Chapter 12
Integrated Disaster Risk Management and Adaptation

W. J. Wouter Botzen, Laurens M. Bouwer, Paolo Scussolini, Onno Kuik, Marjolijn Haasnoot, Judy Lawrence and Jeroen C. J. H. Aerts

Abstract This chapter discusses integrated approaches to the management of risks related to extreme weather and climate change. This is done with the Loss and Damage (L&D) mechanism of the UNFCCC in mind. Relevant insights are provided for climate policy negotiators and policymakers on how risk management and adaptation interact with L&D solutions, and vice versa, on how L&D-related activities can support risk reduction and adaptation in vulnerable countries. Particular attention is devoted to how risk management can help society confront the impacts of weather disasters in relation to anthropogenic climate change. A holistic view of risk management is presented by discussing: the state-of-the art of risk assessment methods; (cost-benefit) evaluations of risk management options; household-scale risk reduction strategies; insurance schemes for residual risk and their relations with risk reduction; and the design of adaptation pathways to cope with uncertain timing and intensity of climate change impacts. Each topic is illustrated with concrete case studies. Finally, conclusions are drawn on the links between disaster risk management, climate adaptation and the L&D mechanism.

W. J. Wouter Botzen (✉) · P. Scussolini · O. Kuik · J. C. J. H. Aerts
Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands
e-mail: wouter.botzen@vu.nl

W. J. Wouter Botzen
Utrecht University School of Economics, Utrecht, The Netherlands

W. J. Wouter Botzen
Risk Management and Decision Processes Center, The Wharton School, University
of Pennsylvania, Philadelphia, PA, USA

L. M. Bouwer · M. Haasnoot
Deltares, Delft, The Netherlands
e-mail: laurens.bouwer@hzg.de

L. M. Bouwer
Climate Service Center Germany (GERICS), Hamburg, Germany

J. Lawrence
New Zealand Climate Change Research Institute, Victoria University
of Wellington, Wellington, New Zealand

12.1 Introduction: Integrated Climate Risk Management in the Loss and Damage Context

The goal of this chapter is to establish the links between the concept of Loss and Damage (L&D) and climate risk management, with relevance to the L&D mechanism under the UNFCCC. Climate risk management is understood to include natural disaster risk reduction and adaptation to climate change (IPCC 2012). L&D was recognised in the 2015 Paris Agreement as a new pillar of climate policy, next to mitigation of greenhouse gas emissions and adaptation (UNFCCC 2015). Its purpose is to address irreversible losses from anthropogenic climate change, and resulting damages beyond what adaptation can avoid. In this context, efforts are currently made by the UNFCCC to propose activities under this pillar as part of the new climate agreement, in order to address L&D. However, various interpretations exist, which are further discussed in the chapter by James et al. (2018); see introduction by Mechler et al. (2018a); and the chapter by Bouwer (2018). For the purpose of this chapter, we will apply the "Risk management perspective" proposed by James et al. (2015) and further operationalised in the chapter by Schinko et al. (2018).

This implies that L&D refers to impacts 'beyond adaptation,' and that adaptation can prevent L&D (ex ante), while other approaches (such as insurance) can help dealing with L&D (ex post). Appropriate measures for risk management include natural disaster risk reduction through engineering solutions or other measures to mitigate risk, and risk transfer mechanisms, such as insurance. Climate risk management in this chapter is narrowed down to include adaptation to anticipated changes in extreme weather risk due to anthropogenic climate change as well as reduction of extreme weather risk beyond adaptation (the adaptation deficit). Climate adaptation according to the IPCC (2012) definition is:

> the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

In this definition, adaptation would not include dealing with L&D that occur beyond the prevention of risks, because when L&D occurs, impacts have not been moderated in some way. In this respect L&D solutions can be viewed as addressing the residual risk after adaptation. Natural disaster risk is defined as a function of hazard, exposure and vulnerability. In simplified form this function is often described as follows.

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}$$

Hazard is the natural event, in the case of flooding characterised by frequency and intensity (water depth, direction, and flow velocity). Exposure is the set of assets, people and (economic) activities that can be hit by the hazard. Vulnerability indicates the extent to which these assets, people and activities can suffer damage when a hazard occurs. Vulnerability is typically expressed as the mean loss (or the full distribution of losses) for a given intensity of the hazard.

Climate change-related risks, such as weather-related natural disasters, are thus the result of a complex interplay of natural hazards, like storm and flood conditions, and exposure of assets and their vulnerability, i.e. susceptibility to damage (IPCC 2012). While climate change may increase the frequency or intensity of certain natural hazards, exposure and vulnerability are determined by socio-economic development and human decision-making. It is these latter processes, such as population and economic growth in hazard-prone areas that have been the dominant drivers of increases in natural disaster losses in the past (Bouwer 2011; IPCC 2012; see also introduction by Mechler et al. 2018a). Natural hazard risk management can steer these vulnerability and exposure components of risk and traditionally includes all activities aimed at minimising impacts of natural hazards before, during and after an event (Botzen and van den Bergh 2009). Thereby, actions related to anticipated increased risk levels, because of anthropogenic climate change or other drivers, can address the prevention of risk (through adaptation), or the minimisation of impacts during an event (emergency measures), or after the event (clean-up, repair, compensation and rehabilitation). Climate change impacts can be avoided by risk management policies that limit exposure to natural disaster risk, for example by steering development away from hazard-prone areas, by better protecting these developments, and limiting vulnerability of exposed assets, for example through implementing and enforcing building code policies that limit wind or flood damages (Aerts and Botzen 2011; Czajkowski and Simmons 2014).

Integrated risk management takes a holistic view (in the sense that it considers various drivers of risk, and possible mitigation options ranging from structural measures, to emergency management and risk transfer such as insurance). Moreover, it uses a variety of approaches for the assessment of risk and evaluation of options, borrowing methods from natural sciences, engineering, economics, ecology and social sciences. An important cornerstone of successful risk management lies in the application of an assessment of risk, and the analysis of costs (of actions) and benefits (reduced risk) of risk management options in order to identify economically optimal strategies. These analyses show that it often pays off to prevent disastrous damages, or at least prepare for managing these damages when they occur (Mechler 2016). In addition to economic appraisal of risk management options, other considerations can come into play when deciding about the implementation of risk management strategies, such as equity, acceptable risk levels and impacts on the environment.
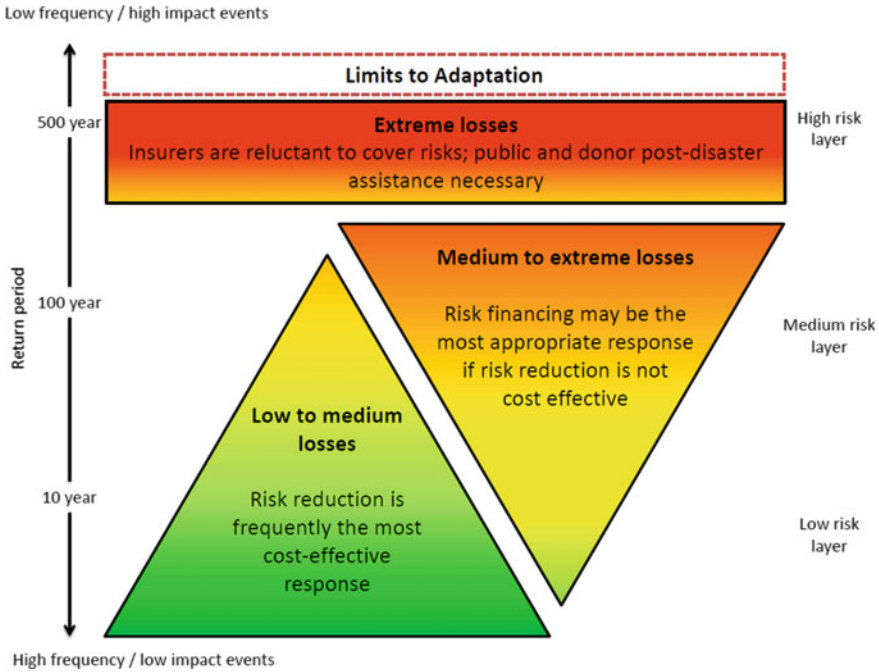
Low frequency / high impact events

Fig. 12.1 Layered disaster risk management. *Source* Mechler et al. (2014a)

The economic efficiency of actions however depends on the frequency and severity of impacts. For instance, Mechler et al. (2014a) proposed an approach (*risk layering*) where frequent (up to a return period of once in 200 years) events are avoided through risk reduction, while impacts from rare events would need to be covered by risk transfer which includes natural disaster insurance and regional risk pooling mechanisms. Extremely rare losses may not be economically efficient to address with insurance, and may need to partly be compensated by the public sector or the international community (see Fig. 12.1; chapter by Schinko et al. 2018).

Alternatively, public-private partnerships in financial compensation arrangements may be needed for covering such extreme risks (Kunreuther 2015). Applied to L&D from anthropogenic climate change, this means that avoiding the L&D by greenhouse gas mitigation or adaptation will often be a preferred approach, at least to a degree that this is economically efficient, rather than having to address L&D. Moreover, it should be realised that important relations can exist between the way L&D measures are implemented and incentives for adaptation. For example, ill-designed compensation mechanisms that do not provide financial incentives for risk reduction may result in moral hazard effects when investments in natural risk reduction decline because financial compensation for natural disasters from external parties is expected. On the other hand, adequate financial incentives for risk reduction may be integrated in L&D measures, for example, when natural disaster insurance arrangements stimulate

risk reduction by their policyholders through risk-based premiums which reward risk reduction activities with premium discounts (Bozen 2013). A further discussion of such incentives related to insurance is provided in the chapter by Linnerooth-Bayer et al. (2018).

Risk reduction and adaptation will have a pertinent influence on the vulnerability of countries to anthropogenic climate change. Various actions exist at present, including:

- National and local public actors addressing natural hazard risk, including planning for increased future risk because of climate change, supported by public sector budgets;
- Private actors reducing their risk and planning for climate adaptation, often supported by (national) public actors;
- International support to reduce natural disaster risk, such as through coordinating activities under the UNISDR and through implement disaster risk reduction actions by donors and International Financial Institutions (IFIs), such as development banks;
- International support to implement climate adaptation actions, including support from funds under UNFCCC and from other donors.[1]

This implies that past impacts from extreme weather and climate events cannot be taken as the norm, because future impacts will be different depending on adaptation efforts that are expected to reduce vulnerabilities. This is already clear from the historical record, as can be seen in the chapter by Bouwer (2018). Also, from an economic perspective adaptation actions and risk reduction need to be considered, and economically efficient adaptation solutions should be implemented, before L&D can be accepted as outcome. The underlying reason is that it is cheaper to make the investment to reduce the impacts than to absorb the impacts in any other way, including mechanisms set up to deal with residual damages, like L&D.

In this chapter, different approaches for risk management and their effects on limiting risk from climate change are discussed. An emphasis is placed on case study insight and actions that avoid damages. Successively, we discuss the following levels of actions:

- Assessment of weather-related disaster risk, as a basis for decision making on risk management;
- Cost-benefit analysis of adaptation strategies in which risk assessment methods are used to evaluate the benefits of adaptation;
- Household-level actions to reduce risk;
- Relations between ex post compensation through insurance and incentives for household risk reduction;
- Adaptation planning approaches including adaptation pathways.

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[1]For example see https://www.adaptation-fund.org/projects-programmes/.

The final section provides a synthesis of the different approaches presented in the chapter, and draws conclusions on the links between climate risk management and the L&D mechanism.

12.2   Climate Risk Assessment—Case Studies Jakarta and Ho Chi Minh City

The decisions on adaptation interventions to minimise the impacts of climate change requires the understanding of what is the amount of risk that can or cannot be reduced. The amounts of risk that cannot be reduced (residual impacts) will to some extent be relevant to the L&D mechanism. For risk assessment, two activities are necessary: (1) to quantify the present and future risk in a risk model framework; and (2) to quantify the effectiveness of possible mitigation or adaptation measures in reducing risk.

We present here two recent case studies that apply such assessments for Jakarta, Indonesia, and for Ho Chi Minh City, Vietnam, two Asian megacities that display high vulnerability to natural hazards, in particular floods, and to climate change.

In Jakarta multiple drivers compound the risk of flooding: the huge rate of land subsidence, due to groundwater extraction, sea level rise and change in precipitation patterns, both due to climate change. Following the definition of risk reported in Sect. 12.1. Budiyono et al. (2015) employed a hydrological and hydraulic model to produce maps of river flood. Moreover, they assembled specific exposure and vulnerability data for each land use type, by tapping the expert judgement of local stakeholders. A framework for quantifying flood risk was then build, based on the Damagescanner model of Klijn et al. (2007), which produced results in good agreement with reported flood damages, and estimated current expected annual damage in the order of hundreds of thousand USD per year.

A successive study expanded this modelling framework to project the risk assessment into the future until year 2050 (Budiyono et al. 2016). The hazard modelling incorporated precipitation changes from a combination of four Representative Concentration Pathways (RCP) emission scenarios and five distinct climate models, and a low and a high scenario of sea level rise to explore the probabilities and scenario-dependency of changes in flooding. Furthermore, the effect of the severe land subsidence rates on hazard, and of land use changes on exposure were included. The results show that the probability density function of annual damages shifts to much higher values in the absence of adaptation (see Fig. 12.2). This is primarily due to the effects of land subsidence, but also the result of sea level rise. Climate-change induced changes in maximum rainfall, on the other hand, introduce a large uncertainty in the future damages, as some models and scenarios imply an increase, while others a decrease in hazard. If land use will change according to the government plans, it will have the potential of reducing risk by some 12%. Finally, Budiyono et al. (2017) calculated the risk-reducing potential of a planned upgrade of the polder
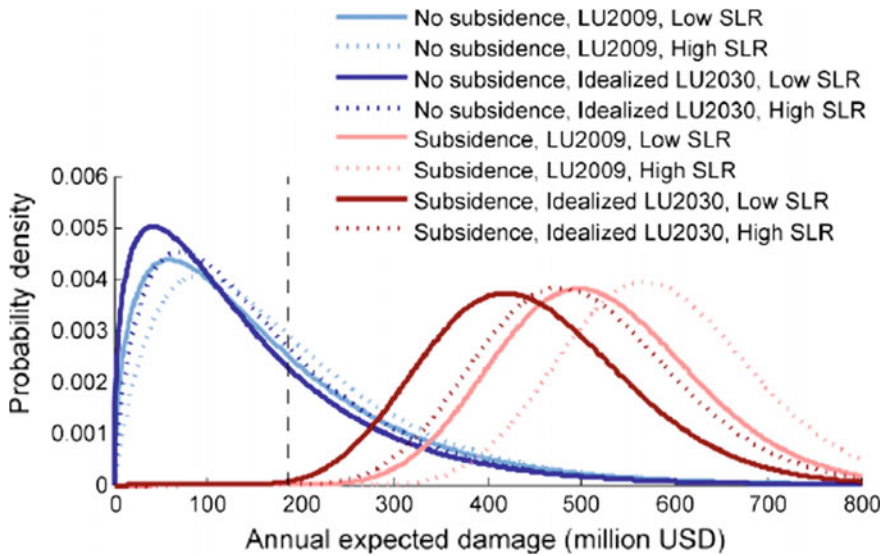
Fig. 12.2 Flood risk in Jakarta measured as annual expected damage. The vertical dashed line represents the present value. The coloured curves represent probability density functions, obtained by fitting gamma distributions to 20 combinations of climate models and emission scenarios, thus each representing the uncertainty in future precipitation extremes. Curves are shown with and without land subsidence, with land use (LU) of year 2009 and LU of 2030, and with low and high sea level rise (SLR). *Source* Modified from Budiyono et al. (2016)

system via construction and rehabilitation of dikes. This is done by cutting the risk curve, also known as the exceedance probability-damage curve, assuming that each polder will provide a standard of protection expressed as the return period of the event it can withstand (e.g., a 50-year flood).

For Ho Chi Minh City, the risk of flooding is quantified under present conditions, and under scenarios of climate and socioeconomic change over the 21st century. This city already suffers regular disruption to livelihoods and business due to seasonal floods, mostly due to storm surges from the South China Sea and heavy precipitation and river discharge.

The assessment includes a number of steps where quantitative information is processed (Fig. 12.3). Following, as for Jakarta, the risk definition in Sect. 12.1, the flood hazard is quantified via hydrodynamic modelling, for four return periods, the exposure is represented by land use and population density maps, and the vulnerability is expressed in vulnerability curves that are specific of the land use. To simulate the future, the framework incorporates: in the flood modelling, projections of sea level rise from regionalised projections relative to two RCP emission scenarios, one of moderate and one of high greenhouse gas emissions; in the impact modelling projections of socio-economic growth from two plausible Shared Socioeconomic Pathway (SSP) scenarios. These pressures are scenario-dependent.
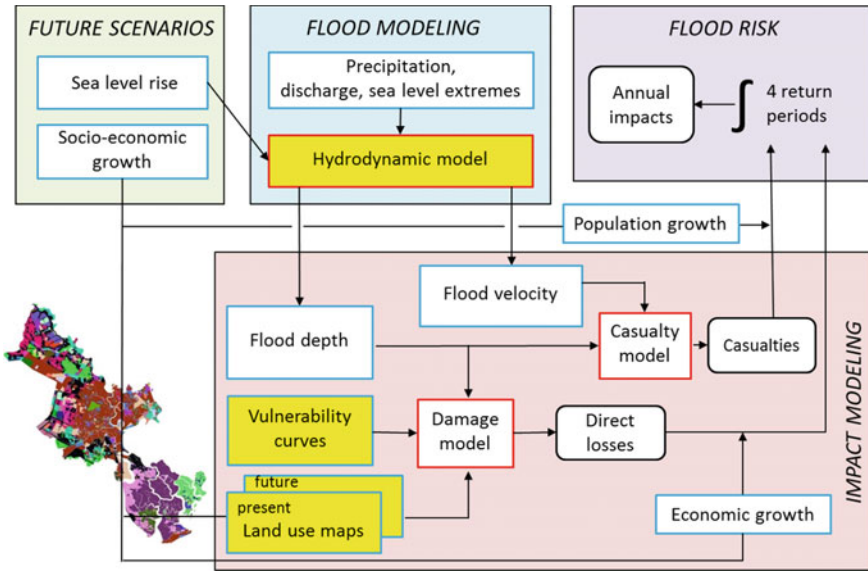
Fig. 12.3 Conceptual framework of the flood risk assessment of Ho Chi Minh City. Yellow boxes indicate the points in the modelling where adaptation measures are implemented. *Source* Modified from Scussolini et al. (2017)

The next step is the modelling of two main impact indicators: the direct economic losses, and the likely casualties. Direct losses include damage to different types of buildings, infrastructure and crops, and are calculated with the Damagescanner model, by combining flood maps and land use maps (for the present and for the future) through the use of vulnerability curves. Casualties are modelled based on the field of flood velocities and depths that is produced by the hydraulic model, and applying empirical relationships to local information on the number people present in Ho Chi Minh City.

The following step is the integration of the impacts of floods of each magnitude across four return periods, to quantify the risk, in terms of average annual impacts. As can be seen in Fig. 12.4 the already large expected annual damage and the potential casualties increase substantially until the year 2050 and 2100, depending on the scenario and if adaptation measures are not taken.

The Ho Chi Minh City case study goes one step further than the Jakarta study by analysing the risk reducing potential of (combinations of) four flood risk management measures. These measures are: the construction of a ring dike around the central districts, the elevation of land in the districts where risk is higher, the retrofitting of residential and commercial buildings by dry-proofing, and spatial reorganisation of land use. These are incorporated in the flood hazard and impact modelling (yellow boxes in Fig. 12.3).
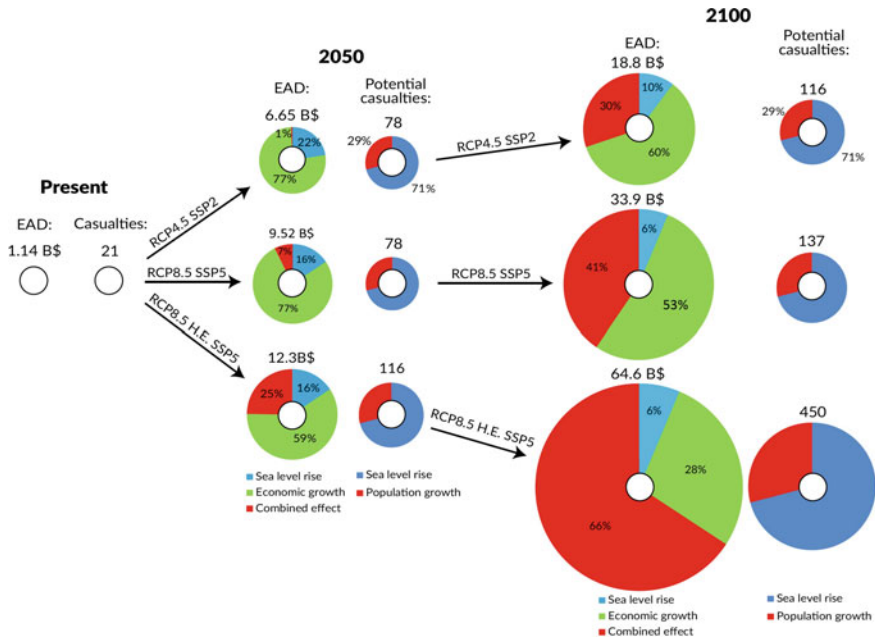
Fig. 12.4 Increase in flood risk (expected annual damage—EAD—and annual potential casualties) of floods in Ho Chi Minh City, from the present to year 2050 and 2100, for three combinations of climate and socio-economic scenarios: RCP4.5 and SSP2, RCP8.5 and SSP5, and the high-end of RCP8.5 and SSP5. The area of the circles is proportional to the intensity of the impacts. The different colours indicate how much of the increase (with respect to the present impacts, in the white circles) is attributed to sea level rise, to economic growth, to population growth, and to the combination of sea level rise and economic growth. *Source* Modified from Scussolini et al. (2017)

The analysis shows that appropriate adaptation can considerably reduce losses and damages (Fig. 12.5), but none of the solutions investigated will reduce impacts to zero, which means that a residual risk remains. The cost-benefit analysis results of these measures are reported in Sect. 12.3. These results can inform decision-making on which adaptation pathway to take.
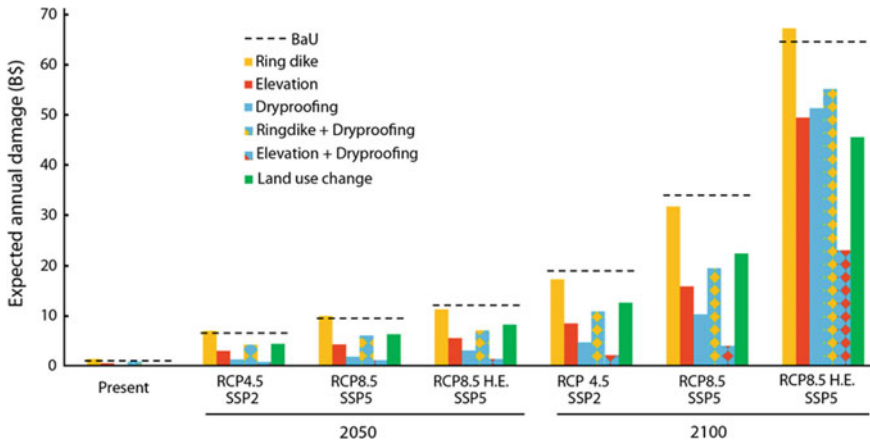
Fig. 12.5 Performance of several adaptation measures and strategies in reducing the future impacts of sea level rise, compared to the situation without adaptation (Business-as-usual, BaU). The risk is displayed in terms of the expected annual damage (not discounted), for the present and for three combinations of scenarios in the years 2050 and 2100: RCP4.5 and SSP2, RCP8.5 and SSP5, RCP8.5 High-End (H.E.) and SSP5. *Source* Modified from Scussolini et al. (2017)

12.3 Cost-Benefit and Multi-criteria Analysis of Risk Management Options—Case Studies from Ho Chi Minh City and The Netherlands

After conducting an assessment of natural disaster risk and identification of risk management options, these options can be appraised using methods like cost-benefit analysis (CBA). CBA is a widely-used tool for prioritising projects, by assessing the project's net benefits to society. In an application to natural disaster risk, CBA can make use of natural disaster risk assessment methods that can estimate the benefits (avoided natural disaster losses) of risk management options. The basic question that is addressed by CBA is: will society as a whole become better off by undertaking this project rather than not undertaking it, or by undertaking instead any of a number of alternative projects? (Mishan 1988). CBA is often used to assess and prioritise risk management options: what are the net benefits to society of this particular option, should we implement it or should we choose any of a number of alternative options, including the one of doing nothing? In CBA all the expected advantages (benefits) and disadvantages (costs) of a project are expressed in money terms, so that they can be compared and the net benefits (benefits minus costs) can be computed.

A CBA of a project ideally identifies all costs and benefits for all parties that are affected by the project over the lifetime of the project. The expected costs and benefits are then valued in monetary terms and the costs and benefits in future time periods discounted by an appropriate discount rate. Finally, the discounted costs and benefits are aggregated into one summary statistic: net present value (NPV), benefit-to-cost ratio (BCR) or internal rate of return (IRR).

Box 12.1 Decision metrics
Net Present Value (NPV): Costs and benefits arising over time are discounted and the difference taken, which is the net discounted benefit in a given year. The sum of the net discounted benefits is the NPV. A fixed discount rate is used for expressing future values in today's terms to represent the opportunity costs of using the public funds for the given project. If the NPV is positive (benefits exceed costs), then a project is considered desirable.
Benefit-to-Cost Ratio (BCR): a variant of the NPV. The total discounted benefits are divided by the total discounted costs. By definition, a benefit-cost ratio of 1 means that the expected discounted benefits of implementing the mitigation equal its costs. Any measure where a BCR is greater than 1 is considered to be cost-effective and should be implemented as the benefits exceed costs and a project thus adds value to society. Any measure with a BCR less than 1 (implying that the upfront cost of mitigation is higher than the expected discounted benefit) should not be implemented. Due to its intuitiveness the BCR is often used.
Internal Rate of Return (IRR): Whereas the former two criteria use a fixed discount rate, this criterion calculates the internal interest rate for which the $NPV = 0$, which is considered the return of the given project. A project is rated desirable if this IRR surpasses an average return on public capital determined beforehand.
Source Mechler et al. (2014b)

An important benefit category in a CBA of disaster risk reduction measures is the expected value of avoided damage created (defined as the prevented risk). Disasters are low-probability high-impact risks. They follow extreme event distributions which are typically very different from normal distributions. Probabilistic analysis is required to assess the expected flood risk as well as the benefits of risk management options in terms of reduced damages. As an illustration for the case of flood risk management in Ho Chi Minh City, Scussolini et al. (2017) used the risk assessment framework of Sect. 12.2 to estimate the NPV and BCR of different flood risk adaptation strategies, including the construction of a ring dike, and dry-proofing buildings and elevating areas at high risk. Costs and benefits are calculated until the year 2100. To ensure that the BCR ranks the adaptation measures in the same order as the NPV, the BCR was normalised to account for the widely different investment costs of the measures. The results are shown in Fig. 12.6. The flood risk adaptation measures appear to yield benefits that substantially outweigh the costs, except for the ring dike in the high climate change scenario. The ring dike has the lowest BCR and NPV, while the combination of elevation and dry-proofing of buildings has the highest BCR and NPV and is, thereby, the optimal adaptation strategy, from a long-term economic perspective. In evaluating risk management options, the results of CBA can be combined with other (non-economic) considerations and indicators. Economic efficiency is usually considered an important aspect of disaster risk management and adaptation, but often not the only aspect that needs to be considered.
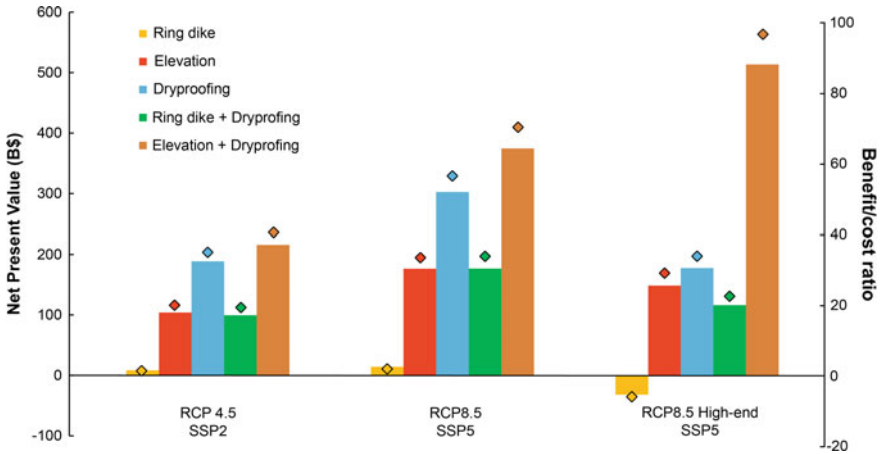
Fig. 12.6 Net Present Value (bars, left axis) and normalised Benefit/cost ratio (diamonds, right axis) of flood risk adaptation measures for Ho Chi Minh City for three combinations of climate change and socio-economic scenarios RCP4.5 and SSP2, RCP8.5 and SSP5, RCP8.5 High-End and SSP5, until the year 2100. Note: discount rate is 2.5%. *Source* Scussolini et al. (2017)

The development of new flood risk protection standards for the Netherlands illustrates the use of CBA in combination with other considerations and indicators (see Box 12.2). The case below also illustrates how the application of CBA in designing region-specific protection standards reduced protection investment costs in comparison to an earlier official proposal for a nation-wide uniform update of the old standards.

There are alternatives to CBA that can be applied. Cost-effectiveness analysis (CEA) is a method that can be applied to identify least-cost options to meet a certain, pre-defined target or policy objective, for example, a certain safety standard. CEA can also be used if the benefits of alternative options are assumed to be similar enough that the choice between options can be made on the cost dimension. The use of CEA is appropriate if the benefits of alternative options are fixed or pre-defined (such as reducing disaster fatalities or losses to a pre-defined level). The advantage of CEA is that it does not require to monetise the benefits of options, such as the monetary benefits of avoiding health or environmental impacts of floods. The disadvantage of CEA is that it cannot determine whether an option is economically efficient, i.e. whether its benefits exceed its costs. Multi-criteria analysis (MCA) is another decision-support method that can be used in certain circumstances. MCA provides a structured way of comparing benefits and costs that are expressed in different units. For example, benefits may be expressed in "number of lives saved" or a qualitative indicator of landscape or environmental quality. MCA is sometimes

called a "qualitative CBA." Box 12.2 describes how a combination of BCA and MCA have guided "Room for the River" measures in the Netherlands which have contributed to improving discharge capacities of rivers as well as environmental values. Recently, robust decision-making approaches (RDMA) have gained increasing attention, especially in the context of climate change adaptation (see Watkiss et al. 2015 for a review). RDMA approaches include qualitative and quantitative methods. They are particularly useful to appraise long-term investments in the face of large or "deep" uncertainty about the future. In such circumstances it may not be possible to make optimal decisions (as supported by CBA), but to select options that perform relatively well across a range of possible futures, and thus to minimise regret about an option when the future turns out to be very different than originally envisioned.

Box 12.2 The use of CBA and MCA in flood risk protection policy in the Netherlands

The Netherlands is by its geographical disposition notoriously exposed to extreme flooding. More than half of its land area faces flood risks, putting two-thirds of its population and 70% of its GDP at risk. Flood Protection policy employs a so-called 'multilayer safety approach,' encompassing prevention, spatial solutions (including adaptations to buildings and infrastructure), and crisis management, whereby prevention of flooding receives prominent attention. On the request of the Delta Committee, which was commissioned 1958 after a huge flood, the mathematician Van Dantzig designed an algorithm to determine optimal dike heights based on the equilibrium between marginal investment costs and marginal expected avoided flood damage. The first Delta Act of 1958 included flood protection standards for coastal areas, which were partly based on the work of Van Dantzig (1956). As of the 1970s, safety norms were assigned to rivers and since 1996 all water safety norms have been written in law. This Water Act determines flood protection standards for all dike-ring areas (polders) in the Netherlands. However, the standards of the 1950s did not take account of the possible impacts of climate change and sea level rise.

In response to near flooding events in 1993 and 1995 an alternative approach to flood protection using dikes has been promoted in the Netherlands which entails improving discharge capacities of rivers using land use change, restoration of floodplains and the creation of wetlands. These alternative flood control policies called "Room for the River" create side-benefits, such as ecological, recreational and amenity values. Brouwer and van Ek (2004) applied a CBA and an MCA to appraise the "Room for the River" measures. These evaluations considered the hydrological, ecological, economic and social effects. The extended CBA included monetary benefits of environmental and social benefits of the measures and prevented flood damages. The estimated NPV is €860 million, which favours investing in these measures. Moreover, stakeholder analysis was used to assess effects of these policies on inhabitants, farmers, the environment, water supply companies and recreation. These effects were included in the MCA which also positively evaluated the "Room for the River" measures. In the meantime, most of these measures have now been implemented in practice. A second Delta Committee advised on an update of the flood protection standards in the light of the growth of exposed population and assets, and projected sea-level rise. The Committee upheld the first Delta Committee's risk-based approach and advised that the new standards should

be based on three factors: (1) the probability of individual fatalities due to flooding, (2) the probability of large numbers of simultaneous casualties, and (3) economic and other damage (to landscape, to natural and cultural heritage values, to the country's reputation and to society). To achieve this aim, the committee tentatively advised that protection levels for all dike rings should be increased by a factor of ten (e.g., if the current protection level was 1/1,000, it should be increased to 1/10,000).

A cost-benefit analysis to determine optimal protection standards for all dike rings in the Netherlands was initiated by the CBP Bureau for Economic Policy Analysis in 2005 (Eijgenraam et al. 2014). This analysis determined the optimal protection level for a dike ring as that protection level where the marginal protection costs would equate the marginal avoided damages. Damages included direct and indirect economic damage, and loss of life expressed in monetary value through the value of statistical life concept (Bockarjova et al. 2012). With this approach, optimal protection levels were determined for all dike rings in the Netherlands (Kind 2014). It is interesting to note that the investment costs of the economically efficient flood protection standards were estimated to be € 7.8 billion: almost 70% cheaper than the investment costs associated with the advice of the second Delta Committee to increase protection standards everywhere by a factor of ten (Eijgenraam et al. 2014). The Delta Commissioner, appointed in 2010, developed flood protection standards up to the year 2050 and takes the potential effects of climate change on sea level rise and river discharge into account. A number of climate and socioeconomic scenarios have been explored for use in the Delta Programme. The underlying climate scenarios were developed by the Dutch Meteorological Institute KNMI. In the scenario with most climate change, regional sea level rise in 2050 is 35 cm, increasing to 85 cm in 2100. For future river discharge, flood protection policies in upstream countries are relevant. The maximum river discharge of the river Rhine in the Netherlands is presently 'capped' at $16,500 \text{ m}^3/\text{s}$, because higher discharge is made impossible by flooding that would occur upstream in Germany. Due to increases in the likelihood of extreme precipitation events, the maximum discharge is assumed to increase to $17,000 \text{ m}^3/\text{s}$ in 2050 and $18,000 \text{ m}^3/\text{s}$ in 2100. Similar calculations have been made for the river Meuse. The Delta Programme advocates adaptive management ('adaptive delta management') to address future uncertainties, including the impacts of climate change, in a transparent manner. The Delta Commissioner combined the CPB economic assessment with the other factors that had been suggested by the second Delta committee, In the first place, the standards should offer a common minimum level of protection for each citizen to be protected by dikes or dunes by the year 2050. Secondly, higher standards are offered in locations where there is a risk of large numbers of victims, or of serious damage to vital infrastructure of national importance, or of high economic damage, as indicated by CPB's economic assessment. The new flood protection standards were presented to and adopted by Parliament in 2014. *Source* Kuik et al. (2016)

12.4 Individual (Household) Level Natural Disaster Risk Reduction—Case Studies Germany and Mexico

In addition to public disaster management policy, like the flood protection policy described in Sect. 12.3, private actors including companies and households, can take measures to limit the potential damage of natural disasters. These individual level measures can be an important component of natural disaster risk management when public protection is not economically efficient. Thereby, these measures can contribute to climate change adaptation, and limit the residual risk that has to be dealt with through L&D. Moreover, even when public strategies are in place to limit risk, individual level measures can be a useful complement to minimise damage when public strategies fail and a disaster happens. For example, it has been shown that relatively low-cost measures, like moving furniture to higher floors and placing sand bags in front of doors and window openings, can save substantial damage when floods occur due to failure or overtopping of flood protection infrastructure (Kreibich et al. 2005). Moreover, during construction or renovation of buildings it is usually inexpensive to make structural adjustments to reduce a building's vulnerability to hazards, like through elevation or applying water-resistant materials (Aerts and Botzen 2011).

Although the importance of natural disaster risk mitigation measures at the individual scale is well recognised, relatively few empirical studies have been conducted to estimate the potential damage savings from these measures and their economic desirability (Poussin et al. 2015). Exceptions are the studies described in Box 12.3, which examined this for flood damage mitigation measures in Germany. The German studies (Box 12.3) use mean comparison tests to examine how much flood damage has been saved when particular flood preparedness measures were implemented by households during floods of the river Elbe. The results point toward clear damage savings of up to 50% of some measures.

Even while household level measures to reduce natural disaster risk are cost-effective, this does not mean that many people will voluntarily invest in these measures. This may be due to low awareness about risk and mitigation measures, since damaging natural hazards are often low-probability events that individuals have little experience with. As a result, building codes and zoning policies can be developed to guide the implementation of damage mitigation measures. Zoning regulations are set to control land uses and setting development standards throughout urban areas. Zoning regulations determine (1) what land uses, or combinations of land uses are allowed in the available space, and (2) how land uses utilise space (i.e. conditions for building construction, for instance, including building codes that limit natural disaster risk). In terms of utilising space for especially urban areas, zoning policies

and building codes are powerful tools for controlling land use and urban development, and hence (changes in-) future land use (Burby et al. 2000). As such, zoning is increasingly seen as an important tool in climate adaptation and managing changes in weather extremes due to climate change (Aerts and Botzen 2011).

Zoning encompasses the following general policies related to urban development and risk management:

- *Restrictions*: Based on hazard maps and or additional risk information, zoning policies may indicate that in certain areas urban development is not allowed;
- *Conditional development:* Urban development is allowed in risky areas, but only when certain conditions are met, for example, by (a) implementing building codes, (b) homeowners have purchased insurance against natural hazard risk (c) buffer zones are respected: building development is only allowed when appropriate distances between establishments and vulnerable risk areas are maintained.

Box 12.3 Effectiveness of flood damage mitigation measures in Germany

Kreibich et al. (2005) interviewed 1248 households that were affected by the severe Elbe flood in 2002 in Germany in order to assess the level of preparedness of households for flooding, and to estimate the effectiveness of damage mitigation measures that households implemented before and during the flood. Mean comparison tests were conducted to examine how flood damage differs between households who have, or have not, implemented a specific flood damage mitigation measure. Overall, this study shows that the potential gains of implementing mitigation measures at the household level can be substantial. The results show that buildings without a cellar suffer about 24% less building damage and 22% less damage to contents. Water barriers reduced flood damage by about 29%. Stable building foundation or waterproof sealed cellar walls reduced flood damage to buildings by about 24%. The most effective strategies were flood-adapted building use and flood-adapted interior fitting. Flood-adapted building use means that parts of the building that can be flooded (such as the cellar and ground floor) are not used cost-intensively or include expensive constructions, such as a sauna. Flood-adapted interior fitting means that only waterproofed building material and furniture and contents that can be easily moved to higher floors are applied in flood-prone parts of the building. Flood-adapted building use reduced damage to buildings and contents by, respectively, 46 and 48%, while flood-adapted interior fitting saved damage to both buildings and contents by 53%. Placing utility and electrical installation on higher floors reduces flood damage by 36%. These results of the effectiveness of flood mitigation measures in Germany have been confirmed by Kreibich and Thieken (2009) who conducted a similar survey after floods in 2005 and 2006 in the city of Dresden. The results of this survey indicate that household preparedness improved before the 2005/2006 floods, compared with the 2002 Elbe flood, and that this improved preparedness resulted in significantly less flood damage in the events. Kreibich et al. (2011) show that the implementation of low-cost mitigation measures, such as the securing of oil tanks and installation of mobile flood walls, are cost-effective in Germany under a range of flood conditions and discount rates. *Source* (Botzen 2013)

Zoning regulations, and in particular zoning for conditional development, can be further refined in 'building codes' regulations for the development and maintenance of buildings in risk zones. Building codes are meant for the adaptation of building structures to lower their vulnerability to natural hazards. Building codes are anchored in planning law, which is operationalized in legally binding land use- or zoning plans. These zoning plans lay out in which areas building codes will be enforced (for examples of building codes in relation to insurance see Sect. 12.5). Building codes and zoning measures, however, also take quite some time to develop and to process them through all regulatory bodies. In many instances, building codes are not yet assessed against expected increases in risk through, for example, as a result of climate change (e.g. Burby 2006).
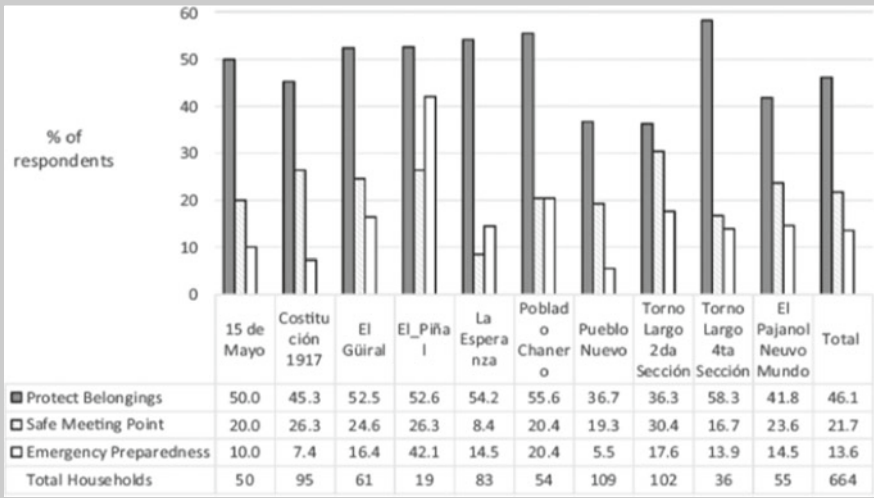
In addition to reducing a building's vulnerability to natural disasters, other measures at the individual level can contribute to enhancing an individual's capacity to cope with natural disaster events. As an illustration, Atreya et al. (2017) show how individuals in poor communities in Tabasco, Mexico, take relatively low-cost measures to cope with almost yearly flood events, by protecting belongings, taking emergency preparedness actions and knowing a safe meeting point to evacuate their family during a flood threat. As described in Box 12.4, the implementation of such measures is found to be positively related to community-level policies, such as having flood risk maps available to communicate about risk, and creating early warning systems and shelters. This shows the important role that communities can play in preparing households to cope with natural disaster impacts.

12.5 Natural Disaster Insurance and Incentives for Risk Reduction—Case Study Germany

Financial compensation arrangements, like in the form of aid, public insurance, private insurance, or public-private insurance systems can be designed to provide financial coverage for residual climate change risks (Botzen 2013). The advantage of having an adequate financial compensation system in place is that reimbursement of damage, for example, after a natural disaster, helps people rebuild and limits negative economic consequences.

Box 12.4 Adoption of flood preparedness measures in Tabasco, Mexico

Floods in the Mexican state Tabasco occur frequently, almost on an annual basis. Individual and community level flood preparedness measures are an important way for local households to cope with flood events. The last decade floods have become more severe in this poor region, which suggests that local communities have to improve flood risk management efforts. Atreya et al. (2017) examined flood preparedness decisions in ten communities in Tabasco conducting a survey among 664 households with questions about their flood preparedness decisions. In particular, they focused on the role that community level measures, such as information provision on risk, play in individual decisions to prepare for flooding. Important flood preparedness measures that people take in Tabasco are protecting belongings against flooding, having a safe meeting point to go to during a flood event, and emergency preparedness actions, such as having a family emergency plan of what to do during a flood, first aid training or disaster drills. The figure below shows the percentage of people in these communities who have taken these measures, from which it is apparent that protecting belongings is the most commonly taken measures, while improvements can be made in taking the other measures which are currently taken by fewer people,

	15 de Mayo	Constitución 1917	El Güiral	El_Piñal	La Esperanza	Poblado Chanero	Pueblo Nuevo	Torno Largo 2da Sección	Torno Largo 4ta Sección	El Pajanol Neuvo Mundo	Total
■ Protect Belongings	50.0	45.3	52.5	52.6	54.2	55.6	36.7	36.3	58.3	41.8	46.1
□ Safe Meeting Point	20.0	26.3	24.6	26.3	8.4	20.4	19.3	30.4	16.7	23.6	21.7
□ Emergency Preparedness	10.0	7.4	16.4	42.1	14.5	20.4	5.5	17.6	13.9	14.5	13.6
Total Households	50	95	61	19	83	54	109	102	36	55	664

Atreya et al. (2017) conducted statistical analyses to examine which factors influence individual flood preparedness decisions. These results show that household preparedness actions are positively related with communities having accessible flood risk maps, early warning systems, and shelters, amongst other factors. This provides insights into community-level flood risk management strategies that can improve individual flood preparedness. For example, very few people (about 8%) currently have access to community's risk maps, while having such knowledge is found to improve individual flood preparedness. Moreover, this can be achieved by better communicating about early warning systems and shelter availability.

It is important to realise that the financial compensation arrangement should be designed so that it is complementary to, and facilitates, the undertaking of cost-effective adaptation measures, and not acts as a substitute or financial disincentive for implementing such measures. A moral hazard effect can arise when individuals prepare less for a risk after they have obtained insurance coverage against the risk. This can occur when policyholders expect to receive compensation from their insurer irrespective of risk reduction efforts and if policyholders receive no financial incentives, like lower premiums, from their insurer to limit risk. This can pose problems for the insurer when due to information asymmetries, the insurer does not observe the heightened risks taken by a particular policyholder. This implies the higher risk is not adequately reflected in a higher risk-based premium. Moreover, such a moral hazard effect is evidently undesirable when climate change increases natural disaster risks since it hampers the implementation of adaptation measures by people covered by insurance.

Hudson et al. (2017) examined the existence of this moral hazard effect using data from samples of households living along the river Elbe in Germany. This is done by estimating relations between flood insurance coverage and the implementation of flood damage mitigation measures, and by estimating whether flood damage outcomes differ between the insured and uninsured, while controlling for a diversity of other relevant explanatory variables. The results show that a moral hazard effect is absent (Hudson et al. 2017). In particular, flood damages of insured households are not significantly higher than those of uninsured households when differences in flood hazard characteristics are accounted for. Moreover, individuals with flood insurance coverage are more likely to have taken specific flood damage mitigation measures than people without flood insurance. These insured individuals did not receive a premium discount for taking flood damage mitigation measures, which implies that other reasons explain why the insured were better prepared for flood risk. The results suggest that behavioural characteristics, like high risk aversion, imply that individuals have preferences for both insurance coverage and risk mitigation.

Although the relations between risk reduction and natural disaster insurance has received little empirical research (see also chapter by Linnerooth-Bayer et al. 2018), the findings by Hudson et al. (2017) do not stand by themselves. Thieken et al. (2006) also observed that individuals with flood insurance coverage in Germany are better prepared for flooding than people without flood insurance. Botzen et al. (2017) find positive relations between having flood insurance coverage and implementing flood-proofing measures among homeowners in flood-prone areas in New York City. Hudson et al. (2017) show that similar positive relations between insurance coverage and risk reduction can be found for windstorm risks in several areas in the U.S. that were impacted by hurricanes Irene, Isaac, and Sandy. These findings are consistent with positive relations between windstorm coverage and windstorm risk reduction activities reported in Carson et al. (2013) and Petrolia et al. (2015).

Additional calls have been made to design natural disaster insurance arrangements in a way that they incentivise risk reduction by policyholders. For instance, insurance could reward investments in damage mitigation measures with premium discounts (Kunreuther 2015). There are few examples of flood insurance arrange-

ments which reward policyholders who elevate their home with lower premiums, like the National Flood Insurance Program in the US (Aerts and Botzen 2011). Nevertheless, most natural disaster insurance systems do not charge risk-based premiums that incentivise risk reduction. Hudson et al. (2016) examine how much additional flood damage mitigation can be achieved when German flood insurance companies start incentivising risk reduction through charging risk-based premiums. For this purpose, they developed an integrated model of flood risk in all main river basins in Germany, the insurance sector, and household flood preparedness behaviour. The results show that the premium incentives for risk reduction limit the expected risk increase that arise from climate change with about 20% on average until the year 2040. These findings suggest that financially rewarding policyholders for taking risk mitigation measures can improve their preparedness for flooding.

In addition to financial incentives provided by insurance, a variety of other mechanisms related to insurance systems can be applied to stimulate natural disaster risk reduction. Insurance systems can be combined with building code and zoning regulations which limit vulnerability and exposure to natural hazards. For example, communities in the U.S. which participate in the National Flood Insurance Program have to limit new construction in floodways and new buildings have to be elevated to the expected water level of the flood that occurs on average once in 100 years (Aerts and Botzen 2011). The French natural disaster insurance system is connected with so-called Risk Prevention Plans which include recommended or compulsory building code and zoning regulations to minimise flood damage (Poussin et al. 2013). Such regulations and standards are useful for setting minimum requirements which are cost-effective for buildings in a specific hazard zone.

12.6 Design of Adaptation Pathways with Policy Makers—Case Studies New Zealand and Bangladesh

There are important challenges for deciding on climate-resilient investment and development pathways under conditions of uncertainty and change, such as anthropogenic climate change. In response to uncertain environmental and socio-economic change, decision makers are urged to develop adaptive plans. A number of approaches that address uncertainty and change have been taken up in practice. These include, real options analysis (Dobes 2008; Ranger et al. 2010), robust decision making (Lempert et al. 2003), iterative risk management (Haasnoot et al. 2011) and strategic planning approaches (Roggema 2009). One of these approaches, Dynamic Adaptive Pathways Planning (DAPP) (Haasnoot et al. 2013), has been used increasingly for implementing climate-resilient pathways for water management, of which the steps are shown in Fig. 12.7.
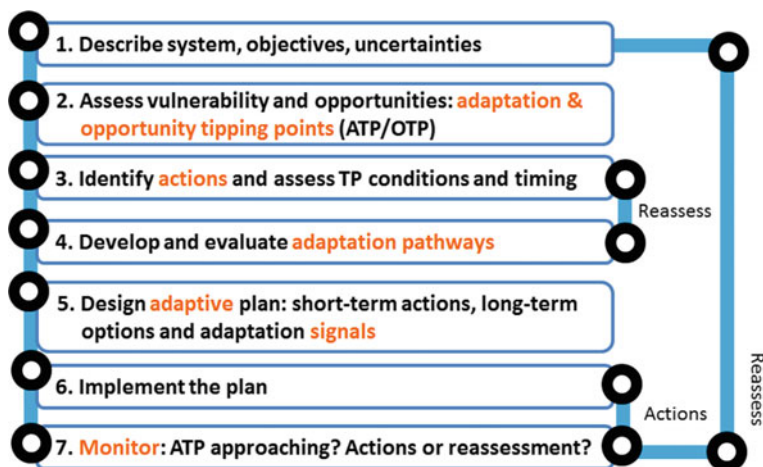
Fig. 12.7 Steps taken in Dynamic Adaptive Pathways Planning (DAPP)

Within the DAPP approach, a plan is conceptualised as a series of actions over time (pathways). The essence is the proactive planning for flexible adaptation over time, in response to how the future actually unfolds. The DAPP approach starts from the premise that policies/decisions have a design life and might fail as the operating conditions change (Kwadijk et al. 2010). A risk assessment can illuminate such adaptation tipping point conditions, as such they can be used to identify up to what changing conditions (e.g. sea level rise) a measure can reach a preferred risk level. Once actions fail, additional or other actions are needed to achieve objectives, and a series of pathways emerge; at predetermined trigger points the course can change while still achieving the objectives. By evaluating different pathways, considering path-dependency of actions and visualising them in a pathways map, an adaptive plan can be designed, that includes short-term actions and long-term options (see Fig. 12.8). Cost-benefit analysis (Sect. 12.3) can be used to evaluate pathways. The plan is monitored for signals that indicate when the next step of a pathway should be implemented or whether reassessment of the plan is needed. It is not only important to identify what to monitor but also how to analyse it. From a policy perspective it seems evident to select signposts that are related to norm or design values, since these are the values upon which the policies are evaluated. However, alternative indicators (i.e. average river flow in summer half year, instead of the 1:10 year return flow)—not necessarily policy related—can be used additionally to get timely and reliable signals for adaptation action. Different levels of assessment are possible to design pathways, from qualitative expert-based pathways to more comprehensive quantitative model-based pathways.
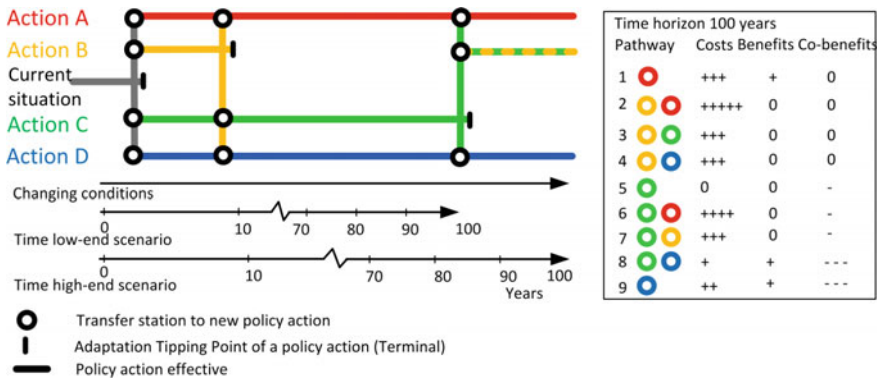
Fig. 12.8 Example of an adaptation pathways map and a scorecard presenting the costs and benefits of the nine alternative pathways presented in the map. An adaptive plan could exist of first implementing action C, monitor the changing condition, and switch to action D if the future unfolds according to the high-end scenario. Action B is potentially a lock-in or regret option, as already after 10 years other actions are needed. If this is the case depends on the amount of the investment compared in relation to the timing of the tipping points and therefore functional lifetime of the action. *Source* Adapted from Haasnoot et al. (2013)

In New Zealand, a combination of serious gaming and development of adaptation pathways were used in a local government flood risk management decision-setting (Box 12.5; Lawrence and Haasnoot 2017) (on gaming see also the chapter by Mechler et al. 2018b). The Sustainable Delta Game (Valkering et al. 2012; http://delta game.deltares.nl) helped participants learn about decision making under uncertain and changing conditions over time. The game has also been used to discuss climate and climate change uncertainty (Van Pelt et al. 2014). The aim of the exercise on the Dynamic Adaptive Pathways Planning (DAPP) approach was to upgrade the existing flood defence system to 1 in 440 years and maintain that level ('level of service' (LoS)) over at least 100 years. The discharge related to the 440 year standard increasing over time as a result of climate change, with a greater change in the higher emission scenarios. As a result, if the existing system is upgraded only to the current 440 year standard of 2300 cubic meter per second (comics), it will fail to provide the required LoS over 100 years and further actions will be required. The efficacy of five options were evaluated for their ability to maintain the protection level over 100 years, using three climate change scenarios, for meeting development/transport/recreation objectives, the effect of land use planning measures, and comparative costs of staged implementation of options. Each option consisted of a portfolio of measures, and for each portfolio the 'adaptation tipping point' conditions were assessed in terms of the

discharge it can accommodate. Three options were taken forward for further evaluation using the DAPP. The figure scorecard (Box 12.5) shows that Pathways 1, 3, 6, and 7 exhibit the best target effect. Option 4 starts to perform unacceptably (not reaching the 1:440 objective) after 40–50 years and thus requires a staged decision to move to Option 2C; Option 2C by itself reaches the target by 2095–2105, and only Option 1 will enable the target to be met going beyond 100 years. The approach of adaptation pathways has been adopted in the national coastal guidance. In Bangladesh, the adaptation pathways were used to develop an adaptive plan inspired by the adaptive delta management approach in the Netherlands. The plan should ensure

> long term water and food security, economic growth and environmental sustainability while effectively coping with natural disasters, climate change and other delta issues through robust, adaptive and integrated strategies, and equitable water governance (Bangladesh Delta Plan, in prep; www.bangladeshdeltaplan.org).

This aim illustrates an important difference in the application of adaptation pathways in the Netherlands and Bangladesh, despite the resemblance in terms of geographic, hydrological, physiographic and climatic vulnerability. While the Bangladesh Delta Plan focuses on *enabling* socio-economic development and food security, the Dutch Delta Plan is oriented at *protecting* the socio-economic system and increasing ecological value of the Dutch water system. In Bangladesh the focus is thus on investments for achieving development goals that should be robust or adaptive under uncertain changing conditions. The difference is also expressed in different criteria that are used to assess risk and evaluate pathways. In addition to flood risk, criteria such as poverty, health, and gender are considered in Bangladesh. Like in the Netherlands, the adaptive plan presents preferred strategies/pathways that exist of short-term (<2030), mid-term (2030–2050) and long-term (2050–2100) strategies. The short-term strategies aim to address present and near future needs and development targets to ensure food and water security in order to become a middle income country. The long-term strategies are based on two iconic end-points, envisioning a delta that is fixed and where water is controlled with dikes and pumps, or a delta that has still dynamics with nature-based solution and land use measures. The Bangladesh Delta Plan pathways are still under construction and need further elaboration to enable implementation. The Bangladesh Planning Commission (2017) published initial results. Regarding disaster risk management for the lower Kulna region, they describe a pathway that starts with construction of sea dykes that may reach acceptable risk levels up to 2050, and can then be combined with a storm surge barrier.

Box 12.5 Adaptation pathways developed for Hutt River City Centre Upgrade Project, New Zealand

The Hutt River City Centre Upgrade Project: the adaptation pathways map shows options, scenarios, decision moments, relative costs of options and potential side effects requiring consideration. Relative impacts are indicated with − and ++; − is negative impact and +positive impact. All pathways except pathway 5 have negative social impacts as land has to be purchased.

Option 1: A 90 m river channel and 50 m berm; right and left stopbanks meets the standard over 100 years in all scenarios; cost $267 m. Option 2C: A 90 m river channel 25 m berm; properties to be purchased; cost of $143 million. Option 4: 70 m river channel; 30 years of flood protection; lower level of protection (2300 cumecs); properties purchased after 20 years; cost $114 m until 2035. Staged option: Option 4 to Option2C will cost an additional $68 million; total cost $182 million.

Source Generated by the Pathways Generator (http://pathways.deltares.nl/) based on (Boffa Miskell Ltd 2015; Infometrics and PS Consulting 2015). *Source* Lawrence and Haasnoot (2017)

12.7   Synthesis

This chapter has discussed integrated approaches to the management of risks related to extreme weather and climate change in the context of Loss and Damage (L&D). We particularly focus on risks from extreme weather, which are expected to increase in frequency and intensity in many regions around the globe. We follow the definition of L&D as strategies that focus on the residual risks that remain after (cost-effective) adaptation strategies have been implemented. Integrated risk management implies that a holistic view is taken in interventions aimed at reducing hazard, vulnerability, and exposure to natural disasters. We discussed a variety of such strategies, like flood-protection aimed at preventing hazards, individual scale damage mitigation measures that reduce vulnerability of buildings to flood impacts which can be formalised in building code regulations, zoning policies that aim to limit (growth in) exposure of properties to natural hazards, and insurance for covering residual risk.

The main conclusions from this chapter can be summarised as follows:

- Risk assessment methods are an important first step in order to identify risk levels on a spatial scale. The mapping of areas with high hazard and risk can guide where risk management strategies may be needed. Estimation of future risk under scenarios of climate change provides insights into the needs for adaptation and L&D measures to limit possible residual risks, as we illustrated for Ho Chi Minh City.
- Cost-benefit analysis allows for a prioritisation of risk management interventions based on economic efficiency criteria. This method allows for identifying economically desirable risk management strategies and adaptation options. The expected reduced risk delivered by a strategy is an important benefit category and can be estimated using a probabilistic natural disaster risk assessment using a variety of scenarios, as our case study of flood risk in Ho Chi Minh City illustrated. Moreover, the case study for the Netherlands showed that a societal cost-benefit analysis can also include important intangible welfare effects, like the prevented loss of life and increased feelings of safety from flood protection. Moreover, multi-criteria analysis can be used for evaluations of risk management strategies with effects that are challenging to express in monetary terms.
- In addition to public natural disaster protection measures it is increasingly recognised that measures taken at the individual scale can be important complements in limiting the impacts of natural disasters. However, few empirical studies have examined the damage savings that these measures can achieve and their economic efficiency. Our case studies for Germany illustrated that in the case of flood, the implementation of household level measures have prevented significant amounts of damage during flood events. Several low-cost measures exist that are cost-effective in flood-prone regions. Moreover, our case study of poor communities in Mexico showed that several low cost-options are available for households to cope with frequent severe flood events, and how the implementation of such options is enhanced by community level actions, like raising risk awareness.

- Although adaptation to climate change will often result in net benefits, completely preventing the expected impacts of climate change on natural disaster risk may not be economically efficient. A residual risk remains to be addressed by L&D options, like financial compensation arrangements which can take the form of aid or a variety of forms of insurance (see also chapter by Linnerooth-Bayer et al. 2018).
- It should be realised that if financial compensation arrangements are part of L&D strategies they should be designed in a way that they stimulate and not hamper the implementation of adaptation measures. Few studies have examined relations between natural disaster insurance and policyholder risk reduction efforts. The studies we described for Germany and other countries show that potential disincentives (moral hazard) to reduce risk from insurance may be minor. Opportunities exist for linking insurance with incentives for risk reduction by rewarding policyholders who limit natural disaster risk with premium discounts and by linking insurance with building code and zoning regulations.
- Even though natural disaster risk assessments and cost-benefit analysis provide important tools for prioritising investments in natural disaster risk management, the uncertainty of climate change impacts complicates adaptation planning. Designing adaptation pathways with policymakers can deal with these uncertainties, as illustrated by the New Zealand case study. The Bangladesh case study shows that risk assessment can be linked to both vulnerability and adaptation pathways to changing conditions, but also to opportunities to enhance socio-economic development.

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