Introduction

The **Port of Rotterdam** is located in the mouth of the Rhine-Meuse Delta in the Netherlands (see **Figure 10.1**). The port's annual throughput amounts to some 450 million tonnes, which makes the Port of Rotterdam the largest port in Europe. Moreover, the port is one of the largest industrial and electricity hubs of Europe. Cargo finds its way to roughly 500 million consumers in Europe over water and over land. It is transported by trucks, trains, pipelines, inland vessels or sea-going vessels. Yearly, approximately 30,000 sea-going vessels and 110,000 inland vessels arrive in the Port of Rotterdam. The industrial cluster contains, amongst others, five oil refineries. The power plants in the port power a quarter of the industry and homes in the Netherlands. The total added value (direct and indirect) of the port is €22 billion, which is about 4% of the Dutch Gross National Income. Moreover, the strategic value of the port, as a logistic hub to the international business competitiveness of the Netherlands, is even 30% higher (Van den Bosch, 2011).

According to the Dutch national climate scenarios (KNMI, 2015; Klein Tank et al., 2009), it is expected that both the intensity and severity of natural hazards such as floods will increase. Severe economic damage can occur from long-term closures of the port and its industry (such events are considered low-probability, high-impact events). Moreover, economic developments and changes in the nature and size of businesses and industrial activities also affect the port's exposure to floods. This raises the question how the port remains safe with respect to flooding in the future.

The case study 'Port of Rotterdam' focuses on the strategic preparation to prevent or minimise economic losses and societal disruption resulting from floods. The ultimate goal is to reduce and/or mitigate flood risk by **strengthening or enhancing the current flood risk partnership** (Multi-Sector Partnership, MSP) involving the Municipality of Rotterdam and the Province of South-Holland.

The initial evaluation of the MSP shows that private sector companies are not fully aware of the flood risk in the Port of Rotterdam. In order to increase the flood awareness, the flood risk has been mapped in a quantitative manner, and has been communicated in workshops with stakeholders.

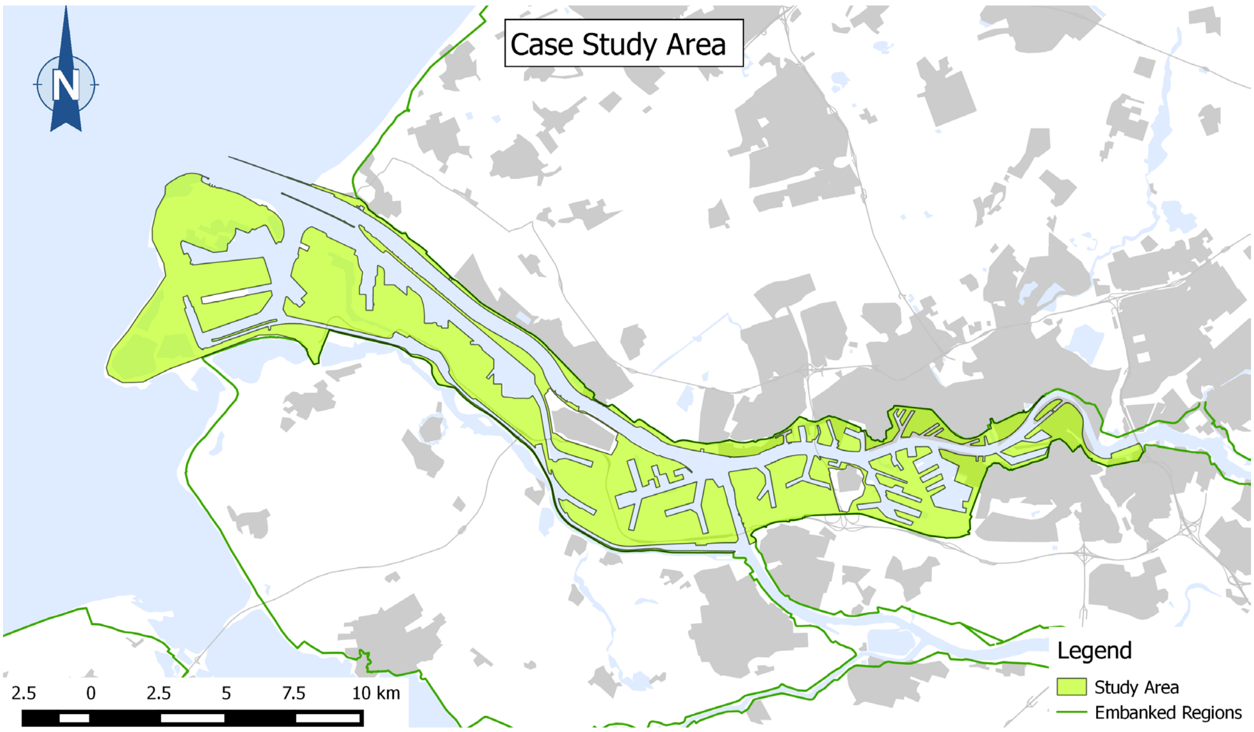
The following research steps have been taken in this joint fact-finding process:

- describe current MSP and responsibilities of partners;
- develop a modelling approach for assessing (direct and indirect) losses in the Port of Rotterdam;
- discuss risk assessment results with all relevant stakeholders;
- define acceptable risk levels for the pilot area;
- specify the next steps for a climate adaptation strategy for the pilot area;
- formulate policy and research recommendations.

This chapter summarises the results of this joint fact-finding process.

“Overall, floods caused more than €52 billion in insured economic losses, making floods the most costly hazard faced by Europe.”

Figure 10.1.
The Port of Rotterdam case study area.



Flood risk governance in the Port of Rotterdam

Most of the industrial areas within the Port of Rotterdam are **unembanked** (see **Figure 10.1**) and, due to its location near the North Sea, the port is potentially prone to storm surges and coastal flooding. To date, however, flood events have not caused any significant damage to the port. Most industrial areas are located on relatively high grounds and the port is considered safe against coastal floods. For most industrial areas, the flood probability is thought to be smaller than 1/1,000 per year, which is lower than the probability of flooding in most other large ports in the world.

The unembanked port areas are not incorporated in the national flood protection policy. Land owners and businesses located in these areas are responsible for their own flood protection. This underpins the importance of a good understanding of the flood risk they face.

The national government has delegated the 'flood risk governance' of unembanked areas to regional authorities. The Province of South-Holland and the Municipality of Rotterdam form the current Multi-Sector Partnership or Multi-Stakeholder Partnership. This MSP primarily aims to reduce the flood risk of new development projects on unembanked industrial areas in the Port of Rotterdam. Since 2011, a new policy framework for building in unembanked areas is enforced by the Province. The City of Rotterdam applies a Risk Assessment Tool in order to evaluate and assess different design alternatives within new land-use and zoning plans. Note that this Risk Assessment Tool has not been developed to assess the flood risk of existing developments. In other words, the policy does not apply to most port areas as the development in these areas date from before 2011. Moreover, the Risk Assessment Tool only takes into account two indicators (casualties and societal disruption), while the direct and indirect economic losses due to a storm surge flood can have a sizeable impact on the Gross National Product. Hence, the question is to what extent the current partnership reduces (economic) flood risk.

Although other parties, such as the ministry of infrastructure, the water boards and the private sector (businesses and industry), were involved in the development of the provincial policy and the risk assessment tool, none of these other stakeholders have any formal liability or responsibility concerning flood protection. Furthermore, they are not involved in the decision-making process.

Health of the current MSP

The **'capital approach'** (Chapter 1) is applied to evaluate the health of the current MSP. Although the municipality and province have to approve outer dike developments, they are not responsible or liable for possible consequences as a result of possible floods. The Port Authority, and especially the users (the private sector businesses), are not directly involved in the MSP.

Our assessment shows that **there is a lack of awareness, information and communication between stakeholders in the port region with regard to flood risk of unembanked areas**. Therefore, improving the available flood risk information, and improving insights in the consequences of a flood can, together with a sound communication strategy, make businesses more aware of flood risks in the Port of Rotterdam. This communication strategy should not only provide a clear overview of flood risk in the Port of Rotterdam, it should also pay attention to the business objective of the Port and the Port Authority. This requires a balance between providing information and evoking fear. Increased knowledge on the consequences of a flood in outer dike areas can be a tool to break the vicious circle between lack of awareness and insufficient communication. When risks are mapped, the information can be shared with stakeholders in the Port of Rotterdam to create a broader MSP.

One possible way to explore new partnerships and possible protection strategies is to organise workshops. Such workshops are primarily aimed to open the dialogue, improve communication, and build trust between the stakeholders. Once this is established, the MSP can focus on the preferred strategy for outer dike flood protection.

Enhancing the current MSP with private stakeholders leads to a more balanced decision-making process, and contributes to consensus and increased transparency. Furthermore, exchange of views can lead to a coherent and holistic flood protection strategy for outer dike areas in which involved parties know their responsibilities and are aware of the consequences of a flood.

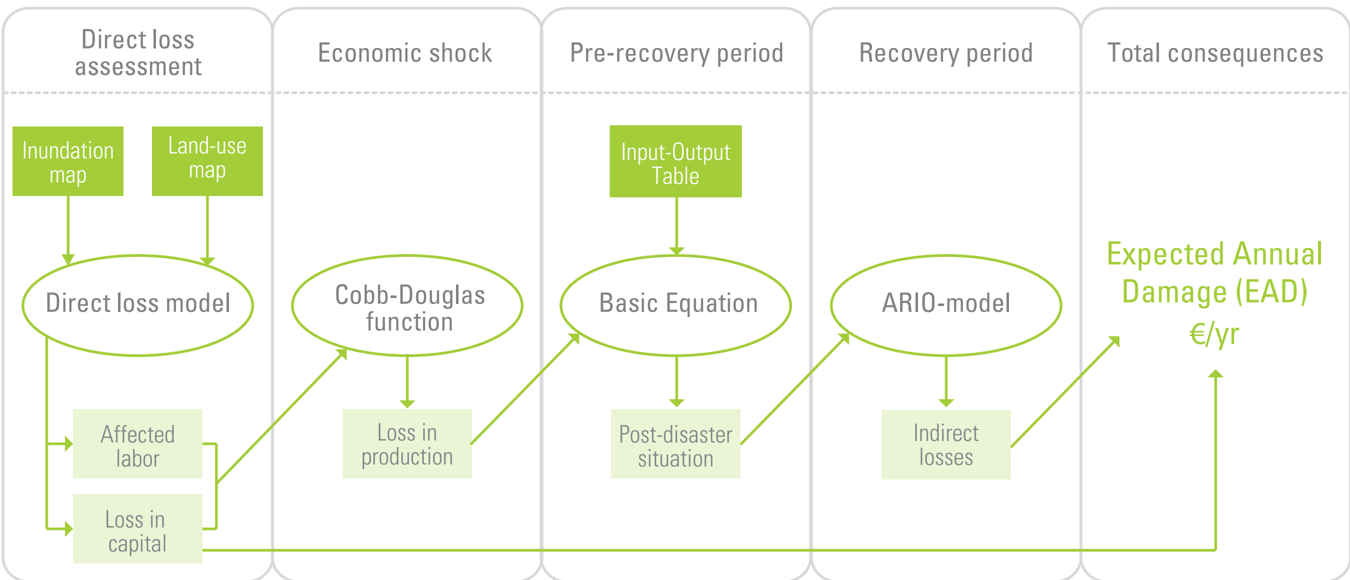
Photo by Katarzyna Wojtasik/Shutterstock.

A quantitative approach for flood risk assessment

To decrease the information deficit, the port's flood risk related to storm surges has been assessed in terms of direct and indirect economic losses, failure of infrastructure and societal disruption. The quantitative assessment is done for both low-probability and high-probability flood scenarios, now and in the future. A modelling framework has been set up that incorporates the flood vulnerability of businesses and industry in the exposed (unembanked) area. The following three indicators have been quantified:

1. direct economic losses (material damage)
2. indirect economic losses (losses due to business interruption)
3. societal disruption.

Figure 10.2.
Overview of the different components of the framework. The dark green boxes are the inputs, the ellipses are the different models and the light green boxes are the model outputs.



Direct losses

The first two indicators are expressed in terms of monetary values. Direct economic losses are also referred to as material damage, stock input losses or asset losses. Direct economic losses have been computed by a **depth-damage function approach** (See Chapter 2). Such depth-damage functions are used in conjunction with **inundation and exposure maps** (e.g. land-use or population maps) to assess the damage at any given point on the exposure maps, based on the depth in the inundation map (see **Figure 10.2**). Every class of land-use has a different maximum amount of potential damage per m^2, which represents the total value of the assets at stake. The different vulnerability curves relate the possible inundation depth on the x-axis to the corresponding damage factor (from 0 to 1) on the y-axis (see e.g. Koks et al., 2014).

Indirect economic losses

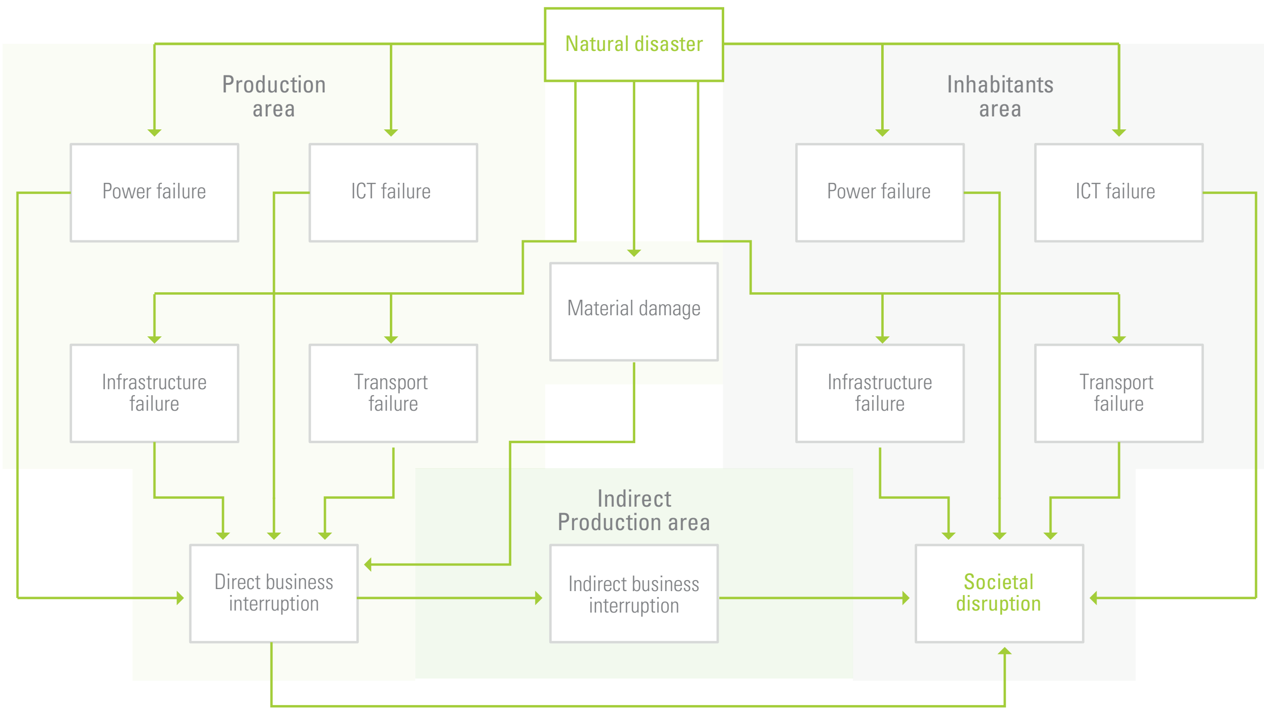
Indirect economic losses are the result of (temporary) business interruptions or a decrease in production capacity. These losses are the lost added value of firms inside and outside the flooded area. Numerous studies have developed approaches to model and estimate the consequences of flooding. A few studies have proposed a more integrative approach for the calculation of both direct and indirect flood damage. For instance, Jonkman et al. (2008) proposed an integrated framework for the combination of direct and indirect losses, and FEMA (2009) developed two modules within the HAZUS-FLOOD model to assess direct- and indirect losses in the United States. However, in our opinion, an integrative model with the capacity to dynamically incorporate various elements of flood damage assessment, such as the flood hazard, the direct damages and the total economic effects, is still lacking. In particular, existing models often fall short of systematic estimation of direct and indirect losses and the coupling between the two. In the ENHANCE project, we have attempted to close this gap. For the development of methodologies, the Port of Rotterdam is used as case-study area.

For the port of Rotterdam, two indirect modelling frameworks have been developed and applied: a single-regional and a multiregional model. The **single-regional model** is a dynamically integrated direct and indirect flood risk model. The framework consists of multiple steps and includes elements salient to integrative loss estimation. For the **multiregional modelling framework**, a new model is introduced that takes available production technologies into account, that includes both demand and supply-side effects, and that includes multiregional trade-offs via trade links between the regions. This model, further referred to as the MRIA (MultiRegional Impact Assessment) Model, is a dynamic recursive multiregional supply-use model in the tradition of input-output IO modelling combined with linear programming techniques (Koks & Thissen, 2014).

Societal disruption

Societal disruption has been defined as 'the extent to which people experience physical, social and emotional hindrance by failure of a function due to a flood'. To quantify this indicator **a novel integrated framework** has been developed (**Figure 10.3**). The framework takes into account societal disruption as a result of business interruption and failure of infrastructure functions (e.g. accessibility, electricity, etc.).

Figure 10.3.
Framework for societal disruption.

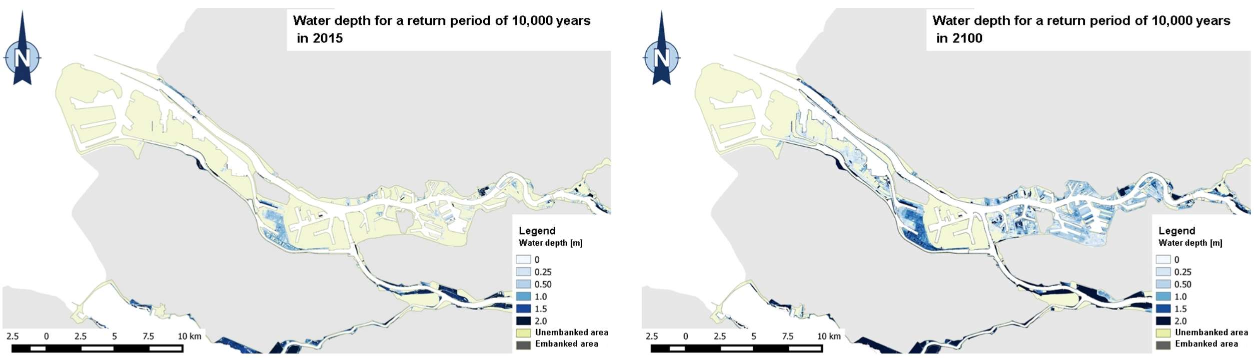


Flood risk assessment Port of Rotterdam

Using the modelling framework described in section 10.3, flood risk has been assessed for three climate scenarios (2015, 2050 and 2100) and six return periods (from 10 to 10,000 years). The **inundation maps** resulting from the flood scenarios are the main input of the quantitative assessment.

The maps in **Figure 10.4** show that the low-probability (1/10,000 per year) floods can lead to severe inundations in several areas covering the Europoort terminal (water depths up to 0.5 m), the docks in the city centre and the Waalhaven (water depths up to 1.0 m) and Botlek-West (water depths up to 1.5 m). In the climate scenarios 2050 and 2100 the probability of such flood depths increases to 1/3,000 and 1/1,000 per year, respectively. High-probability floods are usually limited to parks and river bank inundations in urban and industrial areas.

Figure 10.4.
Water depth of inundated areas Port of Rotterdam for a return period of 10,000 years in 2015 (top) and 2100 (bottom) (Source: Huizinga, 2010).



Direct flood losses significantly increase due to expected climate change (Table 10.1). A 1/10,000 per year flood yields a flood damage between €0.7 billion (now) and €6.8 billion (in 2100, assuming climate change). The flood risk in 2050 and 2100 is comparable to the flood risk in certain, highly protected, embanked areas in the Netherlands. The spatial pattern of the direct losses closely resembles the inundation patterns in Figure 10.4.

Table 10.1.
Direct flood damage (flood risk is expected annual damage).

Return Period [years]	*Direct flood losses (Billion Euros)*		
	2015	*2050*	*2100*
10	0.03	0.21	0.42
100	0.07	0.33	0.69
1,000	0.17	0.59	2.40
2,000	0.20	0.79	3.45
4,000	0.25	1.75	4.75
10,000	0.70	2.79	6.84
Flood risk (M€/year)	**5.84**	**29.5**	**66.6**

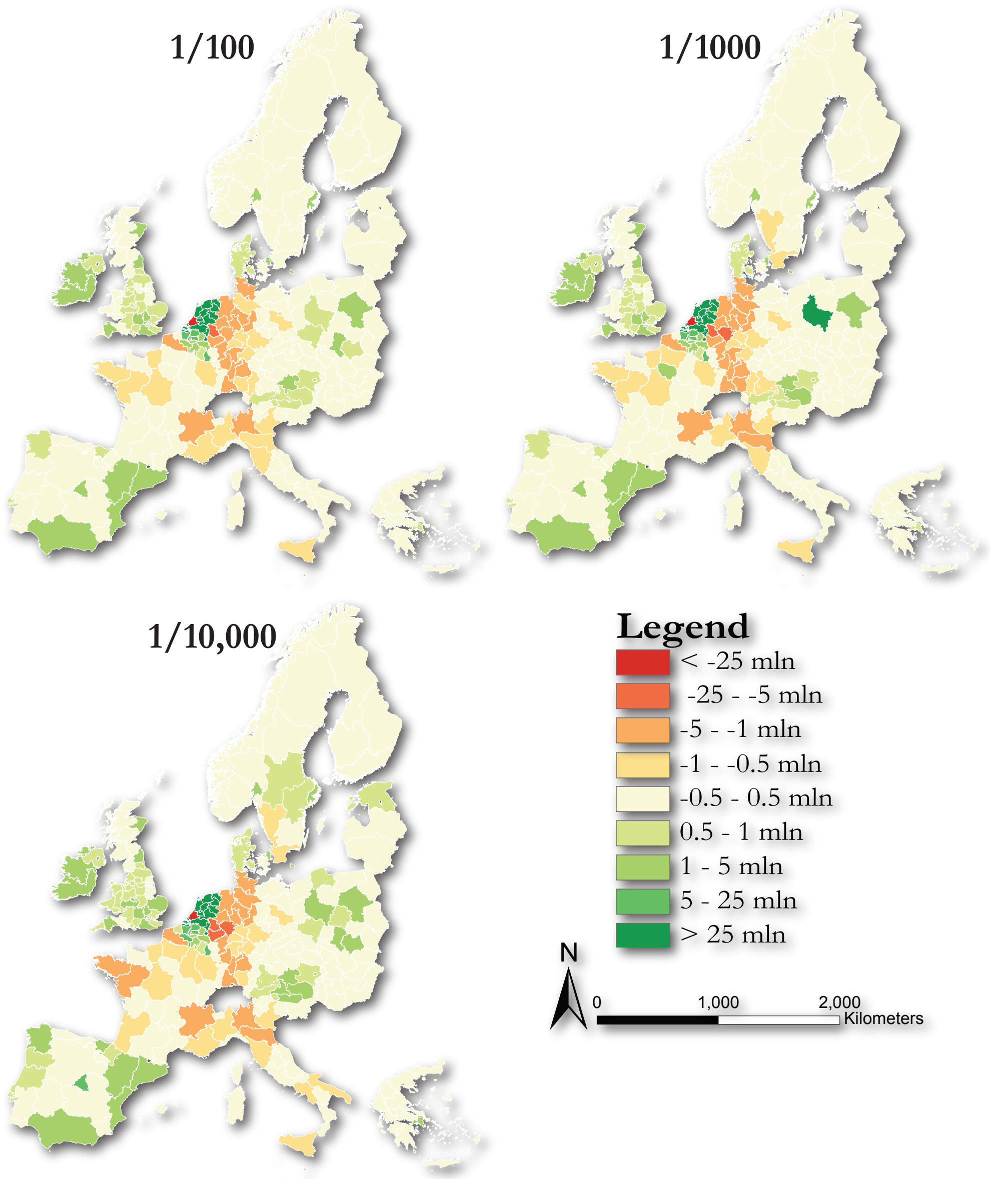
According to the single-regional model, the indirect losses can be substantial and have the same order of magnitude as the direct economic losses. Even though the flood duration is only a few days, the economic recovery to the pre-disaster situation may be several months or up to two years for low-probability floods. Uncertainty and sensitivity analyses show that the losses for a 1/10,000-year flood event range between about €1.1 and €7.3 billion. The model outcome appears sensitive to the large variety in parameter values. Yet, in the context of flood risk decision-making this factor of 7 is not alarming.

The indirect losses are rather robust to different assumptions, although some parameters appear to be of particular importance in this context. An interesting result is that the assumption on available stocks is critical for low-probability floods. A reduction of the available stock by 50% doubles the losses in 1/10,000 year floods. A reduction by more than 50% yields up to 10 times higher losses in such floods. On the other hand, a 100% increase of post-disaster inventories results in a relatively small (8%) decrease of the losses for a 1/10,000-year flood. These results suggest that there might be an optimum value of stock available. Maintaining an inventory to allow a certain degree of flexibility in the production chain is an important focus point for disaster management. It is important that businesses can maintain and quickly restore their inventories to speed up the recovery process.

Indirect losses on the European scale

The multiregional modelling approach shows that the cascading effects of a flood in Rotterdam may lead to substantial indirect losses and strong distributional effects between regions in the EU. The Rotterdam case in Figure 10.5 clearly shows that many regions outside the affected area are indirectly affected by the natural disaster. Some of the neighbouring regions benefit from the flood by increased reconstruction demand or by overtaking some of the production from the affected region. Results show that most of the neighbouring regions gain from the flood, due to increased demand for reconstruction and production capacity constraints in the affected region. Regions located further away or neighbouring regions that do not have a direct export link to the affected region mostly suffer small losses.

Figure 10.5.
Indirect effects per region in the European Union for floods in the region of Rotterdam.



Societal disruption

Application of the framework for societal disruption to the case study area shows that many people inside and outside the Port are affected by a flood. The impact of infrastructure failure (being transport over roads, rail and waterways) is especially high for high-probability flood events. The disruption due to business interruption lasts longer and is more prominent for low-probability floods. The societal disruption indicator appears to be rather robust for assumptions on the critical modelling assumptions and parameters: critical inundation factor, population size and water-borne transport failure.

Photo by strelka/Shutterstock.

Implications for flood risk management

The quantitative flood risk assessment (QRA) highlights the economic losses and societal disruption both inside and outside the port under various flooding scenarios. The expected annual direct losses amounted to about €5.8 million per year in 2015 and amount to up to €67 million per year in 2100. The expected annual losses due to business interruption are of the same order of magnitude. Moreover, the recovery period ranges from 3 months (return period 100 year) to two years (return period 10,000 years). The indicator 'societal disruption' also stresses that the port's downtime affects many people outside the flooded area.

What are the conclusions and implications of the QRA for the current MSP?

- Climate change adversely affects the port's flood risk. The consequences of potential floods are large in terms of economic losses and societal disruption. The Rotterdam port area is vital for the Dutch economy and society, and further discussion is needed to determine who should regulate the port's flood protection: the national or regional government, the industry, the Port Authority or all together?
- The speed of recovery of the economy is an important issue as well. How should the (national) government and the industry deal with the knowledge that the recovery may take months?
- Without adequate risk information, businesses in the Port cannot take adequate risk reduction measures.
- The case study application shows added value of an enhanced risk assessment, which also covers superregional effects in the case of critical infrastructure systems and highly interconnected industrial networks.

Extending the current MSP

The port's future flood risk is comparable to the flood risk in certain, highly protected, embanked areas in the Netherlands. The current risk governance solution, i.e. the provincial policy framework, is not an appropriate response to extreme floods in the future. Especially not for the existing developments. Although the notion of acceptable risk should be elaborated further for the Port of Rotterdam, it is clear that especially the indirect consequences of possible floods (business interruption, societal disruption, etc.) are large and undesired. Hence, the current MSP is not sufficient.

An enhanced partnership should recognise the role the Port of Rotterdam plays at the national level. Also, it should trigger cost re-allocation between the various levels of risk governance. .

The enhanced MSP should at least include:

- the national government as the Port is of strategic importance to the country;
- the Port Authority as main 'landlord' of the Port area;
- the Municipality of Rotterdam;
- business and industry in the Port area as driving force of the Dutch economy;
- the Province of South-Holland;
- other stakeholders with knowledge required to reduce or mitigate flood risk or responsibilities with regards to a safe environment: e.g. environmental agency DCMR, safety region, water boards, and utility companies.

Photo by polderfoto/Morguefile.

Pilot study: Botlek area

On the basis of the recommendations of the national Delta program on flood risk in unembanked areas, the national government started a 'pilot study Botlek' has been started in 2015. This pilot study aims to **develop a climate adaptation strategy for the Botlek area**.

The pilot study project group consists of the following main stakeholders: Port Authority Rotterdam, (executive body of) the Ministry of Infrastructure and the Environment, and the municipality of Rotterdam. The project consists of two phases. The goal of the first phase is to develop **a framework for mapping and assessing risk levels**, which is the basis for discussions with all stakeholders. The ENHANCE project team has fed this framework with quantitative risk information. The second phase, to be started later in 2016, deals with developing the **adaptation strategy**. Here we summarise the main findings of the first phase.

The Botlek area (see Figure 10.1) is an ideal study area for several reasons. The area is located a few kilometres to the west of the city of Rotterdam, and the oldest parts of the area are built approximately sixty years ago. Two major oil refineries and many chemical plants are situated in the Botlek area. Liquid bulk (chemical products and oil) is stored in many smaller and larger storage tanks. The highway A15 and a major cargo railway cross the area. The water system is somewhat complex. The west part of the Botlek area is connected directly with the North Sea. A small dike, which is not part of the primary water defences with specified safety standards, offers some protection to storm surges at sea. The east part of the Botlek area is located behind the Maeslant storm surge barrier and is located lower.

The pilot study started with a broad scope, the initial QRA, and converges to an adaptation strategy including the question of risk governance and responsibility (see Figure 10.6).

Figure 10.6.
Process to involve stakeholders in the Port of Rotterdam to develop a flood risk adaptation strategy.

Enhancing the MSP and societal resilience

The pilot study Botlek area provided the ENHANCE project team a great opportunity to apply and refine the risk methods with detailed information. The stakeholders are still discussing the Botlek-specific assessment. We therefore mention only the most important process steps and their impact on the stakeholder process.

Data on land-use, elevation, location of critical infrastructure objects, economic value and flood vulnerability of buildings, products and installations at (industrial) sites, economic value and vulnerability of infrastructure, and (inter)dependencies between companies have been collected. With these data, new Botlek-specific flood maps have been created and an **initial quantitative flood risk assessment (QRA)** for the Botlek area has been done.

The results have been discussed with the stakeholders in **four workshops**. Several local stakeholders indicated that they were not aware of the potential flood risk in the area. Over the course of the workshops, they gave feedback on several modelling assumptions, which resulted in substantial improvements of the modelling frameworks. For example, they argued that comparatively low water depths can lead to production stops and lengthy business interruption (up to 9 months for some industries). This led to an adjustment of some stage-damage functions and the duration parameters in the indirect loss modelling framework. Also, they estimated direct and indirect economic losses within their business site for several flood scenarios. The model output appeared to be of the same order of magnitude as the business estimates. The process converged to a refined QRA for the Botlek area in terms of four indicators: direct economic losses, indirect economic losses, societal disruption and casualty risk (loss of life).

At the same time, a **conceptual framework for assessing risk levels** has been developed. The ENHANCE project team has mapped quantitative risk information into this framework. The results were discussed with the stakeholders. Discussions on what the stakeholders think is acceptable for them (with respect to each indicator) are on-going. Different stakeholders have different responsibilities and preferences. For example, some businesses say their safety policy asks for preventive measures if a flood with probability of occurrence 1/1000 per year causes damage to installations on their site. Also, since the port areas are heavily industrialised, most stakeholders are much more focused on the indirect effects than on the direct effects of floods.

The joint fact-finding process in the pilot study has stimulated the communication between the stakeholders as well as the flood awareness. Until 2015, it was quite difficult to involve the stakeholders in the discussion on flood risk in the port area. The national authorities had delegated the 'flood risk governance' of unembanked areas to regional authorities, which had just developed a provincial policy framework for building development. The Port Authority, the land-lord of the port area, hesitated to communicate about flood risk with the businesses and industries, who were not really aware about this issue. Finally, in 2015 the research by the Dutch Delta program has initiated the pilot study. The timing could not have been better. From June 1, 2015, the EU enforced the SEVESO-III directive (2012/18/EU). Many businesses and industries in the port area have to show that they take into account flood risks in their safety plans to ensure that major accidents are adequately controlled. As most of the private stakeholders were not really aware of the flood risks in the port area, they were quite eager to join the workshops. In the beginning of the process they asked for information, later they also provided information to improve the QRA. This confirms that flood risk is a joint issue, which can only be tackled through cooperation and open communication.

The workshops in the pilot study Botlek have contributed to a higher flood awareness amongst the stakeholders and a better understanding of (future) flood risk in the area. The expected increase in flood risk and the vital importance of the Port of Rotterdam to The Netherlands ask for a joint response of the stakeholders: a climate adaptation strategy. This strategy will be the basis for further discussions on risk governance, responsibilities and risk financing.