crossovers between climate mitigation and adaptation strategies can reduce the costs of each single adaptation strategy and hence increase opportunities for low-cost adaptation. Especially, measures for improved energy efficiency on building or estate level open opportunities for low-cost dry proofing.

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## § 6.4 Conclusions and discussion

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### § 6.4.1 Is the APM appropriate for local coastal adaptation planning?

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The Feijenoord and Noordereiland case show that the adaptive pathway method (APM) is an effective tool to evaluate and select adaptation measures. In this way it helps to develop a wider portfolio of adaptation responses. In particular, the method helps to better grasp the timing of adaptation, which increases flexibility and opens up opportunities to couple adaptation with other planned investments, or to anticipate for easier adaptation in the future. Furthermore it helps to identify potential lock-ins at an early stage in the planning process.

One of the major advances of the APM is that objectives and ambitions need to be spelled out clearly at the offset of an adaptation planning process. Particularly, translating implicit or general ambitions to specific and quantifiable targets helps to explore effective climate change adaptation actions. Defining the adaptation tipping point is, however, more complex. This is not only because the moment that a system reaches its ability to cope and recover from disturbances is a gradual, rather than a fixed and easy identifiable threshold, but also because it is politically sensitive to define the adaptation tipping point and corresponding ‘threshold values’. In addition, working with different policy objectives and corresponding threshold values for several indicators such as social disruption, flood damages and individual mortality risk, proved to add a layer of complexity rather than simplifying the adaptive planning process. It proved to be necessary to convert multiple policy objectives to clear, sometimes probably too simple, targets and threshold. However, even when little or no consensus concerning the ATP can be reached, or the ATP is difficult to quantify, the AP method is a valuable instrument to explore the effects of potential futures and consequences of different policy choices, thereby contributing to a better understanding of the causal relations between flood risk, adaptation options and adaptation goals. The method thus bridges the gap between model-based risks assessment analysis with area-based planning and design.

The APM is particularly effective under relatively well understood, slowly unfolding transitions. When applied to the level of urban planning and design, defining adaptation options requires detailed information on hydraulic conditions, regional effects of climate change and detailed knowledge on the effectiveness of adaptive urban design. Moreover, it needs consensus among policy-makers and stakeholders on objectives and performance criteria. This makes the APM, when applied at the local level of waterfront development, a time-consuming technique. When detailed information on flood probabilities is lacking, which is often the case in adaptation planning, APM is less useful as a decision support method at the local level. Another concern is that adaptive pathways based-strategies, particularly when they are based on multiple adaptation responses, need constantly monitoring of changing conditions to allow for a timely reacting and change of strategies. This means that planners should develop long-term decision-making structures that are based on monitoring change and adapting the action plan when needed. For example, a building level adaptation strategy as proposed for the Noordereiland requires regular monitoring of the speed of sea level rise but also of the implementation rate of homeowner’s investments in dry proofing or wet proofing. Additionally, it requires planning and development of corrective actions (e.g. a homeowners incentive programme or improved risk communication) to influence the implementation rate. The need for long-term strategic adaptation practice and constantly monitoring runs counter to the short-term focussed and pragmatic practices of urban planning and development (Krabben, 2011). This is a serious problem that, left unrecognized may even lead to a loss of resilience in the long-term.

## § 6.4.2 Towards urban dynamics based adaptation planning

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An important element of adaptive planning is the assumption that a transfer between alternative interventions (and thus developing alternative pathways) is straightforward. However, a fundamental shortcoming of the adaptive pathway method is that in reality 'there is no 'free choose' between alternatives' (Wise et al., 2014: 332). Adaptation pathways may be constraint by regulatory structures, property rights and social norms (Adger et al., 2005a), making a smooth transfer between adaptation actions challenging because it requires major institutional reform, or changes in the dominant cultural values and beliefs. Another challenge is that the transition costs to move to another pathway usually exceeds the costs of traditional approaches (Pelling, 2011). This is clearly illustrated by both cases. Both cases showed that a change of strategy both in scale of intervention (e.g from property-level to a district-wide solution) as type of strategy (reduce exposure or reducing sensitivity) is accompanied with 'transaction costs' and is constraint by legal, financial and institutional barriers. This problem of 'path dependency' means that future pathways are dependent of earlier decisions and difficult to change. Overcoming the economical, and societal barriers is a major challenge and it unfortunately often needs a disaster to change the course of an adaptation path (Jeuken & te Linde, 2011).

In addition to this, there is also a second, more fundamental shortcoming of the method. Although the APM is adaptive, in the sense that it allows for uncertainties to be resolved in time, the method itself is surprisingly linear. Particularly, it ignores the dynamic aspect of urban development and change and new opportunities for adaptation that might arise from it, which are not yet identified, or positively assessed. Moreover, it ignores the fact the socio-economic system reacts on adaptation actions and policies, which influences path dependencies or results in adverse, unforeseen effects. Arguably, understanding the dynamics of urban development and management of urban assets is essential in adaptation planning. It is therefore necessary to develop a method more suited to take into account the opportunities of urban dynamics. To improve the AP method in a context of urban development, it is necessary to (1) assess spatial and timely synchronization of adaptation measures with planning of spatial (re)development and public and private infrastructure maintenance projects; (2) assess institutional and financial barriers that need to be taken to mainstream climate adaptation measures into urban development processes and (3) to assess what opportunities derived from urban development are able to 'break through' the path dependencies that lock-in more sustainable adaptive paths. This also requires identifying which stakeholders benefit to what degree from a specific set of interventions and who is carrying the costs of these measures. In the next section the focus will be on the question how to effectively use urban change and development as moments of change for enhancing resilience.

# 7 Urban dynamics-based adaptation planning

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## § 7.1 Introduction

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As introduced in the introduction section, there is a lack of research that focuses on actual processes of urban development, management and change as an important precondition for a successful implementation of climate adaptation strategies. Several resources (Pahl-Wostl, 2007, Huq et al., 2003, Klein et al., 2005, Bouwer & Aerts, 2006, Zevenbergen et al., 2008b, Uittenbroek et al., 2012) stress the importance of incorporating adaptation to climate change adaptation in other policies, strategies and decision-making processes. In climate change literature this process of making adaptation part of 'the routine' is known as mainstreaming. The concept of mainstreaming originates from development planning (Huq et al., 2003) and has increasingly been used in processes related to resource management, community development, livelihood enhancements, coastal zone management, sustainable development, and risk management (Smit & Wandel, 2006). Also, at the level of practitioners is a growing awareness of the opportunities of mainstreaming adaptation. One of the front-runners in this respect is the city of Rotterdam. Mainstreaming is one of the leading principles in the Rotterdam Climate Adaptation strategy; it is referred to as 'linking in [adaptation measures] with area development, network maintenance or the transformation of real estate' (City of Rotterdam, 2013:26). New York City is promoting the integrating of climate change adaptation — in this case referred to as 'climate resilience' — in its land use and waterfront management policies. For example, climate change adaptation is integrated in recently updated New York City's zoning ordinance and building codes (NYCDCP, 2013b). The Dutch Delta Programme stresses the synergetic advantages and has explicitly adopted mainstreaming as a core strategy, referring to it as 'coupling of mutual goals' (Delta Programme, 2012, van de Ven et al., 2014). The growing attention for incorporating adaptation into regular urban development processes can be explained as part of a political process to redistribute responsibilities to lower levels of authority (e.g. city level) and enlarge the role of the private sector.

## § 7.1.1 Mainstreaming adaptation

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Despite the inconsistent terminology – sometimes it is referred to as “mainstreaming with”, “incorporating in” or “marry with”, the underlying premise behind incorporating climate adaptation into processes of urban planning and decision-making is that it is more straightforward and cost-effective. Cost savings are expected from opportunities to “piggy-back” adaptation upon other activities or from increasing benefits for local and regional stakeholders on the short term. But also to avoid maladaptation in the long run, which may result in increasing costs and poorly integrated solutions. Uittenbroek et al. (2012) argues that mainstreaming increases the opportunities for innovations and improves the effectiveness and efficiency of policy making. Other sources claim that mainstreaming speeds up the process of adaptation (Mees & Driessen, 2011), reduces costs (Klein et al., 2005) and yields synergetic benefits (van de Ven, 2011). In the context of climate change adaptation, adaptation options that are beneficial, or yield benefits in the short term, and add to reduce long-term effects of climate change are referred to as no-regret options (Hallegatte et al., 2012). Despite the positive qualities that has been attributed to mainstreaming, Smit & Wandel (2006) observe that research that focuses on the implementation processes for adaptation is still not common, although they acknowledge that in other fields of research ‘a vast body of scholarship is developed that deals with actual practices and processes of adaptation’ (2006: 285). In practice, adaptation still appears to be proceeding slowly and is faced with many institutional or financial barriers. Barriers that hinder incorporating adaptation are the lack of awareness of potential risks among key stakeholders (Friend et al., 2014), limited resources or information (Measham et al., 2011), the inability of actors to agree upon goals and criteria to assess these goals, and conflicting or overlapping jurisdictions (Moser & Ekstrom, 2010).

Although these barriers are equally important, a more profound criticism is that mainstreaming remains limited to policy development processes at a strategic or tactical level and that it ignores the operational level of urban planning and development. However, processes of urban change, renewal and transition may well be the strongest determinants of success of climate change adaptation, and, more importantly, potentially create opportunities that open new ways for adaptation that are not yet identified. Arguably, urban dynamics and change may be leading drivers in adapting urban environments rather than adaptation urgency being the main driver that steers urban planning.

This section focuses on the question: how can we effectively use urban change and development as opportunity for enhancing resilience? To answer this question it is necessary to explore what urban change or dynamics can be used as a catalyst for enhancing resilience in waterfront communities and how can we use these moments of change effectively to steer urban areas towards more resilient futures? The main goal of this section is to introduce an urban dynamic analysis based adaptation-

planning method and to provide empirical evidence for its applicability. To get to that point, section 7.2 first provides an introduction of earlier tested methods based on identifying life cycles of buildings and urban assets and windows of opportunity in urban development processes. Based on this overview, a new method is introduced (section 7.3) and tested in two case studies of urban coastal waterfronts in Rotterdam and New York (section 7.4). Based on the case study research conclusions will be drawn on the applicability of incorporating flood risk adaptation into incremental and planned processes of urbanisation, and finally, findings on the uniform application of the proposed method are shared and lessons for improving the APM are drawn.

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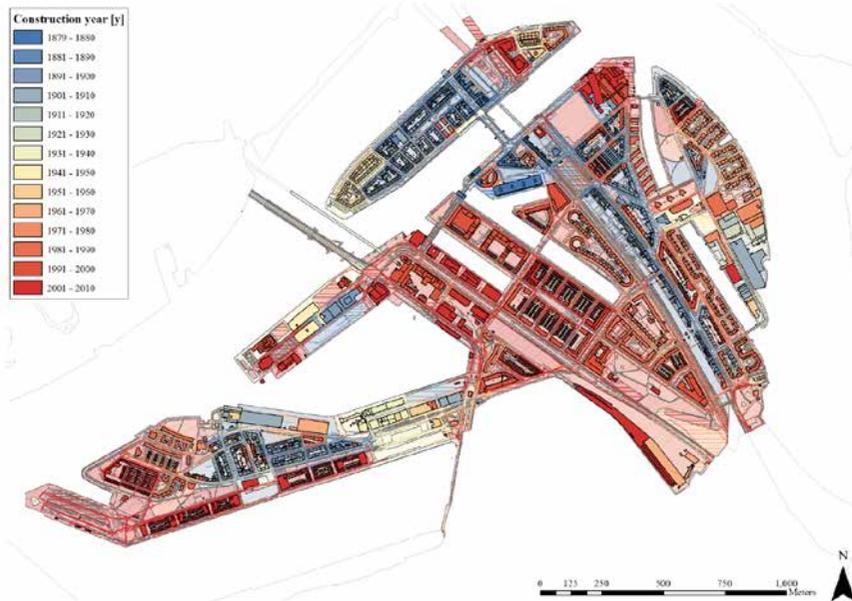
## § 7.2 Towards transitional or transformative pathways: adaptation options, intervention points and new opportunities

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### § 7.2.1 Growing into resilience: life-cycle based planning

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Recently, researchers (Veerbeek et al, 2010b, Zevenbergen et al, 2008b, van de Ven, et al., 2011, Gersonius, 2012) have drawn attention to incorporating adaptation into urban renewal, regeneration and development cycles. The assumption is that actual moments of change in processes of urban renewal and development and life cycles of buildings and assets offer significant ‘windows of opportunity’ that allow for integrating adaptation measures at relatively low costs. Identifying these adaptation opportunities allow for a more ‘opportunistic’ adaptation strategy, in which urban dynamics set the pace and nature of adaptation responses of urban areas ‘growing into resilience’. Van de Ven et al. (2011) identify two major opportunities for neighbourhood life cycle based adaptation. Firstly, the development of greenfields and the transformation of brownfields provide opportunities to include adaptation into the design of buildings, infrastructure and networks. Secondly, the planned renovation of buildings and urban assets offers opportunities to retrofit adaptation measures. When these adaptation opportunities are missed, retrofitting adaptation measures usually becomes more expensive, time-consuming and leads to weakly integrated spatial solutions



**FIGURE 7.1** Assessment of expected End of Life Cycle (EOLC) of buildings and public space based on age, building type and data on sewer and infrastructure conditions for the unbanked areas on the Southbank in Rotterdam. Blue range colours indicate that buildings and streets are close to the expected end of functional lifespan and serve as an indication for high potential intervention opportunities. Picture from Veerbeek (2013)

Gersonius (2012) introduces a method based on the identification of Adaptation Mainstreaming Opportunities (AMOs). AMOs are defined as ‘windows of opportunity’ derived from cycles of maintenance, modification and renewal of urban assets, infrastructures, buildings and public spaces. The Mainstreaming Adaptation Approach is based on identifying project-level adaptation opportunities by (1) identifying all planned or expected spatial investments within a predefined study area, (2) determining the time windows when these investments are likely to occur, (3) modify these investment projects to incorporate climate adaptation measures and (4) analyse if time windows of adaptation strategies and investment projects overlap or coincide. The AMO method has found to be effective when assessing the viability of adaptive strategies in well-managed systems, such as an urban sewer system and when limited to identify ‘project-level adaptation mainstreaming (Gersonius, 2012: 78)’. Veerbeek (2013) introduces a GIS-Based method aiming to identify potential adaptation moments by assessing the expected end of life span of buildings, based on the age and expected renovation cycles of the building stock in Rotterdam (**Fig. 7.1**). This research concluded that ‘due to the relatively long lifespan of Dutch buildings, the possibilities for gradual upgrading are limited (Veerbeek, 2013:9)’.

Although, both approaches initially aimed to assess the adaptive capacity and temporal aspects of retrofitting adaptation of urban regions in general, it may be doubted if

evaluating lifecycles is an appropriate method to define adaptation opportunities at the project-level of urban development and change. Both methods assume a high level of continuity and predictability of urban development and maintenance and assume that investment projects can be predicted with some certainty. This may be true for cycles of planned maintenance of urban infrastructure, such as a sewer system, but the economic life span of buildings is only one of the myriad factors that influences urban change. Other factors, such as ownership, position within the urban geometry, current market values and market conditions, and political incentives (van de Ven et al., 2011, Veerbeek et al., 2010b) are equally important when understanding urban dynamics and identifying adaptation opportunities. Secondly, both approaches limited their focus on identifying the moments of change that allow for incorporating adaptation, but ignored the fact that it needs more to turn these moments into actions. A common problem in adaptation is that costs and benefits of adaptation are not distributed evenly among stakeholders (Adger et al., 2005a). In addition, local governments lack legal instruments to regulate adaptation measures on building level (van Vliet, 2012). These two examples illustrate that it sometimes needs political reform, changing rules, or new arrangements to unlock the full potential of moments of change. Finally, both methods ignore that other interventions (e.g. both spatial intervention and changes in institutional landscape, policy changes or new financial instruments) and agendas sometimes generate new and unexpected moments of change and open up opportunities for adaptation at the local level. Rather than to focus on identifying opportunities of change to assess potential adaptation paths alone, it is more effective to identify urban changes, and new partnerships that create new, and potentially more effective or beneficial pathways to resilience.

To conclude, It is necessary to develop a method that bridges the gap between identifying adaptation opportunities based on actual moments of change in urban development *and* transitional changes in legal, institutional and financial structures that are needed to improve the willingness among stakeholders to invest in adaptation or that unlock the potential of new moments of change.

The method proposed here is based on a distinction made by Pelling (2011) that already has been introduced in section 2.3.3. In his view, adaptation is a result of processes of *resilience* actions, *transitional* adaptation and *transformational* adaptation. Resilience actions aim to improve the performance of a system without changing guiding assumptions or established routines, *transitional* adaptation actions aim to optimise and improve of current policies, rules and technics, and *transformational* adaptation actions aim to develop large-scale or radically new trajectories, approaches, techniques and policies. The point is to distinguish between incremental pathways (combinations of interventions that are part of the routine), transitional pathways that do require some improvement of the set of policies, rules and techniques, and transformative pathways that are based on large-scale institutional and cultural changes and new partnerships that unlock the full potential of these new pathways.

Building on these definitions five aspects of adaptation can be distinguished: (1) *adaptation options*, defined by the IPCC (2014:2) as 'the array of strategies and measures that are appropriate for addressing adaptation needs' (p: 838), (2) *adaptation opportunities*: 'factors that make it easier to plan and implement adaptation actions, [...], or that provide ancillary co-benefits' (IPCC, 2014:2). In addition to these definitions, it is necessary to distinguish between (3) *adaptation intervention points*, which are defined as the actual moments of change that potentially may be used for adaptation, (4) *adaptation transitions* that are defined as changes in legal, institutional and financial structures that unlock the full potential of adaptation intervention points, and (5) *adaptation transformations* that are fundamental changes in urban form, policies, institutional arrangements and norms that could create new *adaptation opportunities*.

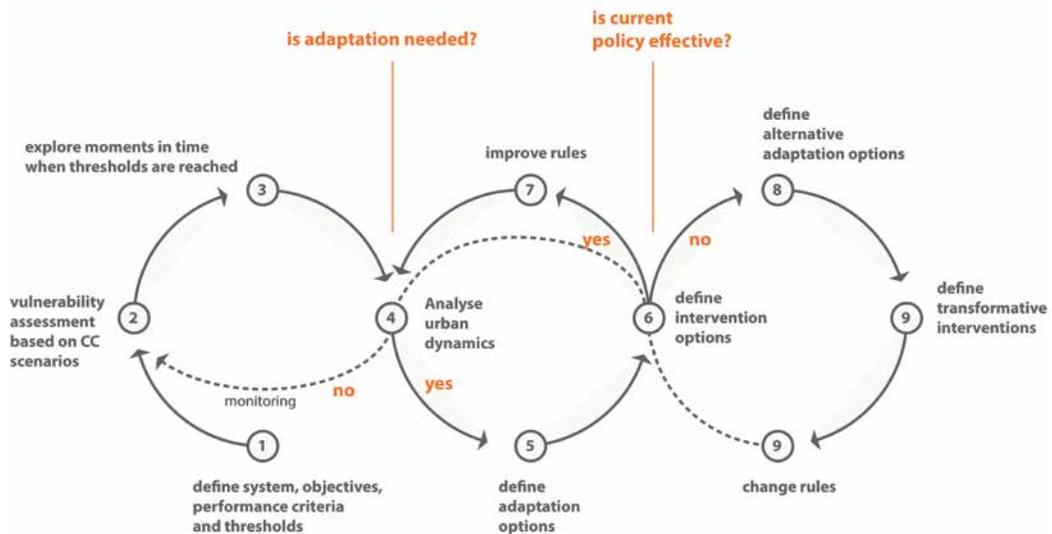


FIGURE 7.2 Adaptation Pathway Method based on incremental adaptation and transformative adaptation pathways.

## § 7.2.2 Introduction of a new framework

Rather than identifying all potential adaptation options and select the most optimal, the method introduced is based on assessing the effectiveness and long-term sustainability of the current policy framework (Fig. 7.2). Building on the work of Haasnoot (2013) and Gersonius (2012) the method starts with the first steps of the

AP method: (1) defining the system, objectives and thresholds, (2) a vulnerability assessment using the ATP, and (3) identifying moments of time when thresholds are reached. It then continues with an assessment of expected urban dynamics, relevant stakeholders, and an assessment of local agendas and ambitions for change in the area to analyse how incremental changes and transformative change affects the vulnerability of the system under review. As an example, an expected spatial change—be it an incremental process of gentrification or a more transformative development triggered by a rezoning— may both positively or negatively affect the vulnerability of the area and influence the position of critical thresholds. A conclusion at this stage of the adaptation planning process could be that adaptation is not (yet) needed, or that incremental urban change leads to a more resilient situation. However, when urban change is expected to increase vulnerability adaptation may be needed in the future. When adaptation is needed or expected, (5) *adaptation options* and *adaptation intervention opportunities* are identified that enhance the resilience of the area within the current policies and regulations frame. Based on this assessment, the effectiveness and long-term sustainability of the current policy framework is judged. A potential outcome of this stage is that the current policy is effective to enhance the resilience of the area, although (7) adjustments of the rules are needed that improve the effectiveness of the policy frame assessed. If so, after implementation of these policy adjustments the method continues with monitoring the timely implementation of adaptation options based on an assessment of urban change (4). Yet, if the improvements of the rules, over time, prove to be ineffective to deliver resilience in the long run (8) alternative *adaptation options* and (9) *intervention opportunities* are assessed and (10) *change of rules* that is needed to unlock the potential of the adaptation options and intervention opportunities identified. As a final step, based on this analysis, the transformative adaptation strategy can be implemented and again a phase of monitoring proceeds (4).

### What is urban dynamics?

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Before moving on to the empirical section, it is necessary to shortly reflect on urban dynamics. Cities change constantly. Change may stem from planned maintenance works, improvements and alterations of streets and public realm or infrastructure systems, and, probably most influential, from private investments in real estate development. Change may also come from planned large-scale renewal or transformation processes in which use, urban form and position of an area are drastically changed in order to bring an area up to a new desired level. Both incremental and planned processes of change provide opportunities for adaptation but differ in terms of timing, impact and scale of the intervention. Although prediction on life cycles of assets is highly uncertain it still is important to explore some aspects of urban change and dynamics to get a better understanding of the mechanisms that guide urban change and may be used for adaptation planning.

One of the early theories on urban dynamics is the life cycle theory of neighbourhoods of Hoover and Vernon (1959). Based on an evolutionary perspective on cities, this theory claims that neighbourhood change is characterised 'by an inevitable trend towards decline' (Metzger, 2000:7). Although criticized on the racial aspects associated with decline, and the lack of attention for the adaptive capacity of local communities (Metzger, 2000), this theory still provides a starting point to understand cycles of urban change, be it mostly ex-post. The theory assumes 5 successive stages, starting with planning and design, followed by phases of development, management and maintenance (exploitation), and finally a phase of decline and demolition leading to a phase of transformation or urban revitalisation<sup>6</sup>. In reality, these urban life cycles more often occur simultaneously or bypass one or two development cycles. Some neighbourhoods are susceptible for decline and have undergone multiple phases of decay and phases of planned renewal, or spontaneous regeneration. Other neighbourhoods show a remarkable vitality over the years and remained stable. In Europe, van den Berg et al. (1982) were one of the first to set out the elements of a theory on urban development and change. Based on statistical analysis of urban development in European countries they found evidence for a cyclical pattern of change of metropolitan areas, in which phases of urbanization and de-urbanization alternates in frequencies of 100- 150 years. These long-term changes provide an explanation for the process of deterioration of city centers that took place in many European cities during the post-war suburbanization period, and it explains the current focus on inner-city renewal and transformation of the existing city. Predicting the course of cities or neighbourhood's change remains, however, difficult and the verification of these theories of urban change lies mostly in ex-post analysis.

More importantly, it is more beneficial to focus on short-cyclical windows of opportunity, for example provided by processes of planned maintenance and refurbishment. Planned maintenance is defined as any work necessary to maintain, extend or improve the performance and services of existing infrastructure and buildings (Wood, 2009). This definition excludes daily and routine cleaning and small-scale repairs but includes all works that are needed to keep streets, public spaces and buildings up-to-date and functioning according to certain predefined functional requirements. This is also called refurbishment. Refurbishment is 'to give [a building, street, or park] a refit or facelift to enhance its appearance and functions (Douglas, 2006: 2)'. In the context of buildings, public realm or infrastructures it primarily involves 'extensive maintenance and repairs as well as improvements to bring it up to a modern standard (Douglas, 2006:2)'. Although refurbishment can be superficial and mainly aiming at aesthetic improvements, it may also comprise major structural

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Note that these stages of urban change ties in nicely with the Panarchy concept of resilience (Gunderson & Holling, 2002) that describes a four-phased adaptive cycle of exploitation, conservation, release and reorganization.

alteration (Douglas, 2006). Nonetheless, large-scale improvement or alteration of a building or urban structure is usually referred to as renewal. Although the definitions of planned maintenance, refurbishment and renewal are somewhat ambiguous and show overlap, it is more important to assess the temporal cycle of change, the willingness of stakeholders to invest, and the likeliness of change.

### Life cycles

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The challenge, however, is how to make a reliable estimation of the return periods of maintenance, urban refurbishment and renewal. Urban assets, such as streets and parks, and buildings have different lifespans. Usually, a distinction is made between maintenance cycles, a functional life and a technical life. The functional (or service, or economical) life is the expected period of time to which a building or infrastructure is able to deliver a certain function or use, or is beneficial to the owner (Douglas, 2006). The functional life can be different than the technical life, which is the period of time a building or asset is physically able to function. For example, residential buildings have a relative long technical life cycle with fewer major changes over their functional lifespan compared to non-residential buildings, such as hospitals or offices that show much shorter cycles (Douglas, 2006). A widely used method to estimate the functional life of assets is by determining the *depreciation rate* that approximates how the price of the asset declines over time in the absence of inflation (BEA, 2003). This method, however, ignores the fact that even within the functional life of an asset major alteration may be needed to bring it up to meet changing requirements. **Table 7.1** shows the functional and technical life of infrastructure and buildings.

	FUNCTIONAL LIFE	TECHNICAL LIFE
<b>Neighbourhood life cycles</b>		
Area transformation	Not relevant	100- 150
Urban Renewal	Not relevant	50 - 100
<b>Infrastructure</b>		
Refurbishment cycles of public space/streets	20-30 (****) 45 (*)	30-40 100+ (**)
Highway and streets	40 -60 (*)	50 - 100
Sewer system	30-50 (***)	30 - 100 (**)
Quays and walls	30-50 (***)	50 - 200 (**)
Dikes and dams	20-45 (* and ****)	
Light and power		
<b>Buildings</b>		
Interior and equipment	11-14 (* and ***)	10-30
Planned maintenance	15(****)-25 (*)	10-20
Renovation and alterations	25(****)-40 (*)	30-50
Residential buildings (1-4 units)	80 (*)	100 (****)
Residential buildings (>4 units)	65 (*)	100 (****)
Non-residential buildings	30-40 (*)	20 - 60 (** and ****)

TABLE 7.1 Overview of average life cycles of neighbourhood and functional and technical lifespan of infrastructure and buildings. Be aware that the life span and cycles of planned maintenance strongly varies depending on type and age of buildings and urban assets. Based on: \*BEA, 2003, \*\*Hallegatte, 2009, \*\*\*Douglas, 2006, \*\*\*\*Statline/CBS, 2014

## Readiness for change: investment horizons

Another important aspect of urban dynamics is the *holding period* of the asset, which refers to the average period a building or asset is owned or held by an investor. The holding period can be different than the functional or technical life of the structure. For example, a residential building has an average technical life of more than 100 years, and will undergo several cycles of planned maintenance, additions and alterations during its life to accommodate new uses or to meet changing demands. The holding period is usually much shorter than the functional or technical lifespan and is a decisive factor that influences the readiness of owners to invest in long-term sustainability. For example, homeowners are inclined to invest in flood proofing their property if the benefits outweigh the costs within a timeframe that equals the maintenance cycles of a building (10-20 year cycles) or the expected period of time before moving to another property (holding period). The average length of homeownership in the Netherlands is in average 12-13 years but varies considerable depending on age, and shows an upward trend caused by the weak real estate market (CBS/PBL, 2013). In New York City the turnover rate of owner occupied buildings is comparable to the Dutch numbers, although the turnover rates of rental units is much higher. Based on 2014 census data, more than 50 % of the home owning householders moved into their unit during the last 15 years (U.S. Census Bureau, 2014 New York City Housing and Vacancy Survey). This means that it is not likely that homeowners will invest in large-scale adaptations

that require a long return on investment, unless the investment is offset by a short-term advantage, such as enlarging the useable space of a building. Consequently, a change of ownership creates an important opportunity for change and adaptation, but may also lockout other, potentially more beneficial adaptation options, for example, to create a district-wide solution.

### Likelihood of change

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Finally, it is useful to distinguish between levels of certainty and likelihood of urban change. Known or highly likely investments are based on planned infrastructure maintenance cycles, planned housing replacement or regeneration cycles. Likely but highly uncertain dynamics result from strategic decisions that not yet have been made but are likely to happen. For example, a private investor may decide on selling its assets on the private market, or to renovate its building stock to rent it out for a couple of decades. Both decisions would introduce different stakeholders and create other intervention options, which would affect the timing and nature of adaptation considerably. Finally, it is important to identify not-so-likely and highly uncertain changes based on longer-term ambitions, agendas and wishes of the key stakeholders. For example, a municipality may 'wish' to change a combined sewer system into a separate system, but lacks the means and political will to realize this transition.

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## § 7.3 Cases Feijenoord and Red Hook

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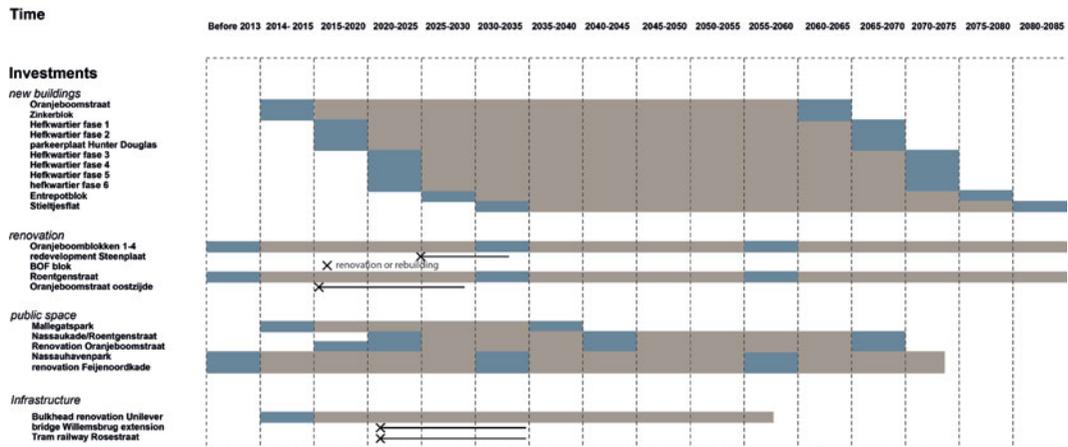
### § 7.3.1 Research approach

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In order to test the proposed method as introduced earlier in this chapter, the urban dynamics and changes, and urban mechanisms that steer urban change of two flood-prone waterfront areas in Rotterdam (Feijenoord) and New York (Red Hook) were assessed. To find potential adaptation options and intervention points, all planned public and private investment projects and expected long-term changes were identified. These changes were assessed on temporal cycle, the readiness among stakeholders to invest and likelihood of change. The analysis was based upon data provided by municipal agencies and information derived from interviews with municipal officials, key stakeholders in local development and community representatives in both cases. In the Rotterdam case, data on planned housing projects

was obtained by selecting projects from a municipal database that contained all real estate developments. This dataset, however, only registered new construction projects that are granted a building permit or to be realised within a time frame of 5 - 15 years. Renovation projects, long-term projects or not-yet defined projects were not included in the data set. To bridge this gap, semi-structured interviews were conducted with representatives of the district authority, city officials and key stakeholders in the area, such as the public housing association, or local community representatives. Data on planning of infrastructure projects and public assets, such as planned renovation of quay constructions and redesign of green areas in Rotterdam, was collected during a workshop with officials of the department of public works.

In New York City, data on planned real estate development is not centrally recorded and not available at district level. Based on literature research, reports of the NYU Furman centre and data provided by city authorities, the average rate of rebuilding and renovation of buildings and infrastructure could be estimated. These lifecycles were used to estimate future investments and calculate the time-scales of adaptation. As a timeframe for adaptation the year 2050 was taken. Interviews with key stakeholders provided information on uncertainties, strategic decisions and potential interrelationships between these investments. The results were mapped and recorded in a diagram as shown in **Fig. 7.3** and a topographical map (**Fig. 7.4**) to identify intervention points both in time and space.



**FIGURE 7.3** Overview of the expected year of realization of planned public and private investments in the Feijenoord area (in blue) and estimation of the functional life, based on general lifespan of buildings, infrastructure and streets (in grey). The black lines indicate an expected investment decisions, of which the outcome is still uncertain, for example to renovate or rebuild public housing buildings.

### § 7.3.2 Situation Feijenoord and Noordereiland

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Feijenoord is a local basin with a relatively high flood probability. More than 90 % of the housing stock in the area comprises social housing. The area also hosts several companies, including a factory of Unilever and an aluminium foundry. The area is struggling with several interacting problems. The overall condition of the social housing stock is in a poor shape. A large part of the buildings consist of poorly renovated nineteenth-century apartment blocks and apartment blocks that have been developed during a previous phase of urban renewal in the late eighties. The low-costs social housing stock no longer meets current housing standards and needs complete renovation. Also, the area lacks public facilities and the quality of public space is poor. As a result, the area is populated by a low-income immigrant community and has one of the highest unemployment rates of Rotterdam. Despite the severe socio-economic problems, the position of de Kop van Feijenoord as a waterfront location close to the city centre and neighbouring the prestigious high-rise district of de Kop van Zuid makes the area highly attractive for redevelopment. In 2012 a new master plan (Rotterdam, 2012) was developed to attract investors. This master plan includes a redevelopment of brownfield areas and a large-scale transformation of the existing social housing stock. A new tramline and a bridge are planned to improve the accessibility of the area. Additionally, it is expected that a large amount of the existing social housing building stock will be renovated or redeveloped in the near future. However, due to the economic crisis and changes in national housing legislation restricting the high-risk commercial urban development projects of social housing corporations, many of the planned developments are currently on hold or being reconsidered.

### § 7.3.3 Opportunities for change: identifying adaptation intervention options

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Previous chapters (5 and 6) have shown that the current flood risk strategy (elevating plots and infrastructure) is not effective. Two alternative strategies to reduce flood risk in the area are assessed. The first strategy is based on keeping water out of the area by gradually raising the low-lying quay shorelines to flood design level, including sea level rise. Because a great deal of the quays and bulkheads already is elevated during previous urban renewal phases, preventing floodwater to enter the area can relatively easily be achieved by raising some of the quays and by constructing small flood walls. A second strategy is to improve the flood resilience of the urban area. This can be achieved by a combination of flood proofing new buildings and retrofit flood resilience into existing buildings, wet-proof utilities and infrastructures. Because of the considerable flood depths and duration of the flood, dry-proofing existing buildings is, however not feasible, incorporating dry proofing in the architecture of new buildings

is considered a viable option. Retrofitting wet-flood proofing to existing buildings is physically possible, but because wet-flood proofing requires substantial structural modifications it is assumed that only in case of new constructions or large-scale renovation projects wet-flood proofing is a low-cost and effective option.

## Urban dynamics

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### Urban redevelopment opportunity for flood proofed buildings

The area has a significant amount of vacant land owned by private developers that recently has been rezoned to allow residential uses. Despite the slowing down of redevelopment of vacant land due to the financial crisis and weak real estate market, it is still very likely that these developments will take place in the short and mid-term. These developments offer opportunities to elevate the plot or creating flood-proof buildings. The inventory also revealed that many public investment decisions, such as renovation of the sewer system or redesign of the public realm and infrastructure, are tightly coupled with real estate development projects. However, despite the weak real estate market it is likely that these plots will be developed in the mid-term, creating a predictable adaptation intervention point. It is expected that almost 842 new building units will be added to the existing building stock (Pohl et al., 2014), particularly along the waterfront, which will double the amount of units in the flood plain.

### Retrofitting flood resilience into social housing redevelopment schemes

As a result of more stringent national regulations, investments in social housing have generally decreased. Despite the poor state of the social housing stock in the flood prone area, it is expected that only a small portion of the housing stock will be sold or rebuild on the short term. The majority of the buildings will be rented out as social housing for at least the next 20 years and undergo basic maintenance. However, a promising transition is the potential privatization of the social housing stock, which would create a window to agree upon investments to enhance resilience. Following the general trend in Rotterdam, it is expected that the share of social housing on the long term slowly decreases, particularly in the more centrally located, more attractive neighbourhoods (Rotterdam, 2015). Social housing units being sold on the domestic market, or to private investors within a sale and leaseback construction would create an opportunity to invest in property level adaptation, as turning social housing apartment to private homes requires large-scale improvement and renovation. Although this transition is particularly promising the social housing corporation has not yet decided on their long-term strategic portfolio management, making it a highly speculative intervention point.

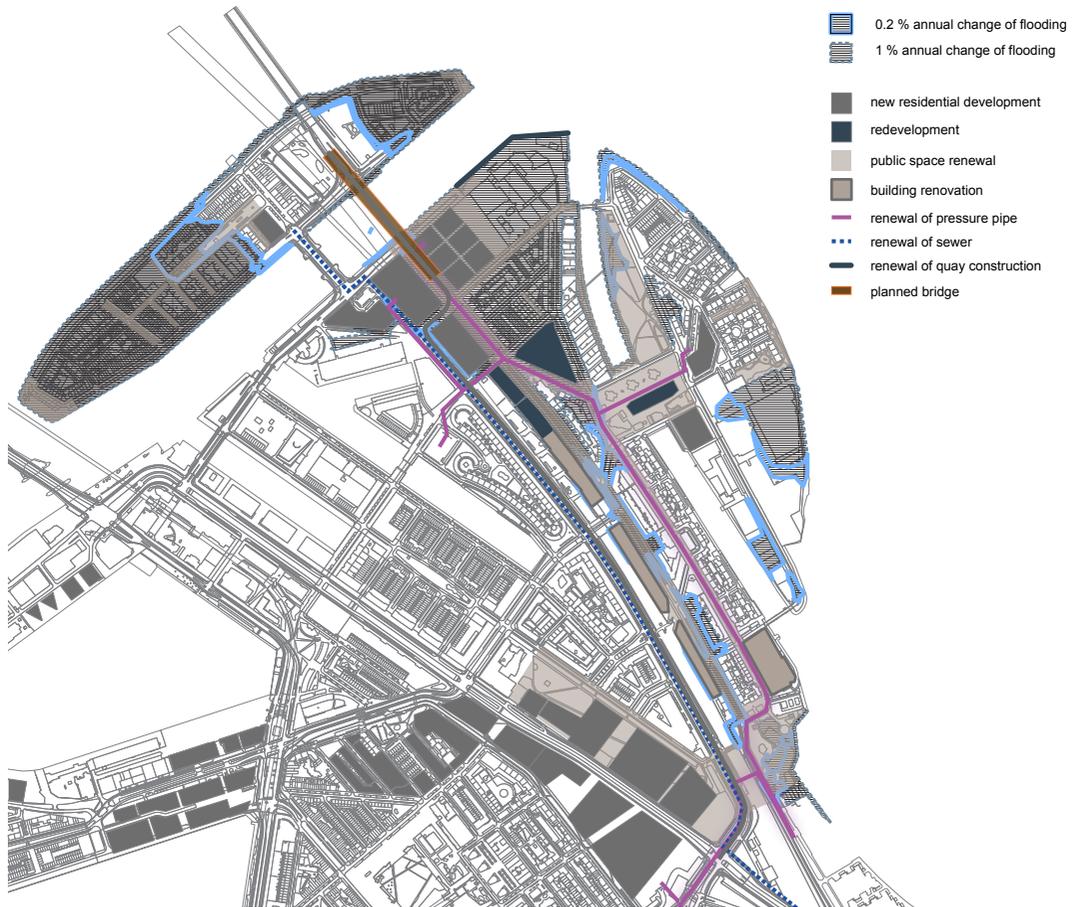
### Urban management

Finally, it is expected that the city will invest in the public realm and infrastructure as part of a long-term regeneration programme and will invest in planned maintenance of the sewer and heating system. Based on the information from city officials it proved that improvements of the urban infrastructure and networks provide only little opportunities for adaptation. For example, improvement works on the Combined Power and Heating infrastructure network and sewer system is mostly based on a replacement of existing infrastructure and is executed independently from other investment. An interesting opportunity to be considered, however, could be the renovation of bulkheads. Many of the bulkheads are in poor conditions and large investments in new quay constructions are foreseen in the next 15 years. Renewal of the bulkheads offers significant opportunities to elevate the waterfront or to create a floodwall at relative low costs. One of the long-term ambitions of the city is to reduce the amount of storm water that is drained to the sewage treatment plant. This requires disconnecting the storm water system from the combined sewer system and to create a local storm water drainage system that retains storm water as long as possible in the area and drains to the river. This transition offers opportunities for adapting the sewer for high water conditions. However, this long-term ambition has not yet been incorporated into the cities investment budget and planning, and remains uncertain.

#### § 7.3.4 From intervention options to opportunities: improving or changing rules

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All strategies provide opportunities to couple with urban development and public investments. **Fig. 7.4** presents a map of all identified public and private investments in real estate development, infrastructure and planned maintenance projects of public assets and infrastructure. The inventory of timing of investments and life cycles (**Fig. 7.3**) clearly shows that the development of new buildings and infrastructure and large-scale renovation projects offer a one-off opportunity to adapt, whereas the shorter redevelopment cycles of public realm and infrastructure offer multiple adaptation intervention opportunities in time. The Noordereiland is less dynamic in terms of public investments but may profit from incremental changes and a gradually privatization of public housing over time. Both areas may also benefit from planned replacement and renovation of historical bulkheads and quays.



**FIGURE 7.4** Overview of all identified public and private investments in real estate development, infrastructure and planned maintenance projects of public assets and infrastructure.

The Noordereiland case shows that, based on average rebuilding and renovation numbers, a renovation based property level adaptation strategy (wet-proofing and dry-proofing) results in a reduction of vulnerable buildings of almost 30% of the total building stock in 2050. Although, this number is expected to increase considering a privatization of social housing, building-level adaptation is not effective because the speed of adaptation is offset by the speed of climate change and sea level rise, particularly at an extreme sea level rise scenario. Buildings that have no elevated ground floor will face future flood levels that surpass the maximum level of dry proofing, making it necessary to change strategies to wet proofing on the long term. To capitalize on building renovation it will be necessary to develop direct incentives for stakeholders to invest in building level adaptation. One of the instruments available is to put a price on adaptation by introducing (compulsory) flood insurance. Flood insurance, however, is still not available in the Netherlands and there are no signs

that a market will develop soon. In addition, flood insurance may potentially cover disaster losses, it is not expected that insurance companies proactively stimulate or fund physical adaptation measures (Bouwer & Aerts, 2006). Also, it is not expected that site-specific building regulations will be integrated in the buildings codes given the tendency to reduce regulations. In other words, a building level adaptation strategy as proposed for the Noordereiland, needs structural improvements of the rules to make the policy more effective, but is no sustainable way to go under more extreme conditions.

### New arrangements to unlock investments

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The Feijenoord area may profit from large-scale redevelopment projects along the waterfront to create a district-wide protection. However, creating a publicly funded floodwall is not compatible with national regulations and requires a fundamental rearranging of responsibilities between the city, water board and local stakeholders. To gain access to funding for management and legal protection in local land use planning, a formal recognition as primary (or secondary) flood defense is needed. One of the major challenges of getting this status is that the legal position of the area would change from unembanked (flood plain) to protected area. This would not only require a national ministerial decision but also the establishment of a formal safety level by the regional authorities, and, finally, the flood wall would need to meet the minimum requirements set out by the water board. Additionally, a legal position as protected area would also lead to an increase in waterboard tax, for which the support of the local community is essential.

Additionally, it requires new financial arrangements to capture potential values and redistribute costs and benefits fairly among the stakeholders (van Buuren et al., 2014). Several potential arrangements were analysed and discussed with stakeholders, of which an area fund or long-term area contract to pool resources and redistribute costs and benefits among stakeholders seemed to be the most appropriate (van Buuren et al., 2014). During a couple of workshops that were organised as part of the Stadslab Initiative<sup>7</sup> with the social housing corporation, urban planners and city representatives these concepts were translated into the concept of a *package deal* aiming to channel the value created by increased flood protection to support local community development. Within this agreement, all stakeholders who benefit from increased flood protection funded by public authorities (e.g. city and water board) are committed to invest equally to the value of benefits accruing from increased flood protection into socio-economic development. This allows for a more flexible and yet comprehensive

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<http://stadmakerscongres.nl>

approach, in which all stakeholders act within their modus operandi, while the local community benefits.

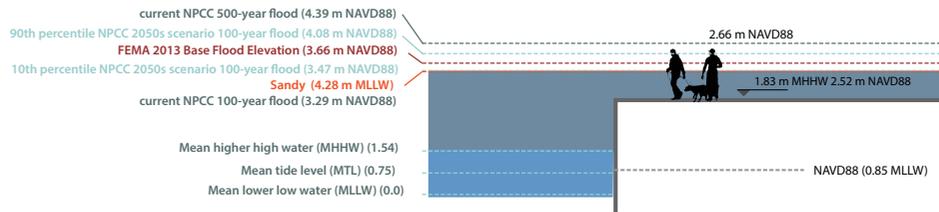
### § 7.3.5 New York- Red Hook

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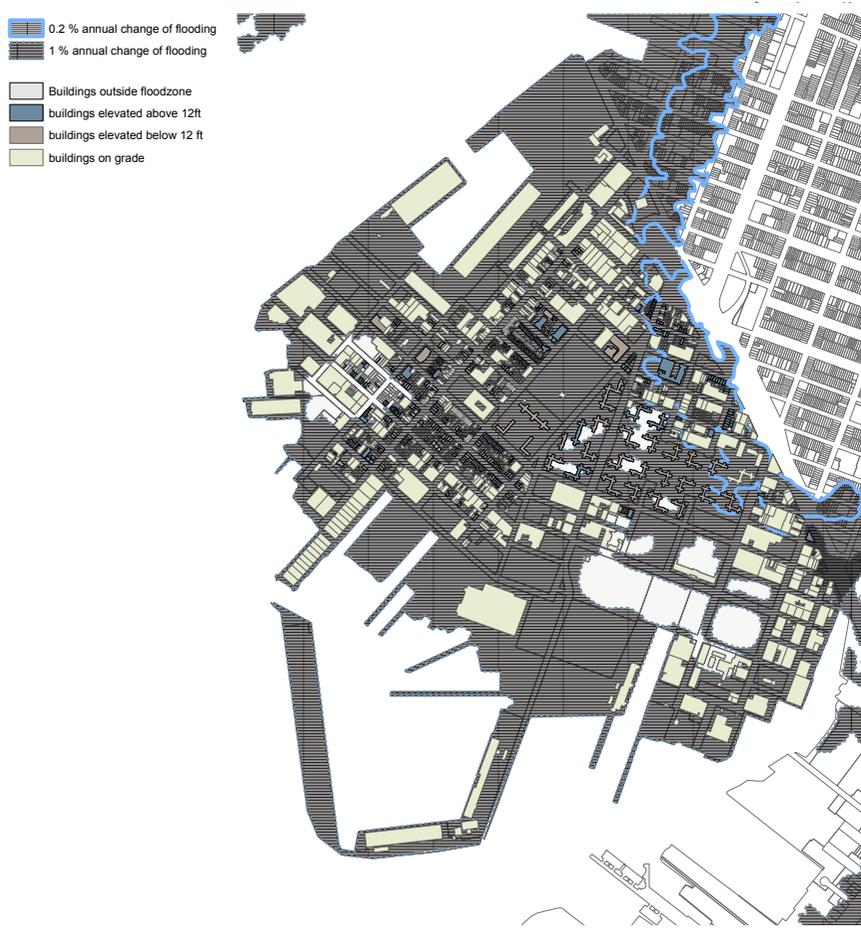
#### Situation

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Red Hook is a rapidly changing Brooklyn waterfront neighbourhood and home to approximately 12.400 people (NYRCRP 2014). As many New York City waterfront areas (see for example: Steinberg, 2014), Red Hook was once a marshy wetland with some natural elevations that were reclaimed and filled to enable industry and business activities (NYCDCP, 2014b) Still, the area has one of the few left working waterfront zones in New York and host significant amounts of industrial, manufacturing and commercial buildings. Given its peninsula-shaped position and the boundaries of the entrance of the Brooklyn-Battery tunnel and the Gowanus expressway, Red Hook is bounded by strong physical barriers and poorly connected to other areas of Brooklyn. The majority of the property in the area is privately owned. However, a significant amount of lots is city-owned or publicly owned by federal or state authorities, particularly along the waterfront area (NYCDCP, 2014b). The area is home to one of the largest social housing projects, the Red Hook Houses. There is a significant number of vacant sites that remained undeveloped due in part of environmental contamination (NYCDCP, 2014b) but potentially also because of speculation on future rezoning. During super storm Sandy, Red Hook suffered flooding from a storm surge coming directly off the Upper Bay and Buttermilk Channel and from surge water that was pushed into the Gowanus Creek (NYC, 2013a). The storm surge flooded almost the entire area reaching to inundation levels up to 1.85 - 3 m and causing inundations of basements and ground floors. Flooding of the sewer system led to sewer backing up in homes and businesses, resulting in local sanitation and environmental problems. The flooding led to long-lasting outages of power and block heating and in some cases running water, leaving many houses uninhabitable for many weeks and even months (NYC, 2013a, NYRCRP, 2014). It is expected that the flood risks will increase in the future due to climate change. The recently updated flood maps showing the 100-year flood plain released in June 2013 by the Federal Emergency Management Authority (FEMA) show significant changes of urban areas that might suffer flooding (NYC, 2013). Also sea level rise predictions show a significant increase in sea level rise ranging between 4 to 11 inches (0,10 m to 0,28 m) in 2020 and 11 to 31 inches (0.10 to 0.79 m) in 2050 (NPCC, 2013). Additionally to coastal flooding, the area also suffers from pluvial flooding caused by poor drainage and sewer backup problems (NYRCRP, 2014).



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**FIGURE 7.5** Picture 1: water levels at the Red Hook waterfront at the current 10-year flood level and projected flood levels at the 10-percentile and 90-percentile NPCC 2050 scenario. The dotted red line indicates the maximum level reached during hurricane Sandy. Picture 2: 100 year (1%) and 500 year (0,2%) flood zones in Red Hook and estimated ground floor levels of buildings.

## Identify adaptation options

### Building-level resilience

Elevating buildings to above the flood level is physically only feasible for typical low-rise urban typologies such as detached wood-framed structures (NYCDCP, 2014a). Elevating attached or semi-detached masonry building in densely conditions is challenging because of structural integrity implications, limited on-site construction space and the need of collaboration with several neighbouring property-owners (NYC, 2013). An alternative option is to wet-flood proof the building to reduce damages. Typical Brooklyn multi-family brick stone buildings use a cellar to locate the mechanical and electrical equipment (Findlan et al., 2014). In general the cellar is located below a semi-below grade basement unit that is rented out as a small garden apartment (Fig. 7.6). Following the FEMA based NYC guidelines (NYCDCP, 2014b) wet flood proofing requires filling of all below grade spaces and relocating the critical equipment to above to BFE, which typically means to a new mechanical room above the basement. This will require extensive modifications to reinforce the building structure and a considerable loss of useable space (NYCDCP, 2014b), which, especially in small 2- 4 family apartment buildings is probably not a feasible option as many of the home-owners rely on the rental income to offset mortgage costs (Stein & Nagy, 2014). However, building owners may invest in flood damage reduction through flood proofing mechanical and electrical equipment, although it will only lead to an insignificant flood premium reduction. Finally, dry-flood proofing the basement and cellar by sealing off all openings is an option. However, under current Federal legislation, dry-flood proofing of residential premises in the 100-year flood plain is not allowed and will not result in reducing flood insurance premiums (Findlan et al., 2014). In addition, Building resilience should be accompanied with investments in critical systems resilience, such as electrical utilities, sewer and communication systems to avoid a long-lasting recovery and rebuilding process after a flood.

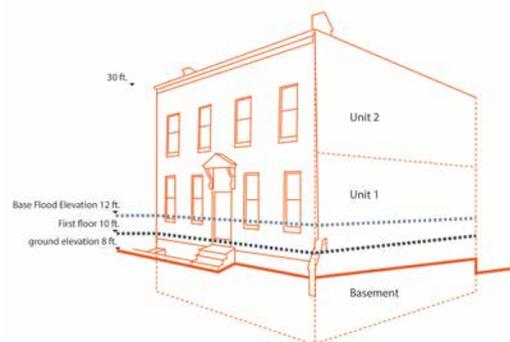
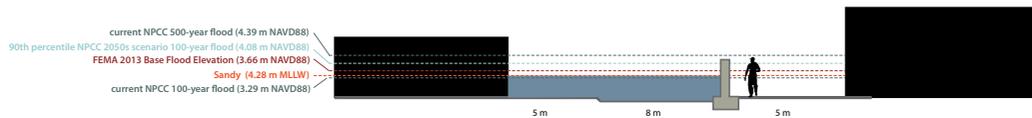


FIGURE 7.6 Typical Red Hook building with semi below grade basement and ground floor apartment located below the Base Flood Elevation (BFE). Photo: Google StreetView.

### Integrated flood protection system

The proposed strategy for Red Hook as mentioned in the report of the NYC Special Initiative for Rebuilding and Resilience (SIRR) aimed to prevent the area from flooding and improve the resiliency of buildings, infrastructures and vital functions in the area. One of the selected citywide solutions mentioned in the SIRR report (NYC, 2013a) is to 'install an integrated flood protection system in Red Hook and harden or modify shoreline parks to protect adjacent communities' (NYC, 2013:254). The proposed integrated flood protection system is a combination of demountable floodwalls that consist of panelised structures that are put in places during a storm or flood and fixed structures, integrated in the design of sidewalks and streets.

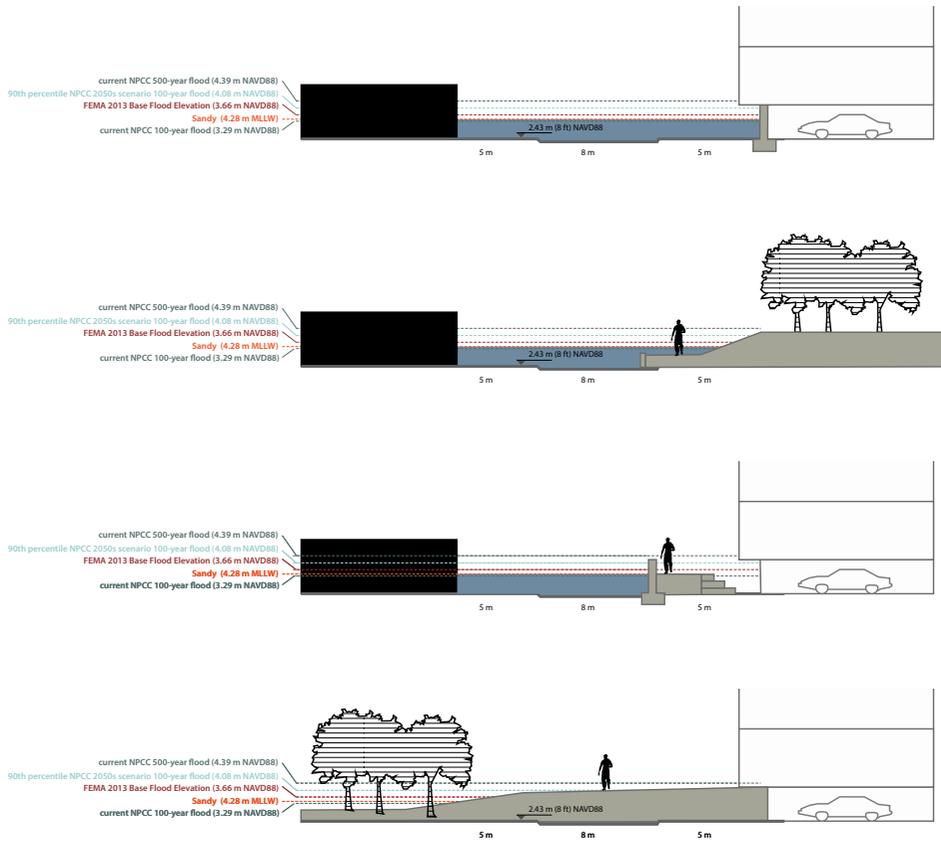
There are two major concerns regarding this option. Firstly, an integrated flood protection system requires many small adjustments of streets, sidewalks and private property and entryways (see **Fig. 7.7**), which make the development a contested and expensive process. Secondly, a floodwall consisting of demountable elements is not compliant with NFIP regulations unless the floodwall is permanent and accredited by FEMA (FEMA, 2014b). This means that a flood protection system will not necessarily result in a full insurance premium reduction (Findlan et al, 2014).



**FIGURE 7.7** Analysis of spatial impact of a permanent or deployable floodwall designed to protect the area from a 100-year flooding, including a safety margin for expected sea level rise in 2050 (90th percentile 2050 NPCC scenario). The black boxes are existing buildings.

### Multipurpose flood protection system

Another option identified, is to develop a permanent flood protection system consisting of elevated waterfront plots, hardened shorelines and floodgates at the Gowanus channel. A permanent flood protection system is highly effective in reducing flood risk and could result in a full reduction of flood insurance premium once accredited by FEMA. Moreover, it offers opportunities for multipurpose uses and co-benefits, such as improved accessibility of the waterfront. It requires, however, large investments and considerable space.



**FIGURE 7.8** Multipurpose flood protection options. (a) Integration of flood protection in new buildings, (b) elevated public space, and (c) partly elevation of street, combined with a bike path, (d) elevation of complete waterfront zone.

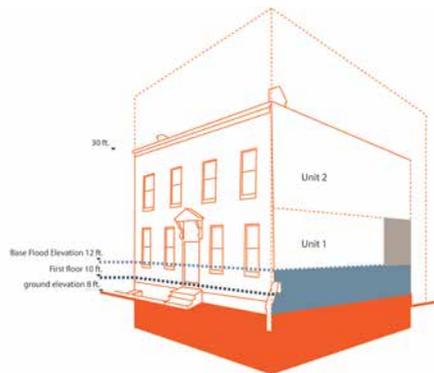
### Storm surge barriers

Finally, an alternative option is to install a series of permanent dams or moveable gates to close off the bay and rivers. Although, hazard reduction is no longer regarded as a short-term adaptation option, it is potentially a long-term adaptation option that is highly effective to reduce flooding of a large part of the urbanized waterfront areas. Bowman et al. (2005) calculated that the rise in water level due to inflow of fresh water discharge from the rivers and storm water runoff during a 20 to 40 hour closing of the barriers is not reaching more than 8 to 16 inches (0.2 – 0.4 m) above mean sea level. The study concluded that the probability of a flooding in the metropolitan region due to freshwater runoff behind closed storm surge barriers is very small. A barriers strategy, however, still requires ‘an elevation of the low lying areas in Brooklyn, Jersey and Manhattan with an additional 1 to 3 ft to accommodate for rising water levels caused by a Hudson river peak discharge during storm surges’ (Aerts et al, 2013:13)

### Gentrification – building improvements and renovations

After many years of degradation, Red Hook is on the rise again and benefits from the strong uplift of real estate value in New York and Brooklyn. Although the area's low-rise building typology is attractive, the area is not well connected to the subway network, which is one of the reasons why the area is not gentrifying in the way other better served parts of Brooklyn are experiencing (NYRCRP, 2014). A second reason is that the areas most attractive assets along the waterfront are largely zoned for industrial, manufacturing and commercial uses (NYRCRP, 2014). Despite this, buildings in the area are renovated and some of the former warehouses have recently been redeveloped into high-end condominiums and shops. Additionally, there are plans for transforming parts of the industrial waterfront areas into residential and mixed used, high-end waterfront development.

The gentrification process offers opportunities for building level adaptation but will only partly reduce the flood risk. New constructions or buildings that are substantially improved are required to comply with the flood resistant building codes of the NYC Building Code. All other building may voluntarily retrofit adaptation measures. The majority of the residential building stock consists of attached or semi-detached masonry constructions on a basement that is not suited for structural elevation, as required by FEMA regulations. However, buildings that have a ground floor above the BFE will physically be able to bring the building up to the full FEMA standards to relatively low costs.



**FIGURE 7.9** To comply with FEMA regulations below grade spaces need to be filled (red) or wet-proofed (blue). Recently updated regulations allow property-owners to compensate for the loss of residential use of basement and cellar by adding an equivalent of space within the building envelope (dashed line).

The amount of buildings that retrofits voluntarily depends on the speed of the gentrification process. A report on the state of the New York housing and neighbourhoods (NYU Furman Center, 2014) show a 5-year average of 0.35 % new units added to the current building stock for Brooklyn and less than a 0,2 % units added to the total housing stock for Community District 6, which includes Red Hook. Based on data on issued Certificates of Occupancy, which serves as indicator for both new constructions and significant rehabilitated units (NYU Furman Center, 2014, Keenan & Chakrabarti, 2013) it may be conclude that the annual newly build and renovation rate is almost 2% of the total building stock of District 6, which is much more than the Brooklyn average (0,4%). Assuming an annual 2% renovation or rebuilding rate, it will take almost 50 years to retrofit the building stock of Red Hook. Considering the relative large increase in flood levels due to sea level rise, it is expected that climate change surpasses the speed of adaptation.

### Improve rules

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Property owners of existing buildings are encouraged to adapt their buildings to comply with the new flood resistant building standards to lower their flood insurance premiums, but the NYC Department of City Planning (2013c) acknowledges that ‘in many instances, zoning regulations or conflicts between Building Code requirements would make it difficult, or in some cases impossible, for owners to build or retrofit to these standards<sup>8</sup>. To stimulate homeowners to invest in flood resilience, the New York City Department of City Planning has recently updated the zoning ordinance and the City’s building codes (NYC DCP, 2013b). One of the adjustments made is an extension of the opportunities to recapture lost floor space due to wet-flood proofing actions, by adding an equivalent amount of floor area to the building as long it fits within the existing building envelope (**Fig. 7.9**). This adjustment allows property-owners to compensate for the loss of residential use of basement and cellar. To assess the effectiveness of this policy adjustment for the implementation of building level adaptation an analysis of building typology, first floor levels and potential for compensation was executed. Based on this assessment it was estimated that almost 30% of all residential buildings in the 100-year flood plain have their first floor elevated above the BFE and it is assumed that these buildings physically can be adapted to comply with NFIP/FEMA requirements. More than 70 % of all residential buildings in the flood plain have a first floor located below the BFE, which means that they are physically unable to comply with the FEMA requirements. However, it is often optional to wet-proof the below BFE floor area. Following the updated city’s Building Codes, wet proofing leads to a substantial loss of space. The majority of these buildings (57%) have not yet reached the maximum allowable FAR and may compensate the loss of all

below BFE uses by adding an extra floor or build out in the garden. However, to bring these buildings up to full compliance with FEMA's requirements requires a substantial investment. It is not likely to happen when buildings are completely renovated.

BUILDING TYPOLOGY	COMPENSATION POSSIBLE	ADAPTATION OPTIONS	NFIP PREMIUM REDUCED?	PERCENTAGE OF BUILDING STOCK
Wood frame detached	-	Elevate	Full reduction	1%
Brick stone and first floor above BFE	Overbuilt or no room in building envelope	Wet proof all below BFE mechanical equipment	Partial reduction	18%
	Room available in FAR and building envelope	Fill all below grade spaces and wet proof all below BFE uses	Full reduction	11%
Brick stone and First floor below BFE	Overbuilt or no room in building envelope	Wet proof all below BFE mechanical equipment	Partial reduction	30%
	Room available in FAR and building envelope	Fill all below grade spaces and wet proof all below BFE uses	Full reduction	40%)

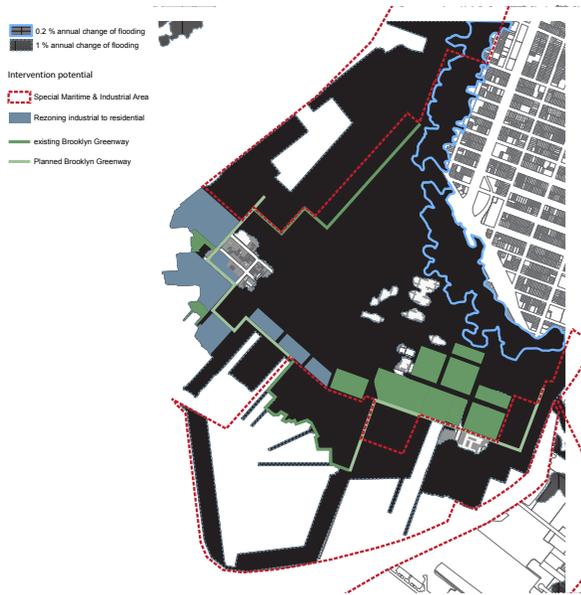
**TABLE 7.2** Percentage of buildings that is able to adapt to the full FEMA requirements and NYC Building Codes or other adaptation options.

As summarized in **Table 7.2**, it may be concluded that of all residential buildings in Red Hook only 11 % of the building stock can be brought up to full compliance relatively inexpensive. The majority of buildings (70 %) have their first floor located below the BFE and may adapt by wet proofing the below BFE spaces. However, 48% of the Red Hook residential building stock is built to the maximum allowable floor area or reached the limits of the building envelope. It is expected that retrofitting these buildings will be physically and financially infeasible.

Despite earlier policy improvements, it is expected that the current policy is not effective to increase the resilience of the Red Hook community. A major step towards improving the cost-effectiveness of retrofitting buildings is to incorporate wider portfolio of adaptation options into the current FEMA requirements that better fits to the structural and spatial characteristics of high-density urban areas (NYCDCP, 2013c). For example, dry proofing residential buildings is, under the current legislation not allowed, although, particularly for high density urban typologies and the relatively shallow flood conditions of most waterfront areas in New York, it is one of the most effective and beneficial adaptation options. Widening the portfolio of flood proofing alternatives, however, requires a Federal-level reform. The impact that these reforms may have on the willingness of stakeholders to invest in flood resilience is, however, unclear. Additionally, in some cases a rezoning is required to enlarge the building envelopes to allow for the construction of habitual spaces to compensate for the loss of space due to wet proofing. This rezoning is, although a time-consuming process, probably one of the most effective policy interventions that increase opportunities to adapt.

### Rezoning Red Hook's waterfront

A large part of Red Hook waterfront is still zoned for manufacturing or industrial uses, which acts as a buffer between the industrial waterfront and the residential zoned areas. Rezoning this area to allow residential or mixed residential uses opens up opportunities to negotiate local amenities, such as affordable housing or public space in exchange for a higher density development (NYU Furman Center, 2014). Rezoning to higher density uses unlocks significant value that could be captured to finance a district-wide flood protection. Additionally, rezoning may increase densities or height limits that triggers the redevelopment of resilient buildings or replacement of non-resilient buildings (NYCDPC, 2013). While rezoning has been successful in transforming large parts of the Brooklyn waterfront to improve public access and create a continuous bike and pathway, until now, district-wide flood protection infrastructure as a trade-off of a rezoning process is not common (interview NYC Department of Urban Planning). Another major concern is that the Red Hook waterfront is granted special protection and is designated as one of six Significant Maritime and Industrial Area (SMIA) by the City of New York to protect and encourage concentrated working waterfront uses (NYCDPC, 2011). This special indication means that the sites are protected to rezoning that would allow residential development (NYCDPC, 2011). In addition, regarding potential conflicting interest of the local community, such as loss of affordable housing and local jobs, rezoning Red Hook will probably be a contested and long-lasting process. However, a combination of linking some existing elevated parks, rezoning of industrial sites to residential, and a bike path serving as flood protection could provide integrated flood protection for the area.



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**FIGURE 7.10** Left: overview of intervention opportunities. A large part of the Red Hook waterfront is protected for rezoning by an indication designated as one of six Significant Maritime and Industrial Area. However a chain of elevated parks (green), potential residential sites (blue) and a bike path (green line) could provide opportunities for creating an integrated flood protection for the area. Right picture: artist impression of redevelopment of the Red Hook waterfront. Source: <http://ny.curbed.com/neighborhood/1324/red-hook>.

Developing a flood preventive system up to the current FEMA 100 year flood level would still require additional measures to cover the residual risks of the failure of critical systems and vital infrastructure. In addition, it requires to be accredited by FEMA to result in a full insurance premium reduction (Findlan et al, 2014).

## § 7.4 Conclusions and discussion

### § 7.4.1 Cases

One of the key finding is that there is little potential to build resilience from household redevelopment or renovation within an acceptable timeframe even when new complementary policies and regulative instruments that support building-level resilience would be developed. Because the speed of retrofitting adaptation depends

on the speed of regular renovation and rebuilding rates, in both cases it was found that retrofitting would require at least a period of 30-50 year, which would hardly surpass the expected increase in future flood risks. The case of Red Hook has shown that retrofitting resilience of existing buildings is challenging from a technical and economical point of view and will require a considerable period of time. Additionally, these policies do not necessarily result in infrastructure vulnerability reduction (sewer and electrical systems outages). It is necessary to develop complementary policies and regulative instruments that support easy-to-implement or low-impact building-level resilience. In the Netherlands, developing a flood insurance policy that covers the costs of building flooding could cover the losses of low frequency flooding, although it is not an effective incentive to homeowners to invest in building level protection. In the US, widening the portfolio of building level adaptation that allows for a full insurance premium would increase the willingness among stakeholders to invest in building level adaptation and increases opportunities to harvest on incremental urban change.

A district-wide protection is effective in terms of flood reduction but requires large-scale transformations of the waterfront zone to seize opportunities for developing integrated protection at low costs. The Feijenoord case shows that the planned new developments and renovation projects of the bulkhead, new waterfront development and public realm offer an unique one-off opportunity to realize a district-wide embankment scheme at low costs, while keeping options open to adapt in the future. Both cases show that the development of a floodwall / multipurpose embankment offers new opportunities for creating a greener and accessible waterfront, which affects housing prices and unleash new urban potentialities. This collective strategy, however, needs new financial arrangements to capture potential values and redistribute costs and benefits fairly among the stakeholders. Additionally, it requires large governance reforms, for example a widening of responsibilities of the water board. Also in the case of Red Hook, it was found that a district-wide solution, such as a floodwall or interconnected system of elevated waterfront plots might be effective. However, it not only requires a rezoning, more importantly, it requires a long-term coordinated approach that affects all waterfront development. This would not only require leadership at the local or city level, but also a culture of integral planning and development, which especially in the US context is probably a bridge too far.

## § 7.4.2 Method

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This section has explored to what extent climate adaptation can be incorporated into processes of urban development and change. It was argued that adaptation planning in its current definition mainly focuses on policy development processes at a strategic level and ignores the chaotic, fragmented and uncertain processes of urban development, renewal, management and incremental change. To adequately incorporate adaptation into urban dynamics, transitional actions need to be identified that unleash the potential of adaptation options, creating opportunities for adapting at relatively low costs or that yield additional benefits. Both cases have shown that identifying intervention opportunities, based on an assessment of life cycles and investment projects and potential transitional interventions and “changes of rules” is helpful to assess options to realize adaptation measures at low costs. Moreover, it helps to identify key interventions – spatial, legal or financial arrangements – that are needed to unlock the potential of adaptation options. However, probably the true value of the proposed method is that it has proved to be effective to understand the complex relations between potential physical adaptation options, urban dynamics and intervention transitions. Thus, the method bridges a gap between flood risk management, urban development and governance and it can be applied to assess long-term transitions that affect urban development.

Several remaining issues are identified. First, one of the challenges when working with the method is that it proved to be very complex to identify project-level adaptation points beyond a time frame of 5-10 years, with any objective certainty. This can be explained by a lack of strategic asset management, but also because decision-making processes of urban development and renewal are by nature fragmented and uncertain. Data on the average rate of rebuilding and renovation of buildings and infrastructure provided a basis for assessing the long-term viability of the retrofitting process, but it still remained speculative. However, it may be interesting to use scenario-based analyses (see section 3.2.2) to understand the variety of future developments and opportunities for integrating adaptation and to assess the robustness of investments based on an assessment of the sensitivity towards future trends.

Stakeholder engagement is crucial to understand the needs and agendas and to identify mechanisms of change that lead to adaptation opportunities. This is particularly true for adaptation planning for the mid- and long term, because this requires to understand long-term ambitions, rather than to focus on project-based adaptation planning. Finally, it is arguable that both the urgency to adapt to increasing and more extreme flood events *and* the urban potentialities of waterfront development are a powerful combination to create added value. In a way, this is the case in Feijenoord and Red Hook where the development of a floodwall not only offers new opportunities for creating a greener and accessible waterfront, but also depends on a rezoning that affects housing prices and unlocks new urban potentialities.



*Belmar Boulevard, Belmar, Jersey, USA*



*Elisabeth river waterside, Norfolk, Virginia, USA*



*Sai Gon river, Ho Chi Minh City, Vietnam*

## PART 3 Conclusions & recommendations





# 8 Conclusions and recommendations

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## § 8.1 Introduction

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This thesis started with the observation that the increasing vulnerability of urbanised deltas and coastal cities to flood risk is largely caused by processes of urbanisation, socio-economic change and human-induced stresses to the natural system. As a consequence, in response to climate change it is likely to be most effective to increase the overall resilience of coastal cities to deal with more extreme conditions in the future. This approach is known as the resilience approach and can be recognised in many policy development and long term climate adaptation projects in deltas worldwide. Resilience, however, is criticised as being backward looking and reactive, in the sense that it focuses on restoring the pre-existing situation including its systemic errors and structural vulnerabilities, and that it is not aimed at adapting to slow environmental change. However, urban environments are and can be further adapted by using moments of change in urban development and management as windows of opportunity for low-cost adaptation. A basic assumption underlying this thesis is that the system-based approach to flood risk reduction is more effective in reducing risk compared to prevention based approaches, particularly in the context of uncertain climate change. Additionally, this research assumes that the integration of increased flood risk adaptation responses into urban planning and design is a more flexible, (cost) effective and value-adding approach to enhancing the resilience of urban waterfronts as compared to prevention-based approaches.

When adapting urban environments, three challenges are identified. First of all, to effectively integrate resilience in urban development and planning it is necessary to understand when in time, or under what conditions, urban systems become less resilient or, otherwise stated, when adaptation is needed, and what (combinations) of measures are the most effective to improve resilience. Secondly, a major challenge in adapting existing urban environments to the effects of climate change is that it requires anticipating long-term trends and changes that easily exceed periods of 50 to 100 years. This brings large uncertainties into the design and planning process. When facing deep uncertainty, it is necessary to improve adaptability. Improved adaptability can be both tactical-operational (designed) and strategic (planned). Designed adaptability is based on design concepts such as enlarging adjustability, built-in expandability and convertibility. On a strategic level adaptability can be achieved by developing sequences of adaptation options that keep options open in

anticipation of future conditions. Sequences of adaptation options (pathways) that are reversible and offer multiple options for adaption should be favoured over irreversible and non-flexible paths. Finally, key to the successful adaptation of urban environments is to effectively use moments of change in urban development and management as windows of opportunity for low-cost adaptation, and to yield additional benefits. This requires a better understanding of the opportunities to spatially and in a timely manner synchronise adaptation measures with spatial development, urban management and infrastructure maintenance projects.

**So, the main question of this thesis is: “how can we adapt existing coastal urban waterfront areas to changing climatic circumstances and how can we take this adaptation process as an opportunity for creating added value?”**

To answer the main research question, this main question is broken down into four sub-questions:

- What adaptive measures and design principles are effective when improving the flood resilience of existing urban waterfront areas?
- What pathways to resilience are most effective, provide flexibility and deliver added value in the long run?
- How can we use urban change and development as opportunities to enhance resilience?
- Is the Adaptation Pathway Method (APM) an effective method to develop adaptation strategies at the tactical-operational level of urban development and management? The scope of the research was limited to existing urban waterfront areas in deltas, estuaries and along coasts that suffer from coastal and fluvial flooding and are at risk from climate change, particularly sea level rise and increasing river run-off. Secondly, the focus of this research was limited to existing urban coastal waterfront areas as these environments are generally the most vulnerable. Finally, the main focus of this research is on building physical resilience, not social resilience. However, as explained in more detail in the theoretical chapters, both physical and social resilience in urban areas are closely linked and strongly related to cultural, institutional, financial and organisational aspects. Acknowledging this, the more social aspects of resilience are assessed and evaluated as long as they pose constraints or opportunities for the successful implementation of physical resilience.

In the next section, the sub questions are answered. Section 8.3 discusses the meaning of these conclusions for the Dutch and US water management approach and research methods, and discusses the role of Research by Design methods in crafting and selecting adaptive pathways and evaluating adaptation measures. To conclude, recommendations for further research are provided.

## § 8.2 Answering the research questions

### § 8.2.1 What adaptive measures and design principles are effective when improving the flood resilience of existing urban waterfront areas?

#### Critical infrastructure vulnerability contributes significantly to risk of flooding

There is a wide range of adaptation actions available ranging from small-scale building-to-building adaptation to large-scale and long-term flood protection offering many opportunities for a complete redesign and rethinking of the position of the urban waterfront. The case studies show that the specific geographical, hydraulic (e.g. storm surges or small inundations) and social and spatial conditions strongly determine the urban vulnerability, and hence the effectiveness of specific measures when improving flood resilience.

To reflect on the effectiveness of these actions it is necessary to elaborate on the relative vulnerability of coastal waterfront areas. Using the Adaptation Tipping Point method a detailed analysis of the flood risk of the thresholds (potential flood entry points) of buildings and urban assets was performed. By combining potential flood levels with cross-sections of typical building blocks and local electricity distribution stations, predictions could be made for at which flood levels water may possibly enter the building or cause power outages. A detailed flood risk assessment of 9 residential waterfront buildings in Rotterdam and Dordrecht showed that the nineteenth-century building stock generally has a higher level of flood resiliency, because the doorstep level is usually raised up to 50 cm above street level. The direct costs of damages to the interior and constructions of residential buildings are relatively low compared to the costs of adaptation measures, although the damages may vary considerably depending on building typology and use. In general, it may be concluded that the position of critical building systems, such as for heating and power, largely determines household flood damages and recovery time. In addition, flood damages for companies and shops are expected to be considerably higher, particularly when the indirect costs, such as loss of working hours, are considered.

However, the vulnerability assessment also revealed that the vulnerability of urban systems to relatively shallow, low-energy flooding is mainly determined by the failure of critical assets, such as the sewer system, power and main infrastructure such as tunnels and subways. This conclusion was confirmed by the assessment of flood damages in the Red Hook case. In both cases local power distribution stations appeared to be extremely vulnerable to flooding. Even a 30 cm inundation can already cause power outages that last a considerable period of time and, because of expected

cascading effects, affect a much larger area. Thus, increasing the resilience of urban waterfront areas should cover both building level adaptation as well as adapting critical infrastructure. The evaluation of flood risk policy in both cases studies however, showed that both local and national policies largely ignore the infrastructure vulnerabilities and lacked legal instruments to enforce the adaptation of critical infrastructure and assets.

### Building level adaptation is effective under moderate flood conditions

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This research started with the hypothesis that incorporating flood resilience into the design of buildings or retrofitting flood resilience to existing buildings is an effective approach to reduce the vulnerability to flooding in existing waterfront areas. However, this research concluded that retrofitting resilience into existing buildings is only effective and economically beneficial for high frequency and low depth, low energy flood conditions. Dry-proofing (making a building watertight) is generally less expensive and more beneficial compared to wet-proofing (making a building water resistant) but is limited to shallow flood levels of not more than 0.60 m. Wet-proofing is more expensive and less cost-effective but can be applied to more extreme flood conditions.

An additional benefit of dry-proofing is that it can be implemented relatively quickly, independent of other investments. Wet-proofing generally requires large-scale refurbishments and renovations to be cost-effective, which makes the implementation of these measures rather slow. An important consideration is that property level protection does not offer the same level of protection compared to a district-wide flood defence infrastructure. However, it is an effective method to manage the consequences of flooding when a district wide flood defence would be infeasible. Additionally, property level adaptation combines with measures that reduce flood depths such as storm surge barriers, breakwaters or land elevations.

Because the speed of retrofitting adaptation depends on the speed of regular renovation and rebuilding rates, in both cases it was found that retrofitting flood resilience would require at least a period of 20-50 years, which would hardly surpass the expected increase in future flood risks. Additionally, due to policy regulations and financial restraints it is expected that only a small portion of the building stock will adapt incrementally. Consequently, one of the key findings of the case study research is that in high density urban conditions there is limited potential to build resilience from household redevelopment or renovation in the long run even when new complementary policies and regulative instruments that support building-level resilience would be developed.

## Integrated or multipurpose flood protection is highly effective, flexible and adds local quality

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This rather narrow range of flood conditions in which building level adaptation is effective and beneficial makes a transfer to a district-wide protection option attractive, both from an economic and a spatial perspective. District level protection measures, such as floodwalls, elevated shorelines, or temporary flood protection are effective under a wider range of flood levels and probabilities. Based on a cost-benefit assessment of the Feijenoord case it appeared that an integrated flood protection system (e.g. an elevated shoreline or flood wall) is more beneficial compared to building level adaptation and, more importantly, proved to offer many opportunities for improving the accessibility and urban design of the waterfront area. However, to ensure an integrated design, district-wide protection requires considerable implementation time and long-term comprehensive planning. District-wide protection is effective in terms of flood reduction but requires large-scale transformations of the waterfront zone to seize opportunities for developing integrated protection at low cost. Additionally, both cases showed that developing an integrated, or multipurpose flood protection requires large governance reforms, for example a widening of responsibilities of the regional Water Board, and financial arrangements to capture potential value and redistribute costs and benefits fairly among the stakeholders. This makes realisation of an integrated or multipurpose flood protection system a time-consuming adaptation action. Another major concern is that district-wide protection negatively affects the risk awareness and reduces flood sensitive behaviour among stakeholders, which may further increase consequences of a flood.

An effective way to increase the adaptability of multipurpose or integrated flood protection is to incorporate provisions into the design to allow for a future extension, adjustment or change of use. Over-sizing is a commonly applied design strategy in the design of large infrastructure systems or structures that come with large life cycles or that cannot easily be modified. However, it requires higher up-front investments, which is relatively expensive and may become redundant when change is not evolving as predicted. Designing for flexibility means minimising interdependencies or providing measures that allow for an improvement or change with minimal negative effects to other components. A loosely coupled design, consisting of structurally independent but spatially integrated flood protection measures and multipurpose uses should be favoured over completely integrated designs, to avoid a loss of flexibility. Design strategies that increase flexibility are based on improving adjustability, convertibility and expandability.

## § 8.2.2 What pathways to resilience provide flexibility and deliver added value?

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### A multi-layered approach based on district flood protection and building level protection is not complementary

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To develop adaptive pathways, it is necessary to select effective sequences of adaptation measures. To do so, it is important to know what combinations of options that reduce hazard, exposure or vulnerability are complementary and most effective at reducing the risks of coastal flooding. This research shows that most adaptation actions are path dependent and lock out alternative strategies. Only a few combinations of adaptive measures are complementary and provide options for sequenced strategies. The Feijenoord case shows that a district-wide flood protection strategy provides the most beneficial solution and opens up opportunities for low cost adaptation by capitalising on investments in the urban realm and improvements of the waterfront. It is however, a one-off solution that locks out alternative adaptation measures, such as building level adaptation. The Noordereiland shows a more diverse portfolio of adaptation responses, although there are only a few combinations of adaptation responses that are complementary to deal with change in the long run. A potential adaptation strategy for the Noordereiland is based on sequencing property level protection (wet-proofing and dry-proofing adaptation measures), followed later by the development of a permanent or temporary floodwall. An alternative pathway is composed of building-level protection and continuing this 'living with water' approach, giving up the residential use of ground floor spaces as water levels increase. Both cases illustrate that adaptation planning requires a tailor-made approach, based on a careful assessment of local flood conditions, building typology and urban dynamics.

### A change of adaptation pathway comes with high transaction costs

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A change of strategy, both in scale of intervention (e.g. from property-level to a district-wide solution) as well as in type of strategy (accommodate to protection), is usually accompanied with high 'transaction costs' and is path dependent. For example, retrofitting property-level protection runs a risk of economic lock-in. Every single investment in building level resilience reduces the overall flood risk and hence the benefits accruing to a district-wide protection option. This makes a 'transfer' to a higher-level solution less feasible from an economic point of view. In addition, the potential loss of investments of individual homeowners attributable to a change of strategy could lead to societal and political resistance to change. This effect increases when a change of strategy is implemented later on in the process. Also a district-wide flood protection scheme negatively influences the cost-benefit ratio and effectiveness of both property level protection and regional interventions. The residual risk due

to a risk of overtopping or a failure of the flood protection system comes with low probabilities but produces relatively high flood levels, making dry-proofing ineffective and wet-proofing less cost-beneficial. At the same time, the reduced flood risk reduces the financial incentives to invest in a regional storm surge protection system. Co-benefits and added value arising from increased flood protection can have a positive effect on reducing the transfer costs between strategies, although the efficiency strongly depends on site conditions. For example, building level adaptation (wet- or dry-proofing) can also be effective to deal with increasing pluvial flood risk, which is, particularly in tropical cities, a major source of flood risk.

### Changing strategy requires large-scale governance interventions

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In addition, changing a pathway requires transitional interventions in the legal, financial and organisational structure to improve the adaptation outcome. Sometimes whole system changes are required to open up new pathways to a more resilient future. These transformative interventions are, however, difficult and need large-scale regime changes that are sometimes only triggered by powerful external forces or extreme events, such as a disaster or political change. Transformative adaptation requires a high degree of political engagement and leadership and strong civil society, which is not always the case. The New York case showed that a change of strategy in favour of a district-wide integrated flood protection solution, although clearly more sustainable in the long run, is difficult to reach. Also the Dutch cases showed that a transition towards district-wide flood protection calls for a widening of responsibilities of the regional Water Board, which requires a national level governance reform. Similarly, supporting building level resilience at the Noordereiland would require a governance reform in which a water board tax cut is passed onto homeowners who invest in flood protection. Overcoming the 'transition costs' and governance barriers of moving between adaptation measures at multiple levels of intervention is a major challenge for implementing multi-layered adaptation strategies. This problem of cross-scale interactions in adaptation planning is an area that requires further research (Zevenbergen et al., 2008a).

### Short cycle adaptations "to buy time" for an integrated solution

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A more effective approach is to select a combination of adaptation measures, both on the regional, district and local scale that create the best conditions for adaptation at each scale of interventions. Economic lock-in can be avoided by combining low-cost building level adaptation measures that reduce the consequences of a flood in the short term (such as an early warning system and low-cost dry-proofing measures) to "buy time" and increase opportunities for coupling district wide flood protection in the long term with investments in the urban realm, or renovation of the bulkheads.

This, however, requires careful long-term planning and strong stakeholder support. An alternative – and probably more promising – combination of measures is provided by a “fine tuning” of the flood probabilities in the short and midterm by lowering the closing threshold of the Maeslant barrier. This intervention attenuates the effect of long-term sea level rise on the lower and mid probability flood levels. This creates a larger period of relative stability in terms of flood probabilities and, more importantly, it extends the time frame in which property level protection is effective and beneficial.

In view of the above, adaptation planning should support a layered strategy in which each intervention on every scale creates the conditions for adaptation interventions at a lower scale. Secondly, it seems to be necessary to decide early in the process on the long-term preferred solution and to support this strategy with short-cycle, low cost incremental adaptations aiming to buy time and increase the opportunities for an integrated and multipurpose design that offers new opportunities for urban development.

### § 8.2.3 How can we use moments of urban change and development as opportunities for enhancing resilience?

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This thesis has shown that the added value created by coupling adaptation actions with other spatial investments potentially offsets investment costs. In particular, the costs of district-wide flood risk protection are significantly lowered when integrated into an overall redesign of the waterfront area. However, this research also showed that retrofitting flood risk resilience adaptation measures, particularly at the building level, offer no added value or co-benefits, and may have adverse effects on the architecture or the streetscape’s vitality. In addition, the Noordereiland case shows that the relatively high costs attributable to the construction of the flood retaining components of a multifunctional flood defence, also means that options to reduce investment costs by coupling investments with a redevelopment of public space are limited. After all, the bulk of the costs are caused by the investment in flood protection itself. In this case, the urgency to adapt to increasing and more extreme flood events will arguably become a key driver for urban change and development.

The Feijenoord case shows that the planned new development and renovation of bulkheads, new waterfront developments and investments in the public realm offer a unique one-off opportunity to realise a district-wide embankment scheme at low cost, while keeping options open to adapt in the future. In this case the development of a district-wide floodwall also offered new opportunities for creating a greener and more accessible waterfront and for attracting public and private investment to the area. The Red Hook and Feijenoord case shows that both the urgency to adapt to increasing and more extreme flood events *and* the desire to unlock the urban potential of waterfront development form a powerful combination to create more resilient urban

waterfronts. In particular, the Red Hook case showed that the development of an elevated waterfront provides the most effective flood risk reduction and unlocks new urban potentialities.

In general, enlarging the diversity of project-level based adaptation options increases the opportunities for incorporating adaptation into urban development processes. However, it proved to be very complex to identify project-level adaptation opportunities beyond a time frame of 5-10 years, with any objective certainty. This is due to a lack of strategic asset management but also because decision-making processes in urban development and renewal are by nature fragmented and uncertain. To adequately incorporate adaptation into urban dynamics, transitional actions need to be identified that unleash the potential of adaptation options, creating opportunities for adaptation at relatively low costs or to seize additional benefits. The Feijenoord and Red Hook cases show that identifying intervention opportunities, based on an assessment of life cycles and investment projects and potential transitional interventions ("changes of rules"), is helpful to assess options to realise adaptation measures at low costs. Moreover, it helps to identify key interventions – spatial, legal or financial arrangements – that are needed to unlock the potential of adaptation options. It is also necessary to *create* new opportunities that unleash the potential of adaptation options or that create additional benefits.

#### § 8.2.4 **Is the Adaptation Pathway method an effective method to develop adaptation strategies at the tactical-operational level of urban development and management?**

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##### **The ATP method is effective to evaluate resilience**

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Assessing the flood risk of the flood prone areas of Rotterdam using Adaptation Tipping Points (ATPs) appeared to be an effective method to systematically analyse and compare the flood risk of several flood prone areas. This assessment not only provided new insights into 'ranking' flood prone areas according to their relative vulnerability, it also revealed that vulnerability to coastal flooding is highly attributable to the micro-morphology and building typology. The main added value is that the method contributed to a better understanding of the vulnerabilities of the built environment and delivered information on the applicability of adaptation measures. For example, contrary to initial expectations, Feijenoord appeared to be more vulnerable to flooding than the Noordereiland, although the Noordereiland experienced floods more regularly. Developing a local flood risk adaptation strategy should therefore be based on a careful assessment of general flood characteristics, local morphology, building typology and critical infrastructure.

Defining the position of the ATPs proved to be challenging, particularly because public policy objectives and standards were weakly defined. In this context, the ATP is useful in well-governed systems in which some sort of agreement on standards and targets has been achieved, which is the case in the Dutch flood protection system. When there is no agreement on policy objectives – as is the case in the unembanked areas, it is necessary to explore the ATP in close collaboration with experts and local stakeholders. The buffer, recovery, adaptation and transformation tipping point framework as introduced in section 3.3.1 provides a basis for further development. In addition, as seen in the earlier chapters, the resilience of social-ecological systems is determined by the complex interaction of physical, social and ecological subsystems that each have their own ATP or sometimes come with multiple tipping points. If multiple parameters define an ATP it is necessary to first find the dominant causal relationships between subsystems and cross-scale interaction between tipping points, before higher level ATPs can be found (Kwadijk et al, 2010, Jeuken & te Linde, 2011). For example, the dominant tipping point for adapting the closing threshold of the Maeslant flood barrier is defined by the cost benefit assessment of increasing costs of dike improvement and port logistics, not so much by the increasing costs of flood damages in the unembanked areas. Understanding the cross-scale interaction between sub systems' tipping points is important to define the feasibility of cross-scale pathways.

### The Adaptive Pathway Method is helpful in evaluating and selecting adaptation measures

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Developing resilience and adaptation strategies for existing flood-prone urban areas demands an interface that bridges the gap between flood risk assessment, defining performance criteria and goals, and urban design. The Feijenoord and Noordereiland case show that developing adaptive pathways using the Adaptive Pathway Method (APM) is an effective tool in evaluating and selecting adaptation measures. The method is especially useful in identifying lock-ins and path dependencies of strategies in response to slow long-term change, thus providing essential information for strategic decision-makers in the short term. Additionally, the method helps to better grasp the timing of adaptation, which increases opportunities to couple adaptation with other planned investments, or to anticipate easier adaptation in the future.

### Towards an urban dynamics based adaptation planning

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A general criticism that is often made is that the adaptation pathway concept remains rather conceptual and is difficult to operationalise in the complex reality of adaptation planning. A key assumption underlying the Adaptive Pathway approach is that building a strategy based on the sequencing of adaptation options increases the ability to adapt to future conditions and thus adds to strategic flexibility. A key presumption

is that moving between alternative interventions (and thus developing alternative pathways) is straightforward. However, a fundamental shortcoming of the adaptive pathway method is that in reality there is no 'free choice' between alternatives (Wise et al., 2014). As already concluded in the above sections, breaking through path dependencies arising from vested interests, governance barriers, financial lock-ins, or incremental behaviour remains a major obstacle to moving systems towards more sustainable, more beneficial paths.

In addition to this, there is also a second, more fundamental shortcoming of the method. It ignores the dynamic and interacting aspect of urban development and change and new opportunities for adaptation that might arise, which are not yet identified, or positively assessed. A more effective approach is to focus on interventions and changes in the economic and institutional processes of urban development that create new opportunities for adaptation. This research has introduced an urban dynamics based method that focuses on identifying the following: adaptation intervention *points*, which are defined as the actual moments of change that potentially may be used for adaptation; adaptation *transitions* that are defined as changes in legal, institutional and financial structures that improve or unlock the full potential of adaptation intervention points; and, finally, adaptation *transformations* that are fundamental changes in urban form, policies, institutional arrangements and norms that could create new adaptation *opportunities*. For example, retrofitting wet-proofing measures to buildings is less expensive when it is part of a large-scale renovation. However, as learned from the Red Hook case, legislation that enables homeowners to compensate for the loss of habitable space can have a positive impact on the willingness among stakeholders to invest. Identifying these transitional interventions in the governance structure helps to identify effective governance interventions. Applying this approach to two case study locations in Rotterdam and New York proved that identifying intervention opportunities, based on an assessment of life cycles, investment projects, potential transitional interventions and "changes of rules" is helpful to assess options to realise adaptation measures at low costs. Moreover, it helps to identify key interventions (e.g. spatial, legal or financial arrangements) that are needed to unlock the potential of adaptation options. Thus, the added value of the urban dynamics based method is that it adds to the explorative nature of the APM, and helps to identify interventions in the 'socio-technical regime' (Geels, 2004) that can unlock pathways towards a more sustainable future.

## § 8.3 Reflection and recommendations

### § 8.3.1 Is coastal resilience a useful concept?

This thesis started with the assumption that the concept of resilience as a system-based perspective on urban flood risk management is probably more effective to analyse the root causes of increasing risk and hence, to identify the intervention options that mitigate those risks most effectively, or that yield additional benefits. While answering the question of whether the resilience perspective is indeed more successful than a traditional approach goes beyond the purpose of this research, it is an interesting question to reflect upon. The empirical section of this research showed that an important value of the resilience concept is that it helps to understand the direct and indirect causes of risks and to unravel some of the complex interactions between household vulnerability, flood risk regulations, and governance structures, and thus to identify the most effective intervention strategies. For example, the Noordereiland case showed that low flood risk awareness among homeowners triggers flood insensitive behaviour, leading to increasing flood risk damage costs. In addition, both cases showed that there is a much larger portfolio of adaptation measures available that reduces local exposure and vulnerability to increasing flood risk and that offers opportunities for resilient-inclusive urban development and change. A general principle of more resilient systems (see section 2.2.5) is that the higher the diversity in overlapping or complementary functions, or the more the variety of responses that are available in reaction to a disturbance or slow environmental change, the less likely it is that a system becomes unstable. In this sense, understanding the mechanisms leading to reduced resilience and widening the opportunities of a larger group of stakeholders to address risk, in itself can be understood as a strategy for increased flood resilience. Finally, resilience is often framed as a metaphor for the ability of communities to self-organise and recover after disturbance, in this sense opposing the engineered and prevention-based intervention strategy. This research shows that system-resilience must be understood as the whole capacity of the socio-technical system to deal with changing and more extreme conditions in the future. The challenge is not so much in selecting one of these presumed opposing strategies for flood risk management but in selecting the most beneficial interventions, depending on a careful assessment of the root causes of risk in coastal urban environments, beneficial or adverse effects of interventions, and an assessment of the 'governance landscape' to design pathways towards a more resilient future. This holistic approach requires a new perspective on design principles that is no longer based on economic optimisation of subsystems, but in which the overall resilience and adaptability of the whole system is considered.

### § 8.3.2 What lessons can be drawn for adaptation policy planning in Rotterdam, the Rhine Estuary region and New York City?

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If system-resilience is an effective perspective to guide urban waterfront areas towards a less risky future, what implications does the resilience perspective have for urban policy, or more precisely: what lessons can be drawn for improving adaptation planning in Rotterdam and New York?

#### Towards resilient communities

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The empirical research of this thesis showed that continuing the prevailing strategy, both in New York City and in Rotterdam leads to an expensive and ineffective approach that adversely affects the streetscape and architecture of residential areas. An important consideration is that both flood risk policies are norm-based and prescriptive, in the sense that both policies define highly prescriptive risk mitigating measures (e.g. wet-proofing or elevating buildings in New York City and elevation of building lots in Rotterdam) leaving no room for alternative measures. In contrast, the cases in Rotterdam and New York showed that a ‘tailor made’ adaptation approach based on a careful assessment of flood characteristics and specific local vulnerability of the built environment delivers a more effective approach to flood risk, while opening up opportunities for creating added value. This resilience perspective on flood risk requires a change of focus from rules, norms and prescribing detailed measures to a focus on managing the predefined level of resilience that is to be achieved. In other words, a resilience based flood risk adaptation strategy is performance based. This shift from a norm-based and prescriptive policy to a more performance based flood risk strategy addressing specific local needs, calls for a community based approach in which flood resilience (as a “service level”) is based on a careful risk assessment and coupled with the agendas and needs of a local community<sup>9</sup>.

There are some important changes needed to allow for a community resilience based approach. First of all, it requires standardisation of what is meant by flood risk resilience and the development of instruments to empirically measure and monitor resilience at the level of communities (see also Cutter, et al., 2008). The urban dynamics based APM method as proposed in this thesis, is a helpful method in systematically assessing or ranking communities on flood resilience, particularly when applied in a participatory process with local stakeholders. Secondly, a community

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<sup>9</sup> An interesting approach, in this respect, is the concept of resilient communities that was proposed by HR&A with Cooper, Robertson & Partners, one of the finalists of the Rebuild by Design competition for Red Hook ([www.Rebuildbydesign.org](http://www.Rebuildbydesign.org))

based approach requires a relocation of authority and funding to the local community to help them invest in the elements that increase resilience the most effectively, or that yield most benefits. This requires the preparation of a community level resilience plan in which the long-term strategy (path) towards a more flood resilient future is outlined, and incremental and transformative intervention opportunities are identified based on an assessment of local agendas, needs and the potential for transformative change. Thirdly, enlarging the diversity of adaptation responses requires removing legal, institutional and financial barriers that obstruct the implementation of local adaptation measures. The Rotterdam case for example, showed that the lack of formal responsibility within the water board for flood risk of the unembanked area constitutes a major obstacle both for financing and managing local resilience planning. Consequently, a nationwide reform allowing the use of water board tax money to invest in community flood risk would speed up the process of resilience investments, such as the development of local flood protection and building level protection measures. Finally, it requires a monitoring system, in which regular and centrally coordinated audits are performed to measure progress and to make adjustments to the plan when necessary. This process of monitoring helps to identify the higher scale ATPs and to identify any changes required for higher-level interventions.

#### Policy implications for New York City

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It is necessary to develop complementary policies and regulative instruments that support easy-to-implement or low-impact building-level resilience. For example, adaptation of flood insurance policies, such as providing a flood premium reduction to stimulate alternative adaptation options would probably increase the willingness amongst homeowners to invest. However, retrofitting buildings is only partly a solution to reduce the vulnerability of coastal waterfront areas, particularly that of high-density urban typologies. An essential part of the flood damages can be traced back to infrastructure vulnerability (sewer and electrical system outages) and requires additional investment to improve resilience during, and ensure fast recovery after, a flood. Improving flood protection using waterfront redevelopment opportunities would create long term resilience to climate change at relatively low (public) costs. Although district-wide protective measures are recognised as the most effective flood risk management strategies for most affected areas, they are not easily achieved, mostly because of financial and governance challenges.

#### Building level adaptation to flood risk (layer 2) in the Dutch context is not effective.

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A key element of the flood risk philosophy introduced by the Dutch Delta Programme is a multi-layered approach based on prevention (Layer 1), adaptation of the built environment and vital infrastructures (layer 2) and recovery and disaster management

(Layer 3). In this approach physical adaptation of urban structures and vital infrastructures is needed to minimise the effects of flooding (PBL, 2014). A central assumption of spatial adaptation is that incorporating climate change adaptation into processes of urban development and management of buildings and the built environment is a (cost) effective approach to minimising the effects of flooding or other climate change related impacts. Although policy aimed at minimising the consequences of flooding still lacks clear goals and concrete targets (PBL, 2014), an essential part of the Delta Programme's policy is to adapt the built environment and prevent an increase in vulnerability caused by urban (re)development, as far as reasonable and practicable (Deltaprogramma Ruimtelijke Adaptatie, 2014).

Based on the findings of the empirical section of this research, building level adaptation of existing buildings is only (cost) effective under moderate flood conditions (0.1 – 1 m flood levels) with relatively high probability (up to 1/50 – 1/100 per year), such as that caused by pluvial and fluvial flooding, but rarely by coastal flooding. This conclusion supports an earlier observation by Asselman & Slager (2013) who concluded that from an economic perspective, property level protection is only effective in areas where flood probabilities are greater than 1/250 a year. Due to its low-lying conditions and highly developed flood protection system, flooding in the greater part of the Netherlands is characterised by relatively high depths and extremely low probability events, ranging from 1/1,250 to 1/10,000 a year (Asselman & Slager, 2013). For these areas the level of investment in property protection is disproportionate to the benefits of reduced annual average coastal flood damages. However, this research shows that the cost effectiveness of property level protection is only effective for flood conditions under higher probabilities and that for dense and large urban environments, area-wide protection for coastal flooding is more effective and beneficial. In the western part of the Netherlands there are only a few locations that are characterised by shallow and high probability floods and which might benefit from property level adaptation. However, when flood protection is not available, such as in other delta or coastal cities, such as Ho Chi Minh City, property level adaptation might be the best option.

A second assumption underlying the multi-layer safety approach is that using investments in urban development and management as opportunities for improving adaptation reduces costs and speeds up the process of climate adaptation. The case study research shows that in urban dynamics based adaptation, considerable cost-savings can be realised, particularly when area-wide flood protection is combined with investments in public space and urban development. Options to reduce costs of property level protection adaptation (e.g. dry-proofing, wet-proofing, elevated buildings) are usually more expensive than district-wide flood protection and offer limited opportunities for cost-savings, particularly when it comes to retrofitting adaptation into existing buildings. Also, flood resilient design of new buildings requires a substantial investment that cannot be offset by development costs, although the level of additional investment depends on the architecture and type of adaptation measure.

In addition, retrofitting flood resilience, based on planned maintenance and large-scale renovation cycles, requires a considerable time. On the other hand, district-wide flood protection measures require larger scale actions and investments than property level protection adaptation, making implementation more complex.

This thesis concludes that in the Netherlands, building level adaptation to coastal flood risk (layer 2) is not effective. However, adapting vital infrastructures and assets to improve disaster management and increase options for a fast recovery are probably effective, although empirical evidence could not be provided for this claim. Moreover, the elevated unembanked areas provide the best conditions for evacuation and creating safe shelters during an extreme flood event in which parts of the urbanised low-lying polders of the Netherlands are flooded. Using the unembanked areas as safe havens however, requires a redesign of the vital infrastructures serving these areas to provide basic amenities such as power, sewage and drinking water, functioning separately from the flooded parts of the city.

### § 8.3.3 Reflection on Action Research as research method

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#### Action based research

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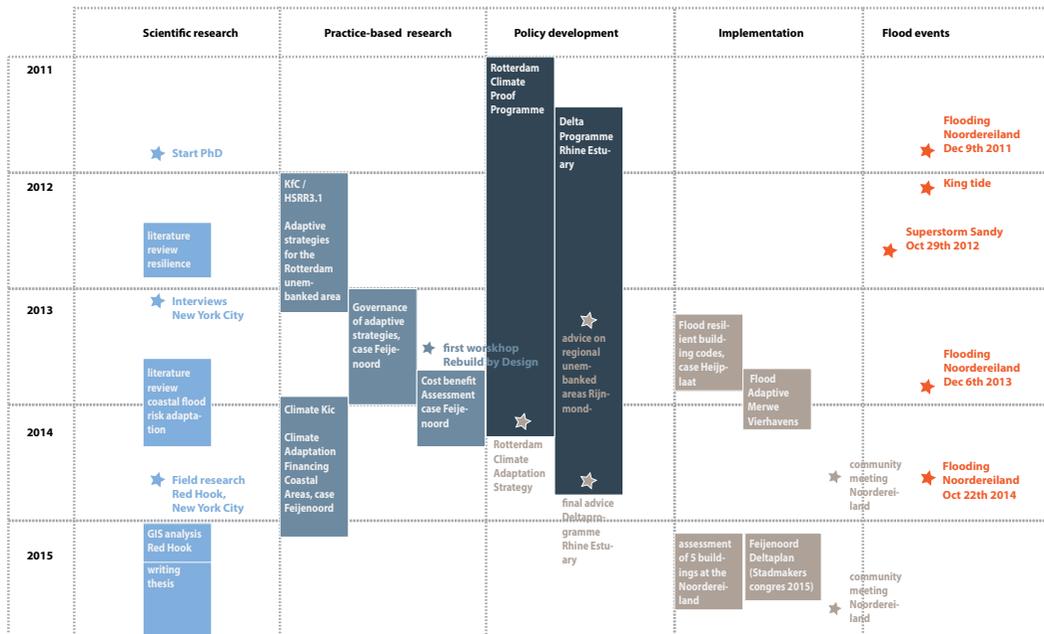
This research is using action based research methods in which knowledge is produced in a collaborative learning process through actively involved stakeholders, participants and communities. This research methodology requires the researcher to constantly change role: from observer, to actively intervening and influencing a process by introducing new knowledge while safeguarding scientific quality. As an action based research method risks biases due to conflicting interests and lack of critical distances, the method requires transparency of, and a continuous reflection on, the research process. This is particularly important as the role of researcher, practitioner, and sometimes stakeholder changed constantly during this research process.

First of all, it is necessary to provide transparency on the relations between the research and policy development, and implementation processes at the city of Rotterdam.

**Table 8.1** provides an overview of the interactions between academic and practice-based research, policy development processes, policy implementation projects and community meetings. This research is partly based on several knowledge development projects funded by the Knowledge for Climate Change Programme that were conducted between 2009 and 2013. These science-practice knowledge projects were used as a scientific basis for the development of the Rotterdam Adaptation Strategy. In addition, this research builds on knowledge generated in two key policy development processes at the Urban Planning Department of the City of Rotterdam, as well as the regional

flood risk management strategy, as part of the National Delta Programme. Both policy development processes provided rich sources of information, particularly on the effects of interventions to other systems within the delta. Finally, working with the local community and stakeholders at the Noordereiland and Feijenoord during several community and stakeholder meetings and workshops provided a unique opportunity to gather insight, information and develop new knowledge on the readiness of residents to invest in building level adaptation. An important part of the information on (cost) effectiveness of adaptation strategies was provided in a joint Knowledge for Climate research project with the Rebel group, technical experts of the city of Rotterdam and private consultancy firms. Finally, this research builds on work of the Climate KIC Flagship project (CAFCA), in which the case of Feijenoord served as a real life example to test some private sector investment propositions for climate change adaptation. This research provided information on financial arrangements and the building blocks on which the urban dynamics-based adaptation planning method is grounded.

Working as both a researcher and urban planner presented both an opportunity and a challenge. This research benefited greatly from the opportunities to develop knowledge within an innovative and award winning policy development process, in one of the frontrunner cities in climate change adaptation. By alternating between the role of researcher and my work as practitioner, I was able to build a rich resource of individual research projects that were necessary as the building blocks for this research. Much of the knowledge presented in this thesis would in fact not have been generated to the level of detail as it is, without the perspective of scientific research and perseverance driven by the need for scientific evidence. The academic research helped to improve definitions (e.g. adaptive buildings) and to eliminate several persistent assumptions underlying the Climate Adaptation Strategy, such as the idea that flood resilient buildings are to be preferred above district level flood protection.



**TABLE 8.1** Overview of academic and practice-based research projects, policy development processes, community meetings and (near) flood events that provided information for this thesis.

However, balancing between practitioner and scientific researcher proved to be challenging, particularly to step back and critically reflect regularly. In this sense, the New York City case proved very helpful in reflecting on the APM and taking a more critical distance from the Rotterdam case. Finally, the challenge of ‘knowledge ownership’ proved to be a recurrent issue. In most of the research projects I acted as project manager or client representing the City of Rotterdam and, in some cases, as one of the participating stakeholders. The co-produced knowledge within these projects was in some cases published in technical or scientific reports or policy briefs. To clearly distinguish between the several sources of information, in this thesis reference is made to the original reports, acknowledging the fact that the information was produced in a joint research process.

### Research by design

This research uses Research by Design as a research method. During the case study research phase, it proved to be very effective to demonstrate the spatial and visual effects of adaptation response actions and strategies, to communicate with stakeholders and to identify new and unexplored opportunities that derived from combining different agendas and ambitions. An interesting exercise was to develop

ATPs in a participatory process together with local residents and stakeholders using research by design tools to inform and communicate about the short-term and long-term spatial consequences of adaptation paths. Research by Design as a tool to illustrate the effects of transformative interventions and new opportunities needs more emphasis and attention in research on adaptation planning.

A challenge for using design-based research to inform decision makers on the local level is that urban design and architecture require information as precise as decimetres not just meters. Particularly at the district and neighbourhood level, there is still little knowledge on the actual impacts of flood events and the relative vulnerabilities of urban assets and buildings to flooding. Model uncertainties on projected flood levels resulting from climate uncertainty and local morphological differences, amounts to a high level of uncertainty that is conflicting with the need to design as precisely as in decimetres. In particular, the high uncertainties regarding the 100-year flood risk predictions and lack of detailed information, as found in the NYC metropolitan region, causes considerable design challenges, particularly when flood risk needs to be integrated into the design of new buildings and assets. Although current flood modelling is progressively improving and many GIS-based flood models are able to deliver information on local flood levels, velocities and durations of a flood with increasing precision, there is a scale 'misfit' between climate models and 'what is needed by decision makers and planners' (Hallegatte, 2009). To bridge the gap between climate change scenarios, large-scale flood modelling and local planning and design it is therefore necessary to integrate field analysis data and Research-by-Design methods into GIS-based modelling.

### § 8.3.4 Recommendations and outlook for research

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#### Towards adaptive planning and design of urban waterfronts

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Deltas, estuaries and coastal landscapes are, by nature, highly dynamic environments that are constantly shaped and transformed by balancing processes of sedimentation and erosion. Urbanisation processes in contrast tend to curb these natural dynamics and to create stable conditions that are necessary to provide safety, and, probably more importantly, to create the certainty needed for long-term investment decisions. Considering the deep uncertainties of climate change and the growing recognition of the dynamic nature of delta landscapes (Meyer, 2016) it is time to review some of the basic principles of modern town planning to allow for a more adaptive urban design and planning. One of the challenges of adaptive design and planning is to determine the best possible balance between the benefits of long-term flexibility and the short-term costs of adaptation investments and to use this information for the

development of principles for adaptive urban design. Additionally, adaptive design requires innovations in land use planning and real estate development economics to allow for temporary and more flexible land uses. Adaptive planning requires solving the problem of transaction costs and path dependencies that hinder a transfer between alternative strategies.

### Multilevel Delta Design

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Although many researchers acknowledge the need for understanding the complex interactions between urban development, governance and flood risk management in the long term adaptation planning of urbanised deltas, there is still little attention paid to the interactions of urban development and flood risk management at different temporal and spatial scales (Zevenbergen, et al., 2008). A better understanding of these cross-scale interactions and time dimensions is necessary to enhance the overall resilience of urbanised deltas and support evidence based decision-making. Many delta cities are struggling with the question of at what level and timeframe an intervention or policy is most effective or provides opportunities for benefits or added value. The issue of scale also questions the current cost-benefit approach, in which long term benefits as well as the adverse effects of interventions in other subsystems until now remain unvalued. A more complex assessment should also include the costs of inaccurate prediction, any adverse effects of the investment on other elements, and enhanced opportunities that arise from an adaptation action. It is necessary to develop a framework that is able to assess (1) the effects of adaptation interventions, (2) potential benefits, added value and adverse effects to other (sub) systems within the urbanised delta and (3) potential governance transitions required to unlock these opportunities in several spatial and temporal dimensions.

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## PART 4 Annexes



## Annex 1 Glossary and definition of terms

**Adaptation** – Collective efforts to reduce exposure to, or minimize the impacts of, disturbances and slow environmental change (Davidson, 2010).

**Adaptive capacity** – The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 4<sup>th</sup> assessment report glossary).

**Adaptability** – The collective capacity of the actors in the system to manage or influence resilience (Walker et al., 2004).

**Anticipatory adaptation** – Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.

**Autonomous adaptation** – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.

**Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC, Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability, glossary, 2007)

**Adaptation tipping point (ATP)** – A situation where political or societal objectives prove no longer to be attainable, under pressure from changing conditions.

**Adaptation pathways** – A policy response to a major shock or slow environmental change, with the aim of managing a system towards a sustainable future, or away from non-sustainable futures.

**Maladaptation** – Actions that inadvertently increase vulnerability (Denton et al., 2014)

**Path dependency** – A situation where earlier decisions rule out options and sets a path that cannot be left without costs and eventually leads to outcomes that are regrettable and costly to change

**Resilience** – The capacity of a system to absorb disturbance and re-organize while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al., 2004).

**Storm surge** – Storm surge is a rise in coastal water level associated with a hurricane or other strong coastal storm above the level associated with normal astronomical tides. The storm surge height is the difference between the observed storm tide and the astronomic tide. (Source: NYCDCP, 2013b)

**Transformability** – The capacity to create a fundamentally new system when ecological economic, or social structures make the existing system untenable (Walker et al., 2004).

**Tipping points** – The moment when changing conditions are forcing a normally stable state of an (eco)system into another state or urge a system to adapt.

**Vulnerability** – Vulnerability is a function of the exposure and sensitivity of that system to hazardous conditions and the ability of the system to cope or recover from the effects of those conditions (Smit & Wandel, 2006)

## Annex 2 Bio and published work

Peter van Veelen (1977, Rotterdam) is an urban planner and researcher specialized in planning and design of water sensitive cities and adaptive coastal areas. As urban planner at the Rotterdam Department of Urban Planning he worked on the development of a climate-adaptive flood risk strategy for the flood prone areas of both the city of Rotterdam and the wider metropolitan area, as part of the national Delta Program Rijnmond-Drechtsteden. For the Rotterdam Adaptation Strategy he designed and managed several multidisciplinary research projects on multifunctional flood defences, adaptive strategies for the unembanked areas, and governance of adaptation. These projects delivered new information on flood resilient architecture and opportunities for urban development and were implemented in close collaboration with urban renewal processes and local communities. As a member of the Rotterdam Rockefeller Resilience Program, he coordinated the Focus Area Climate Change. He has been involved in several design workshops on integrated and adaptive flood risk management in the Netherlands and urbanized deltas such as New Orleans, New York, Norfolk, Taipei and Ho Chi Minh City. He lectured for the Delft Delta Interventions Studio, Unesco-IHE, Houston University and Washington University St. Louis. His PhD research was conducted at Delft University of Technology, Faculty of Architecture and the Built Environment. He continues working at Delft University as coordinator Urban Deltas, responsible for developing cross-sectoral research and education focussing on challenges of urbanizing deltas worldwide.

### Refereed articles and book chapters

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- Veelen van PC (dd), Developing Resilient Urban Waterfronts; Integrating Adaptation into Urban Development and Management in: Deppisch (eds.) Urban regions now & tomorrow: between vulnerability, resilience and transition, Springer-Verlag Berlin Heidelberg New York (accepted, to be published 2017)
- Veelen, van PC, K Stone and A Jeuken (2015) Planning Resilient Urban Waterfronts using Adaptive Pathways. Proceedings of ICE water management 168-2, pp 49-56, themed issue on Flood Resilience, published online: September 02, 2015
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## Research reports

- Pohl, I, S Schenk, A Rodenburg, T Vergroesen, P van Veelen and M Houwen (2014). Cost-Benefit Assessment, Rotterdam Climate Adaptation Strategy, Casus: Kop van Feijenoord. Rebel group report 17-4-2014.
- Veelen, van PC (ed.), D Doepel, P Kronberger-Nabielek, M Gazzola, K Stone, M Hoogvliet, W Veerbeek, B Gersonius, A Kokx, M Van Vliet, E Siepman and U Blom (2013) Adaptive strategies for the Rotterdam unembanked area, synthesis report. KfC report 89/2013
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- Veelen, P. (ed.), F Boer, R Hoijsink, H Schelfhout and C Haselen (2010). Veilige en goed ingepaste waterkeringen. Rotterdam, KvK026/2010, ISBN/EAN 9789490070304

## Professional publications

- Veelen, van P.C. Multifunctionele waterkeringen: Living Apart Together. Published online September, 2015 at Deltalinks (waterviewer.tudelft.nl) en Gebiedsontwikkeling.nu
- Kronberger-Nabielek, P and PC van Veelen (2014) Adaptation tipping point: bridging the gap between risk assessment and urban design, Urban Design, nr. 132, autumn 2014
- Veelen, van PC (2014) Climate adaptation in Rotterdam. Book chapter in: Terrin, JJ (ed) (2014). Villes inondables, Prévention, adaptation, résilience, Cities and flooding, prevention, adaptation and resilience, édition bilingue français et anglais, Marseille, Parenthèses, 288 p.
- Pol, P & PC van Veelen (2014). Naar een klimaatbestendige stad – meekoppelen van klimaatadaptatie met stedelijke dynamiek, SenRo 03, 2014
- Kronberger, P en P. van Veelen Klaar voor Hoogwater, waterveiligheid en gebiedsontwikkeling in Rotterdam, SenRo, November 2012

## Lectures, workshops & conference presentations

- Design workshop Dutch Dialogues Norfolk, Virginia, US, June 19 – June 23 2015
- Training on adaptive and integral flood risk management for planning officials Albania Tirana, Sept. 2015
- Presentation 'Adapting the existing, retrofitting buildings for flood risk in Rotterdam and New York, Environmental Challenges and opportunities conference, Antwerp 24-25 March 2015
- Lecture on adaptive planning of waterfront areas at Washington University, St Louis, USA
- Organisation of science-practice session 'Resilient Cities Talk' at Deltas in Times of Climate Change 2014, Rotterdam
- Presentation at H209 Forum, Water Challenges For Coastal Cities, Sept 9 and 10 2013, New York City.
- Workshop Flood areas in the city: new urban and architectural approaches, cases Dunkerque, Rotterdam and Lyon, March 10-11 2014, Rotterdam
- Design workshop New York- second phase Rebuild by Design competition, September 2013
- Organisation of Science-practice session *Best practices of urban flood risk management, cases Hamburg, Dordrecht and Rotterdam*, ECCA conference March 18-20 2013
- Lecture Adaptive Waterfront Development, Houston University, February 2013
- Design workshop and training Ho Chi Minh City moving towards the sea with climate change adaptation, September 10-14, 2012
- Lecture Planning Department Taipei, Taiwan, November 2011

## Annex 3 Overview workshops and interviews

GOVERNANCE OF LOCAL ADAPTATION IN FEIJENOORD	
March 12 2013	1 <sup>st</sup> workshop research group 'Governance of local adaptation in Feijenoord, Rotterdam'
April 12 2013	2th workshop Governance of local adaptation in Feijenoord, Rotterdam
June 11, 2013	3th workshop Financial and organisational aspects of local adaptation in Feijenoord, Rotterdam
FLOOD RESILIENT BUILDING CODES, CASE HEIJPLAAT	
March 21 2013	1 <sup>st</sup> workshop 'drafting principles and objectives for flood protection at Heijplaat, Rotterdam'
April 9 2013	2th Workshop 'technological aspects of resilient buildings'
May 14 2013	3th workshop 'Resilient buildings and building code, zoning and regulations'
STAKEHOLDERS FLOOD RESILIENT URBAN DEVELOPMENT FEIJENOORD	
January 21 2014	meeting Diana van der Meer (risk manager) and Rob Cloossen (innovation manager) of power infrastructure company Stedin
April 14 <sup>th</sup> 2015	Meeting Teun Adriaansen (plant manager Unilever), Liesbeth Meeuse (environmental manager Unilever) and Marcel van Blijswijk (projectmanager City of Rotterdam)
May – Sept 2015	Stadslab Feijenoord workshops with Dennis Lausberg (social housing corporation Woons-tad Rotterdam), Andries Geerse (Architect), Els Leclerq (urban planner), Okach Bouchtaoui (area manager Feijenoord), and Willem Sulsters (area developer)
COMMUNITY MEETINGS NOORDEREILAND	
Oct 2014	1 <sup>st</sup> community meeting Noordereiland
June- Sept 2015	research on flood resilience of 5 buildings at the Noordereiland
Nov 10th 2015	2th community meeting Noordereiland
COST BENEFIT ASSESSMENT FEIJENOORD	
November 19 2013	workshop designing, engineering and cost calculation of flood protection Feijenoord
February 13 2014	cost calculations flood resilient buildings Feijenoord
April 18 2014	final report CBA

## Annex 4 Steps urban dynamics based planning method

### SCOPING

#### 1 Vulnerability assessment

- Define key elements of the system that affects the vulnerability of the locality (water system, urban, economic, infrastructural systems)
- Explore changing conditions (climate change, urbanization, changing hydraulic conditions)
- Explore flood exposure of the area: flood probabilities, flood depths, velocities, etc.
- Explore vulnerability: assessment of impact of flood on buildings, urban assets and vital infrastructures

#### 2 Define adaptation thresholds

- Define policy objectives or performance indicators (no flood is accepted that exceeds... the areas should recover within x hours...electricity remains function during a xx flood)
- Define measurable critical thresholds under which the performance indicators cannot be met anymore (flood levels/return periods) for each indicator

#### 3 Assess when and where these critical thresholds are reached, regarding current and future conditions

### OPTIONEERING

#### 4 Explore Adaptation measures

- Select possible adaptation measures (preventive, adaptive or recovery-based) and on what spatial scale (building, block, district, area, watershed, etc.)
- Evaluate adaptation measures on performance criteria (flood reduction, cost-effectiveness, social equity, spatial quality, additional benefits, negative side effects on other levels of the system)

#### 5 Explore intervention opportunities for incremental adaptation

- Stakeholder assessment (who has the risks, who pays, who benefits)
- Evaluate all planned investments and life cycles of urban assets in an area and evaluate ambitions of stakeholders.
- Understand economic drivers behind urban development and change
- Assess institutional/financial barriers that preclude implementation
- Determine potential changes in institutional landscape to allow effective use of intervention opportunities (land-use planning, regulate financial instruments, etc.)

#### 6 Develop adaptation pathways/routemaps based on

- Combine measures to adaptation pathways based on a decision pipeline or pathway map
- Select pathways that are based on improving the prevailing approach (Incremental) and based on large institutional or physical interventions (transformational)
- Assess the effectiveness of pathways in terms of (move thresholds to acceptable levels and are cost-effective (costs for adaptation vs. reduction of risks), or that show potential to use urban dynamics.
- Select pathways that show a high level of flexibility starting from the current approach (ability to move from one path to another) or robustness (ability to deal with a wide range of futures)

### DEFINE TRANSITIONAL OR TRANSFORMATIONAL INTERVENTIONS

#### 7 Develop final adaptation strategy

- Confront adaptive pathways with intervention opportunities and select the viable pathways
- Develop long-term and short-term projects business cases