Knowledge for Climate

Flood risk in unembanked areas

Part D Vulnerability of port infrastructure

KfC report number **KfC 022D/2010**

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Contents

Summary

Large parts of the port of Rotterdam are located outside the primary flood defence system. In order to reduce the frequency of flooding, port facilities and infrastructure are constructed at elevated terrains. The expected sea level rise associated with climate change could result in increase of flood risks. Flood risk is defined as the probability of flooding multiplied by the damage which occurs due to flooding. The impact of sea level rise on the vulnerability and actual risk of the unembanked areas has not been studied extensively and a good method to assess the actual flood risk of port infrastructure in these unembanked areas does not exist. The following questions have been addressed in this study: What is the vulnerability of port infrastructure in unembanked areas to flooding? How do we evaluate this vulnerability to flooding in comparison to other (flood) risks?

This study has been subdivided into two parts. In Part A, a qualitative assessment was made of the vulnerability of port infrastructure to flooding. Part B focuses more detail on the flood risk of chemical installations in unembanked areas.

Part A: Vulnerability of port infrastructure
In this part insight has been given in the characteristics of possible flooding of parts of the port of Rotterdam. A literature study on the vulnerability of port infrastructure has been conducted. Based on an inventory of port infrastructure and other land use categories and functions in port areas, a qualitative assessment was performed of the vulnerability of these functions. This was done by a group of experts from various backgrounds who gave a qualitative ranking of various effects, such as societal disruption, economic damage, loss of life and environmental pollution. The following conclusions can be drawn for this part of the study:

- The functions liquid Bulk and public & logistic infrastructure are most vulnerable to flooding. An important effect will be the societal disruption also outside the area itself.
- The port function of provision of goods to the hinterland is especially vulnerable to flooding
- The number of casualties, given a flood scenario with a depth of 1m, is expected to be small. Dozens of casualties are expected at most. This is due to:
  - Highly populated areas are generally not within immediate range of most of these facilities.
  - It is expected by most of the attendees that effective measures are taken within the process installations to prevent explosions or the release of hazardous goods in the normal design and procedures of process installations and storage facilities. In addition, if flooding is expected, plant operators can mitigate the risk by measures to reduce the vulnerability of the plant.
  - The frequency of flooding for most of the port area is very small
- The category public logistic infrastructure is vulnerable to flooding because
  - Power failure affects many other processes
  - ICT is very important for other functions such as crisis management during floods
  - Roads, tunnels and pipe lines provide transport of people and goods. This is severely interrupted during floods.
- It was found that given the complexity and interrelatedness of numerous functions in the port area a site and scenario specific assessment of the risks would be preferable.

Part B: Vulnerability and flood risk assessment for chemical installations
This part of the study concerned an assessment of the flood risk of chemical installations in unembanked areas.

The following steps were made:

Step 1. Flood risk assessment of chemical installation
The frequency and the potential consequences of flooding of a chemical plant are estimated in this first step. This study presents a method to perform a quantitative flood risk assessment. This method has been developed for this study, as no general applied method exists to date. As no detailed risk assessment could be made within this study a hypothetical case study has been used to quantify the

flood risk. This case study is mainly representative for chemical installations on newly developed port areas with a relatively high elevation (NAP + 5.50m or higher).

Step 2. Risk evaluation in various frameworks
The flood risk of a chemical installation as defined in step 1 is discussed and evaluated in the context of flood standards in the Netherlands. In addition, the flood risk has been compared to external safety standards and risk evaluation procedures from the chemical industry. These different risk evaluation frameworks are than set next to each other and conclusions are drawn.

Step 3. Discussion of results and follow-up activities
Part B was concluded with a workshop. Findings of the risk analysis have been presented in the meeting as well as the different risk evaluation frameworks, both for chemical plants and for flood risk assessments of embanked areas. During the workshop, a range of people involved in flood risk management and external safety discussed the outcomes and possible applications of this study and recommendations for further research.

The following conclusions are drawn from the case study as presented in this study. This case study was formulated for newly built areas in the port of Rotterdam. The conclusions below are therefore applicable to these areas,

- The number of immediate casualties as a consequence of flooding of a single installation as presented in the case study is not likely to increase due to flooding. This means that the number of offsite casualties for a worst case release scenario is expected to be limited to nil.
- Following the reasoning during the case study, the non-lethal health effects of the worst-case scenario including flooding are worse than the health effects without flooding: the toxic material can be distributed by water to distant locations. This is fundamentally different from a situation in which the hazardous goods are contained on the dry soil in a situation without flooding.
- In general, it is expected that for unembanked, sufficiently high elevated areas (> NAP + 5.5 m), the additional risk of flooding of chemical facilities is relatively small compared to the day-to-day risks of the industry. This is due to the fact that the frequency of flooding and consequent hazard frequency is relatively small, due to the elevated terrain heights.
- The (additional) risks are small compared to risks of flooding of embanked areas, such as South Holland, and are expected to be acceptable within the limits of external safety policy in the Netherlands and the risk evaluation framework used by chemical companies.

The above findings are based on the hypothetical case study, which is realistic for the Rotterdam situation for new port areas. However, given the limitations of this approach a number of recommendations has been given below. These are based on the desk study and the discussions during the closing workshop.

Recommendations regarding the application of the risk methodology:

- During a high water or storm surge a large part of the port of Rotterdam could be flooded and multiple facilities are affected simultaneously. In this study, the risk for a single (hypothetical) facility has been assessed and an assessment of the cumulated risk for multiple installations is recommended. The concentration of chemical companies in the unembanked areas is high.
- The case study referred to one hypothetical type of scenario and facility. Other substances and facilities could lead to different scenarios and risks, which could in some cases be more severe. Therefore it is needed to consider the additional risks of flooding of chemical installations on a case-by-case basis. Preferably, companies should play a major part in this because they have the best information.
- It is interesting to present an overview of risks in the port area of Rotterdam. This can be done by defining hotspots in terms of risk for various areas. These hotspot regions will be those areas that are close to urban areas and include hazardous installations. The information provided on www.risicokaart.nl could be a good starting point.
- For this study, newly developed areas have been taken into account in the risk assessment and evaluation, using flood depths representative for the new port development Maasvlakte 2. It is recommended to perform a similar risk analysis to existing areas more land inwards. These areas will have different (sometimes lower) terrain elevations than the situation studied here.
- In this study, the main focus was on casualties and societal disruption. The effects to the environment were studied in less detail. Given the fact that the case study indicates that

significant environmental damage is expected during a flood event, more research in this field is recommended.

Recommendations regarding risk evaluation and policy development

- At this moment, it is not fully clear how responsibilities are defined in flood risk management of chemical installations in unembanked areas. Is it a public task of the Province of Zuid Holland as part of the flood risk policy for unembanked areas (or the municipality of Rotterdam or national government)? Or do flood risks have to be included in external safety regulations in these specific cases? It is recommended to explore these questions in more detail with relevant stakeholders.

General closing remark

As could be concluded from the above points and the discussions during the workshop, there are many questions and issues that require further attention and knowledge. An important remark during the workshop was made that this project and the workshops can be seen as a first step in the development of this relevant knowledge and policy field. The combination of knowledge from different fields (external safety, flood risk management) and backgrounds (policy and experts) is what is needed in that process. The professionals that have participated in the workshops and this project will form an important network in this respect. Hopefully initiatives will develop in the nearby future which will continue down this road. This can be the government by means of the Province of Zuid-Holland, but also the chemical industry. One conclusion was that the knowledge from this study should be consolidated and made available to different parties. The information, knowledge and experience developed for this study could also be very relevant for the development of the policy of the Province of South Holland for managing the risks of unembanked areas.

Samenvatting

Grote delen van de Rotterdamse haven bevinden zich buiten de primaire waterkering, en liggen dus buitendijks. Deze gebieden liggen op verhoogde terreinen, zodat deze een lage kans van overstromen hebben. Echter, door klimaatverandering zal de zeespiegel rijzen, en zal de kans van overstromen en daarmee het overstromingsrisico van deze gebieden ook toenemen. Hierbij is het overstromingsrisico de kans van overstromen maal de schade die zal optreden door een overstroming. Een methode om het overstromingsrisico van de Rotterdamse haveninfrastructuur in buitendijkse gebieden te bepalen is echter niet voorhanden. Daarnaast is het effect van zeespiegelrijzing op het overstromingsrisico van buitendijkse havengebieden niet eerder bepaald. De volgende vragen zijn daarom in deze studie behandeld: wat is de kwetsbaarheid van de haveninfrastructuur voor overstromen? En hoe moeten we deze overstromingsrisico’s beoordelen in het licht van andere (overstromings) risico’s?

Deze studie is opgedeeld in 2 delen. Deel A geeft een kwalitatieve beoordeling van de kwetsbaarheid van overstromen van buitendijkse haveninfrastructuur. Deel B gaat meer in detail in op het overstromingsrisico van buitendijkse, chemische, installaties.

Deel A: Kwetsbaarheid haveninfrastructuur voor overstroming

Deel A geeft inzicht in de omstandigheden die zich voor doen tijdens een overstroming van delen van de haven van Rotterdam. Een literatuurstudie is gebruikt als vertrekpunt voor dit inzicht. Vervolgens is, na een inventarisatie van haveninfrastructuur in Rotterdam, een kwalitatieve beoordeling gemaakt van de kwetsbaarheid van de verschillende havenfuncties. Deze beoordeling is uitgevoerd in een bijeenkomst van experts uit verschillende kennisvelden. Hierbij is gekeken naar de gevolgen van overstroming in termen van maatschappelijke ontwrichting, economische schade, slachtoffers en milieuschade. De volgende conclusies zijn getrokken bij deze beoordeling:

- De functies natte bulk en publieke, logistieke infrastructuur zijn het meest kwetsbaar voor overstroming. Dit is het gevolg van maatschappelijke ontwrichting die plaats kan vinden bij uitvallen van deze functies.
- De voorzieningsfunctie van de haven voor het achterland is hierbij kwetsbaar voor overstroming.
- Het aantal slachtoffers, gegeven een hypothetische overstroming van 1m op de haventerreinen, is uiterst gering. Ten hoogste enkele tientallen slachtoffers worden verwacht in een extreme overstromingssituatie. Dit komt vooral omdat:
    - Het aantal omwonenden in het gebied over het algemeen niet erg groot is .
    - Bedrijven hebben al de benodigde procedures en beveiligingsmechanismen die het gevaar voor ontploffingen of het vrijkomen van gevaarlijke stoffen tot een minimum hebben gereduceerd. Tijdens een zeer extreme storm zullen in aanvulling hierop de benodigde aanvullende procedures in werking worden gesteld.
    - De kans van overstroming met enige waterdiepte zeer klein is voor buitendijkse gebieden.
- De categorie publieke logistieke infrastructuur is kwetsbaar voor overstroming omdat:
    - Elektriciteitsuitval grote impact heeft op andere processen en functies
    - ICT zeer belangrijk is voor andere functies zoals crisisbeheersing tijdens een extreme storm situatie
    - Wegen, tunnels en pijleidingen tijdens een overstroming niet gebruikt zouden kunnen worden, wat grote invloed heeft op vervoer van personen en goederen.
- Door de complexiteit van de wederzijdse betrekking van de verschillende functies is het wenselijk om voor het havengebied een locatiespecifieke analyse te maken voor verschillende scenario’s.

Deel B: Kwetsbaarheid en overstromingsrisicobeoordeling voor een buitendijkse chemische installatie

Deel B van de studie is gericht op het beoordelen van het overstromingsrisico van een chemische installatie in buitendijkse gebieden.

De volgende stappen zijn hiervoor gemaakt:

Stap 1. Overstromingsrisico beoordeling chemische installatie
De overstromingskans en de mogelijke gevolgen van een overstroming van een buitendijkse chemische installatie zijn in beeld gebracht. Hierbij is een kwantitatieve aanpak gevolgd. Een hypothetische case studie is gebruikt, voor een buitendijks gebied op NAP + 5.5m of hoger.

Stap 2. Risico evaluatie in vergelijking met verschillende risico beoordelingskaders

Het overstromingsrisico bepaald in stap 1 wordt vergeleken met de normen zoals deze bestaan in Nederland voor overstroming van binnendijkse gebieden. Daarnaast is het overstromingsrisico zoals bepaald in de case study vergeleken met externe veiligheidsnormen en normering uit de chemische industrie.

Stap 3. Discussie resultaten en aanbevelingen

In een workshop zijn de resultaten van stap 1 en stap 2 gepresenteerd en vervolgens besproken. De toepassing van deze resultaten en aanknopingspunten voor vervolgonderzoek zijn vervolgens bepaald.

De volgende conclusies zijn getrokken op basis van de case studie van een chemische installatie op nieuw te ontwikkelen haventerreinen in de Rotterdamse haven:

- Het aantal directe slachtoffers door overstroming van een installatie zal niet toenemen. In een worstcase scenario tijdens een overstroming zal ook het aantal offside slachtoffers nihil zijn
- Wel zullen de gezondheidseffecten in een worstcase scenario toenemen als men een situatie met overstroming vergelijkt met een situatie zonder overstroming. Door het afstromende water kunnen gevaarlijke stoffen over een groot gebied worden verspreid.
- In het algemeen kan men concluderen dat het additionele risico door overstroming van een chemische installatie in buitendijksgebied klein is ten opzichte van de dagelijkse risico's van een dergelijke installatie. Door de hoge ligging van de gebieden (> 5.5 m NAP) zal de kans van overstromen en het hieruit voortvloeiende gevaar klein zijn.
- Het bepaalde risico is klein in vergelijking met bestaande normering voor buitendijkse gebieden. Daarnaast zal het risico voor chemische installaties door overstroming binnen de externe veiligheidsnormering liggen.

De conclusies uit deze studie zijn bepaald voor een hypothetische case studie met realistische uitgangspunten. Echter, gezien de randvoorwaarden en de beperkingen van deze aanpak zijn de volgende aanbevelingen gedaan:

Aanbevelingen met betrekking tot de toepassing van de risicomethode uit deze studie
- Tijdens een zeer extreme hoogwatersituatie zal een groot deel van de haven van Rotterdam onder water staan. In deze studie is naar een enkele installatie gekeken. Het wordt aanbevolen om onderzoek te doen naar de cumulatie van risico van meerdere installaties die onder water zullen staan.
- De case studie is uitgevoerd voor één type installatie en één scenario. Andere installaties kunnen een ander risico met zich meebrengen, eventueel voor andere scenario's dan in deze studie meegenomen. Het wordt aanbevolen om de risicobepaling daarom te baseren op basis van een case-to-case basis. Het zou wenselijk zijn dat private partijen in deze risicobepaling een rol spelen.
- Het zou interessant zijn om een overzicht te geven van het risico op overstroming van het hele Rotterdamse havengebied. Dit kan bijvoorbeeld gedaan worden, door te kijken naar kritieke locaties, of hot spots, in de Rotterdamse haven. De informatie op www.risicokaart.nl kan hiervoor als uitgangspunt dienen

- In deze studie zijn overstromingskarakteristieken gebruikt voor een hoog terrein, representatief voor nieuwe haventerreinen. Aanbevolen wordt om deze analyse ook te maken voor bestaande terreinen met mogelijkerwijs hogere overstromingsfrequenties.
- In deze studie is met name gekeken naar het risico op slachtoffers en op maatschappelijke ontwrichting. De risico's op milieuschade zijn minder goed in beeld gebracht. Gegeven de conclusie dat door overstroming grote milieuschade zou kunnen ontstaan wordt aanbevolen hier meer onderzoek naar te doen.

Aanbeveling risico beoordeling en beleidsontwikkeling

- Het is op dit moment niet geheel duidelijk waar de verantwoordelijkheden met betrekking tot overstromingsrisico's in buitendijkse, chemische, industrie liggen. Is dit een publieke taak van de provincie Zuid-Holland als onderdeel van het nieuwe beleid met betrekking tot overstromingsrisico's van buitendijkse gebieden? Of voor de Gemeente Rotterdam of Rijksoverheid? Of is het risico op overstroming en de gevolgen hiervan een onderwerp dat meegenomen moet worden in de externe veiligheidsnormering geldend voor de industrie in deze specifieke gebieden? Het wordt aanbevolen op deze vragen op te pakken met de verschillende relevante partijen betrokken bij deze problematiek.

Algemene slotopmerking

Uit zowel de conclusies en aanbevelingen als uit de discussie die gevoerd is in een afsluitende bijeenkomst, kan geconcludeerd worden dat er nog veel vragen en kwesties zijn die nadere aandacht verdienen. Tijden de bijeenkomst is een belangrijke opmerking gemaakt die algemeen gedragen werd: dit project en de bijeenkomsten kan gezien worden als een eerste stap in de verdere ontwikkeling van kennis en beleid over overstromingsrisico's van de industrie in buitendijkse gebieden. Kennis en expertise uit verschillende kennisvelden en vanuit verschillende achtergronden is hiervoor nodig, zowel technisch inhoudelijk als beleidsmatig. De professionals die tijdens de bijeenkomsten aanwezig waren kunnen een belangrijk netwerk vormen. Hopelijk zullen er dan ook op korte termijn initiatieven ontplooid worden om de juiste stappen in deze richting te zetten. Dit kan gedaan worden door de Provincie Zuid-Holland, maar ook vanuit de private sector. Een belangrijke conclusie was daarom ook dat de kennis en inzichten zoals ontwikkeld in deze studie moet worden verspreid onder de verschillende partijen. Dit zou relevante informatie kunnen zijn voor de verdere beleidsontwikkeling voor buitendijkse gebieden in Zuid-Holland.

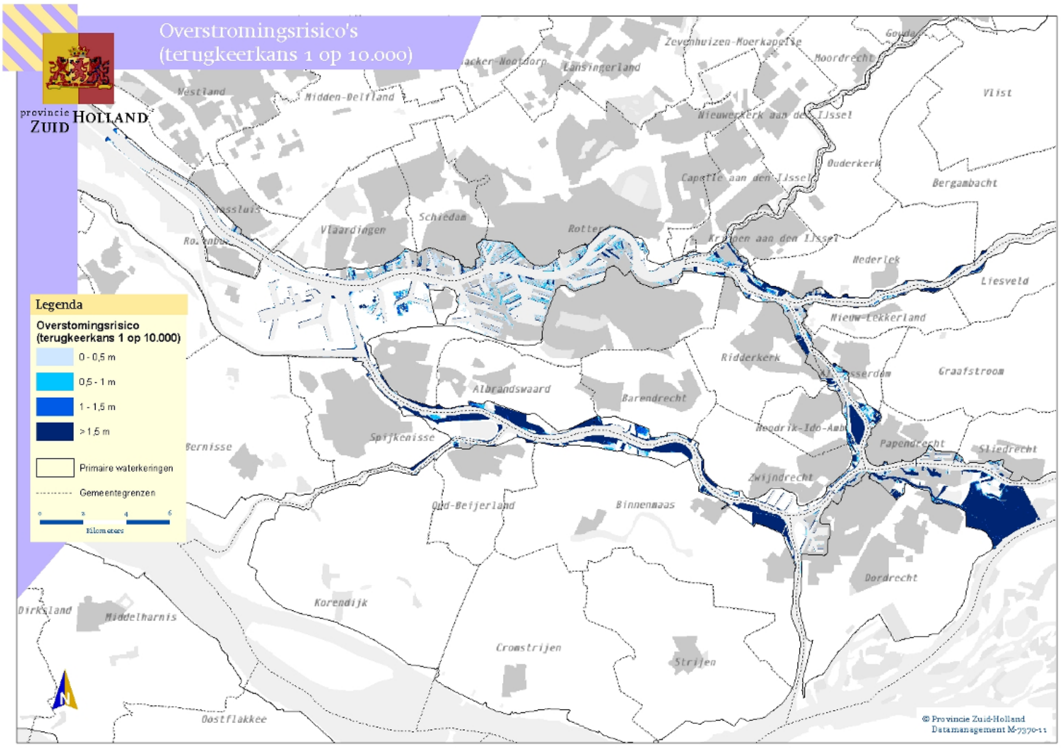
1 INTRODUCTION

1.1 Project background

This report presents the findings of a study into the vulnerability to flooding of port infrastructure in areas not defended by a primary flood defence. This study is part of the project “Flood safety in unembanked areas” (HSRR02) and has been defined under the umbrella of the innovation project “Kennis voor Klimaat” (English: Knowledge for Climate), hotspot Rotterdam region. The Knowledge for Climate project has been commissioned to develop further knowledge into the effects of climate change in the Netherlands.

Rotterdam is the largest port in Europe. The port has developed over the past centuries on the riverbanks of the Meuse Rhine estuary. As a result of this, large parts of the port of Rotterdam are located outside the primary flood defence system. In contrary, most of the urban built-up areas of Rotterdam are located behind a dyke system. Not being protected by a primary flood defence system, results in flooding of the river banks during storm high water levels. In order to reduce the frequency of flooding, especially vulnerable areas (such as chemical plants) have been constructed at elevated terrains. The ground elevation has been increased such that the flood frequency is reduced significantly. A good example is the new Maasvlakte 2 reclamation: for this area a ground elevation of NAP + 5.0 m is used.

Figure 1.1 Overview of flood depth in the city of Rotterdam for a 1/10000 year frequency.



Climate change will likely result in sea level rise and hence flood levels will increase as well. The risk of flooding will therefore also increase as result of an increase in water levels. Risk is defined as the probability of flooding, multiplied by the damage incurred if flooding occurs. The impact of sea level rise on the vulnerability and actual risk of the unembanked areas has not been studied extensively and a good method to assess the actual flood risk of port infrastructure in these unembanked areas does not exist.

Recently, the Province of Zuid Holland has issued a policy document giving an approach for flood safety assessment of unembanked areas[1], “Buitendijkse ontwikkelingen benedenstrooms Zuid-

[1] (see http://www.zuid-holland.nl/overzicht_alle_themas/water/c_waterveiligheid/buitendijkse_ontwikkelingen.htm)

Holland Province of Zuid Holland". In this document, the focus is primarily on urbanized areas in Zuid Holland. Knowledge on the flood risk of the port area is still lacking.

The consequence of flooding of port infrastructure has become apparent in the Hurricane Katrina flooding event in New Orleans during the 2005 Hurricane season. Several industrial facilities flooded, causing spills and releases of industrial goods. Although mistakes were made in the crisis management during the hurricane, both prior and during the hurricane event, the consequences of flooding of industrial site became clear. The spills of a flood event cause environmental damage, economic damage and cause a lot of nuisance and societal disruption to the surrounding areas after the event.

Figure 1.2 Oil spills from storage tanks caused environmental damage and nuisance after Hurricane Katrina hit New Orleans

The Province of Zuid Holland policy document is mainly aimed at the civil infrastructure and urban areas of Rotterdam, whereas many areas in the Port of Rotterdam are occupied by industrial installations and infrastructure.

Figure 1.3 Ground level elavation of the Port of Rotterdam area (source: DHV)

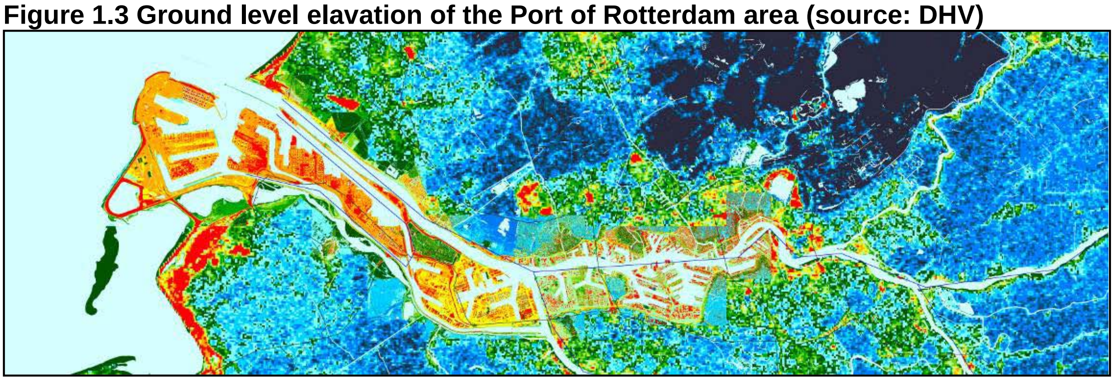
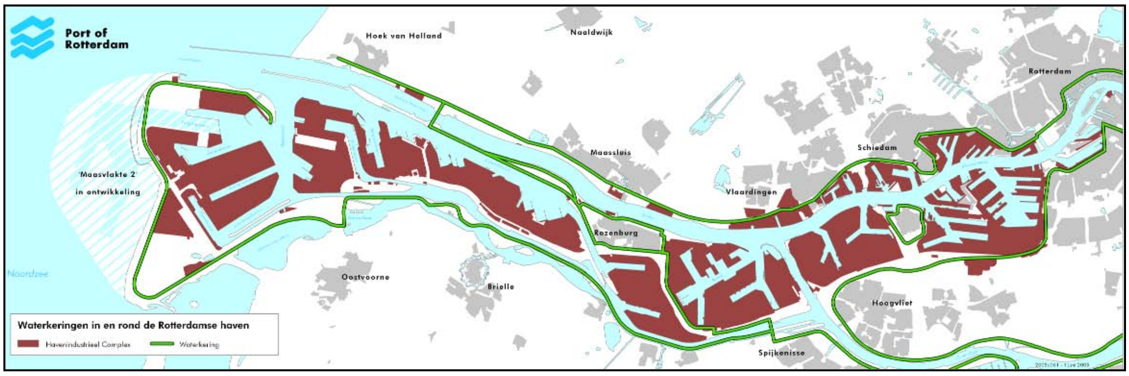


Figure 1.4 Overview of port infrastructure in combination with the outline of the primary flood defence



1.2 Project Organisation

This project was carried out by Royal Haskoning in close cooperation with the Port Authority of Rotterdam, the Municipality of Rotterdam, HKV Lijn in Water, Deltares and IHE UNESCO. During 2 workshops, information gathered and compiled by experts of Royal Haskoning has been discussed with several experts. Doing so, as much information and consensus was anticipated for. A list of attendees and setup of the workshops is given in the appendices. Results and findings of the workshop have been integrated in this report.

1.3 Project objectives and scope

Following the background as mentioned in the sections above the project objectives are defined as follows:

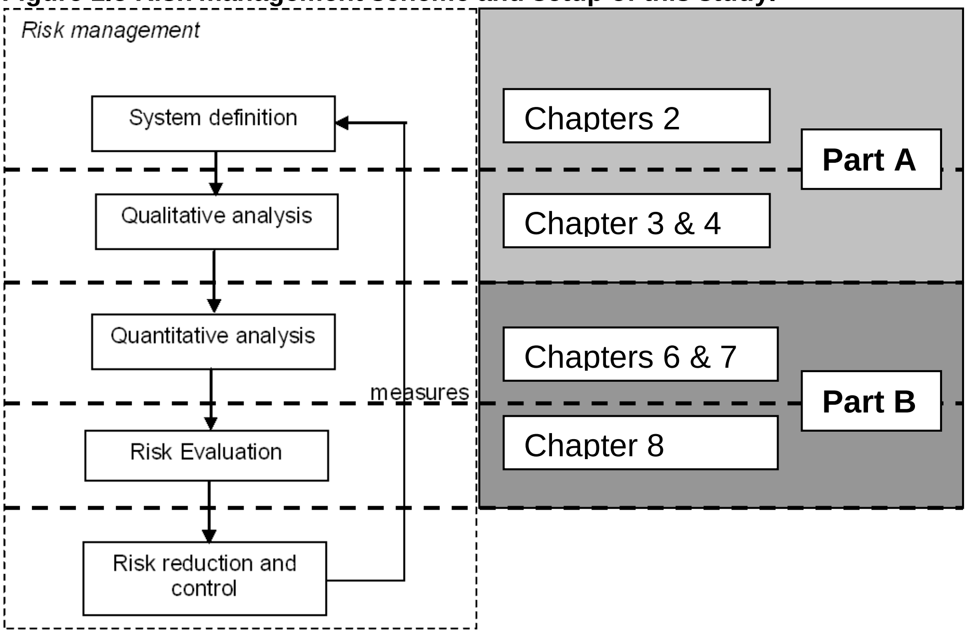
- What is the vulnerability of port infrastructure in unembanked areas to flooding?
- How do we evaluate this vulnerability to flooding in comparison to other (flood) risks?

This research study estimates the vulnerability to flooding of port infrastructure in unembanked areas. Vulnerability is defined as the probability of an object causing considerable consequences and damage due to a flood event. In this vulnerability assessment, the probability of consequential casualties or consequential societal disruption due to flooding is of concern. The vulnerability assessment is made by presenting a risk analysis method applicable to port infrastructure in unembanked areas. The vulnerability methodology is compared to other risk assessments which exist for port infrastructure and industrial sites as well as a safety risk assessment which is applicable to areas which are defended by a primary flood defence. The study is made non-site specific, hence detailed reference to the actual situation in the Port of Rotterdam including existing installations or terrain elevations is not made. The risk assessment is made for industrial developments in newly built port areas, i.e. Maasvlakte 2. Information of existing industrial sites is not taken into account.

1.4 Approach and Report outline

To meet the project objectives, this research has been set up using a general approach in Risk Management, see below (Jonkman 2007).

Figure 1.5 Risk management scheme and setup of this study.



Starting point of this study is an inventory of a very broad range of infrastructure located in port areas as well as a description of circumstances under which flooding occurs (**systems definition**). Secondly, the vulnerability is assessed in a **qualitative** manner further in Part A. Part B will than focus on a case study of a risk assessment of an industrial installation typically found in port areas. Doing so, a **quantitative** method is used to take into account the flood risk in these unembanked areas. This will be concluded by a comparison if this method with other (flood) safety assessments, a risk **evaluation**. The study is concluded by a number of recommendations and considerations for follow up.

Note that no study has been made to risk reduction and control measures. During execution of this study it became clear that given the present state of knowledge with respect to the flood risk of port infrastructure, it can not be concluded whether risk reduction measures and control are necessary. Next to this, these measures will have to be made very case specific and it would therefore be very difficult to develop any general conclusions following from this general study.

Part A is outlined by starting with insight into the flood characteristics during which potential risk occurs, to set the conditions to which a vulnerability assessment will be made (Chapter 2). This is followed by a literature study of relevant documents. After an inventory of port infrastructure and other objects in harbour areas, a qualitative assessment performed by a group of experts is presented (Chapter 3). Finally, results are discussed and conclusions are provided which will be used in Phase B.

Part B continues into more detail by defining the flood risk of chemical installations in unembanked areas. For this, a methodology is presented in Chapter 6. In the method, information and approaches from flood risk and chemical risk assessment are combined. Results of realistic but hypothetical case study are presented in Chapter 7. The results of the assessment of the flood risk of a chemical installation will be evaluated and discussed in the context of existing risk frameworks (Chapter 8). This is concluded by a general discussion and conclusion on the approach and results, followed by defining follow-up activities (Chapters 9 and 10)

PART A VULNERABILITY ASSESSMENT OF PORT INFRASTRUCTURE IN UNEMBANKED AREAS

2 FLOODING OF UNEMBANKED AREAS, INTRODUCTION AND LITERATURE STUDY

2.1 Introduction

This Chapter provides an introduction to flooding of unembanked areas. An overview of existing literature with respect to this subject is given. Following this, an overview of flood characteristics is given in order to:

- give insight into the circumstances for which a flood risk assessment in unembanked areas is made.
- clarify the differences between flooding of embanked areas and unembanked areas. This will be important later in the risk evaluation (Chapter 8).

2.1 Overview of existing literature

As starting point of this study, a literature study was performed in order to:

- Give the present day knowledge with respect to vulnerability assessments of port infrastructure (in unembanked areas). Also appreciation of the relevant policy documents for this study is provided.
- Gather information for estimating the flood risk of port infrastructure in Phase B.
- Use information at hand for input in the workshop of Phase A in which an overall vulnerability assessment is made of port infrastructure.

For this study, mostly the following relevant literature has been reviewed.

- Province of Zuid Holland (2008) “Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland”
- HKV en Arcadis (2009) “Risicomethode buitendijks: Methodiek ter bepaling van risico’s als gevolg van hoogwater”.
- Pimontel (2005) “Economische Schade ten gevolge van Overstroming“.
- Delft Cluster (2003) “Consequences of Flooding: .
- Port of Rotterdam (2005) “Veiligheid tegen overstroming Maasvlakte 2”.
- TNO (2003) “Bescherming Vitale Infrastructuur: Quick-scan naar vitale producten en diensten”
- Cazzoni et al. (2010), “Industrial accidents triggered by flood events: Analysis of past accidents”, Journal of Hazardous Materials 175 (2010) 501–509
- Campedel, A. et al (2008). “A framework for the assessment of the industrial risk caused by floods.” In Safety, Reliability and Risk Analysis: Theory, Methods and Applications – Martorell et al. (eds) 2009.

Main conclusions from the literature study:

- Quite some research has been done into flood risk of unembanked areas. Some research is done on flooding of industrial installations and infrastructure, but references are not abundant. At the moment, no integral method exists for the evaluation of flood risks of port infrastructure or industrial installations in unembanked areas.
- For the Port of Rotterdam situation, especially the policy document of the Province of Zuid-Holland is of importance. Here, the indicators “number of casualties” and the “societal disruption” are of importance to the Province. These indicators will be used as primarily focus in this study as well.
- Specific (although limited) information with respect to damage due to failure of functions such as electricity is found in literature. This information has been used in this study.

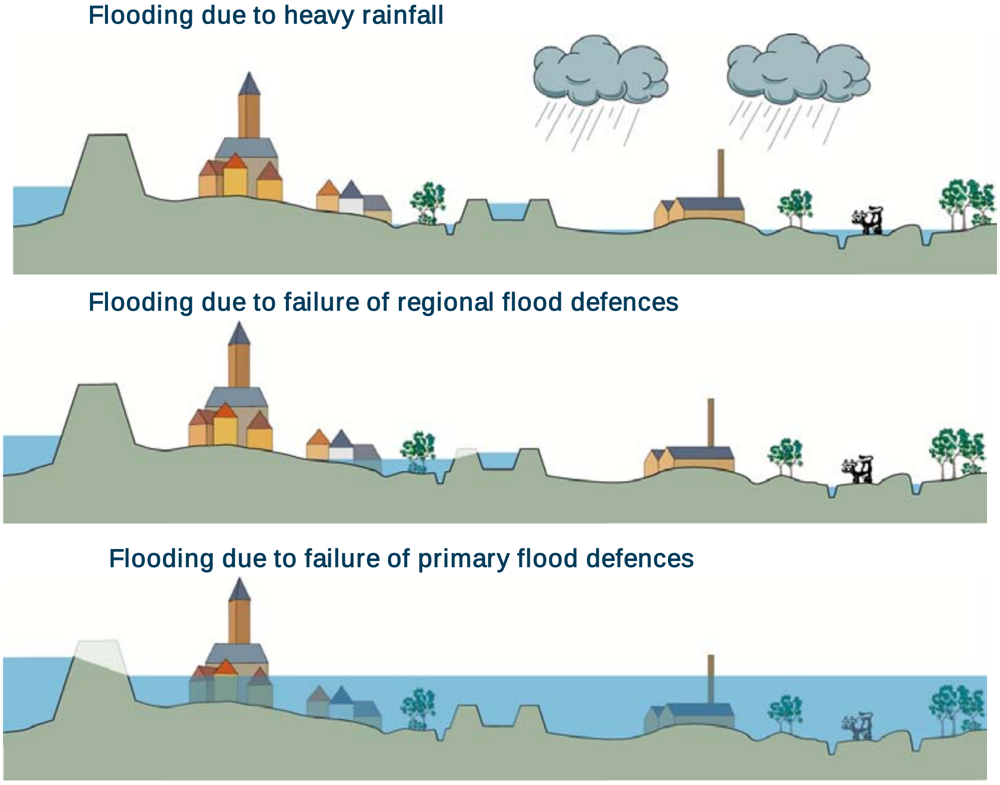
2.2 Flooding of unembanked areas: characteristics

Large parts of the Netherlands are enclosed by a system of primary flood defences. Flooding in most part of the Netherlands occurs due to 3 types of flooding:

- Flooding due to heavy rainfall
- Flooding due to failure of regional flood defences
- Flooding due to failure of primary flood defences

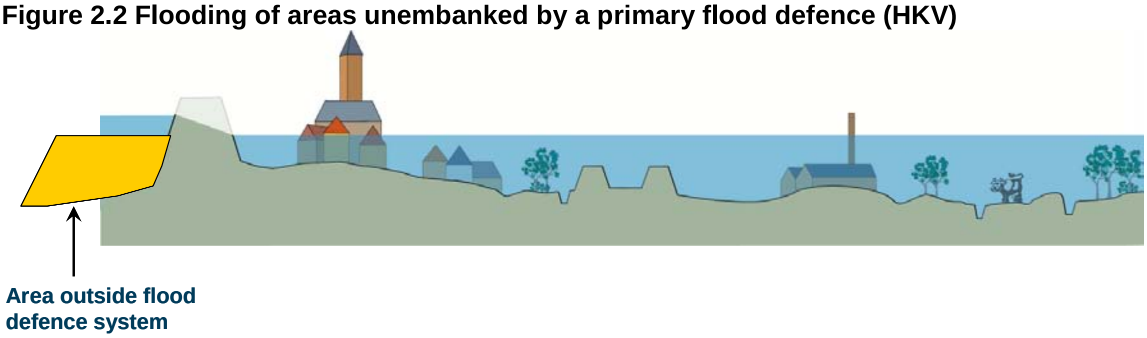
For these types of flooding, national policy documents give guidance to the water boards and provinces how to deal with the flood risks by maintenance and construction of a system of dykes and flood defence structures.

Figure 2.1 Flooding categories in the Netherlands, defended by primary and regional flood defences. (HKV)



The areas which are not protected by a flood defence system are flooded directly when the water level adjacent to these grounds rises above the ground elevation. Historically, ports and cities developed on these high grounds due to geographical advantage and direct access to water. Therefore, in most built-up areas and other developed areas, the frequency of flooding is rather low, due to the high ground elevation.

Figure 2.2 Flooding of areas unembanked by a primary flood defence (HKV)



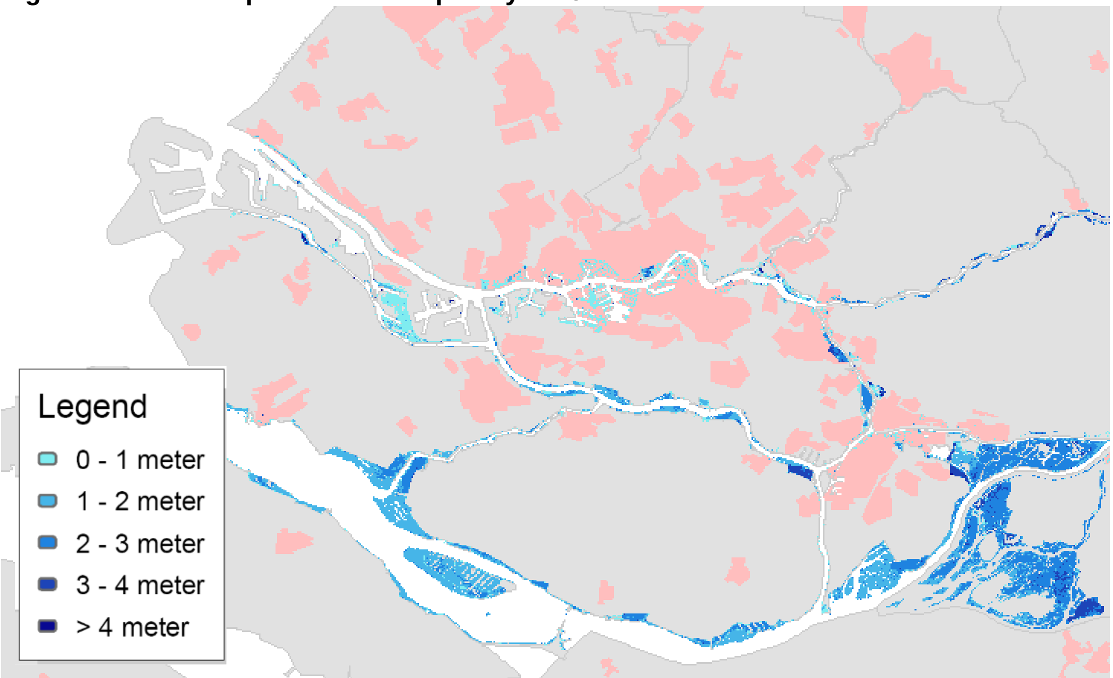
Flooding of unembanked areas has different characteristics than flooding of protected areas after a dyke breach. Flooding after a dyke breach is characterised by a sudden rise in the water level in the polders, with high velocities locally. In general, the water level variation during flooding of unembanked areas is directly related to the water level variation at open sea and partially by river (near Dordrecht). During a storm event, the peak of the surge causes temporary inundation. The water level increase follows the tidal curve and can be predicted accurately.

Figure 2.3 Flow velocities due to high water levels at Dordrecht (Reference Deltares 2009)

Flow velocities are in general not very high due to the fact that the water level rises with the tidal curve. Figure 2.3 presents the computed flow velocities during a flood event in the city of Dordrecht. Comparison can be made to the Dordrecht situation for this study and it is assumed that flow velocities are similar in Rotterdam.

In the Port of Rotterdam, the expected flood depths due to high storm surges are expected to be in the order of 0.5 to 1 m depending on the flood frequency and location. Figure 2 4 below presents a map of flood depths for the port areas of Rotterdam, with a return period of 1/10,000 for the present situation. Most areas more to the west are not flooded at all as these areas are above storm surge height. In 100 years, the effects might be more severe due to further increase of sea level rise and potentially higher river run-off.

Figure 2.4 Flood depths with a frequency of 1/10000 for 2010



Assumptions used for this study

For this study, the following flooding characteristics have been assumed for the qualitative assessment of vulnerability of port infrastructure.

- Flow velocities will be low; <0.5m/s
- Water levels in the order of 10 cm to 1 m.
- Water level rises gradually (no dike breach)

These characteristics roughly correspond to a flooding event with a frequency of 1/4000 to 1/10.000 or more, depending on the location. Inundation depths of > 1m are not seen in the present situation, see Figure 2.4. In future situations (2050), water levels including sea level rise, might well be > 1m at locations. For the existing situation, the picture shows that hardly any areas are flooded and if flooded, for most of the areas the depth is less than 1 m (see Part A “Water safety: Flood depth and extent”).

The effect of wind and waves has not been taken into account in this study. For wind, it is assumed that a risk assessment methodology is available taken account in the existing regulations and policies.

It might however be worthwhile to investigate to combined risk of high water, high wind speeds and waves. The probability of a hazard to occur might increase if these combined effects are taken into account. However, for instance emissions from chemical installations would have less impact die to high wind speeds for instance. Considering this, an easy assumption can not be made. This can be done in a follow-up phase.

3 ASSESSMENT OF VULNERABILITY OF PORT INFRASTRUCTURE

3.1 Assessment methodology

The assessment of the vulnerability of port infrastructure has been divided into 2 steps:

- The assessment of damages due to failure of a function or port infrastructure. Different categories of damages are used for this assessment:
    - Casualties
    - Societal disruption
    - Environmental risk / ecological damages
    - Economic damage
- The assessment of the likelihood of incurred damage (Probability) IF inundated. The relation between flood depth and damage is not taken into account specifically.

The assessment of the vulnerability and the possible consequences seems as an endless task. The number of possible damages and consequences during a flood event seems endless. Figure 3.7 of the TNO study “Vitale Infrastructure”, see section 3.1.7, showed the interrelations between several functions and components of society.
Flooding can also result in a chain of effects, so that not only that function A is interrupted but also function B fails as result of interruption of function A. For this study a qualitative assessment has been performed taking into account the most relevant and likely consequences. Part B of this study will present an example of a Consequence Analysis which should be performed in more detail for port infrastructure which is expected to be especially vulnerable to flooding.

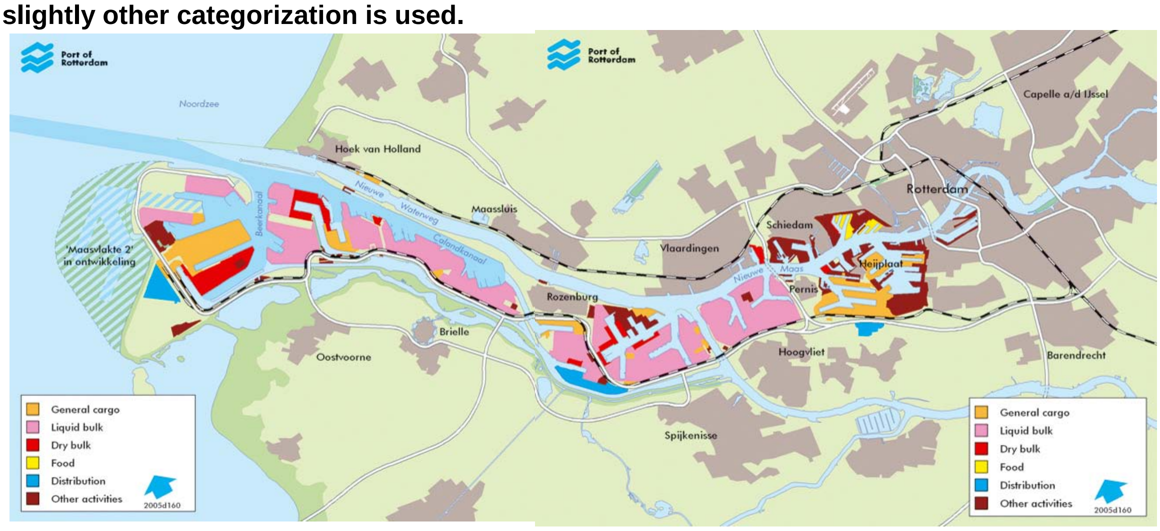
A subdivision has been made into categories of port infrastructure, according to land user category:

Client related infrastructure
- General harbour facilities
- Dry Bulk
- Liquid Bulk
- Containers
- RoRo
- Business areas and other land use

Public related infrastructure
- Public logistic infrastructure

General harbour facilities are applicable to most of the cargo types and are therefore treated as a separate category but applicable to all cargo types.

Figure 3.1 Overview of port area use according to www.portofrotterdam.com. In this study a slightly other categorization is used.



Below, in Table 3.1, a matrix is presented which is used for the vulnerability assessment.

Table 3.1 Scoring matrix used during the workshop

DAMAGE	**Effect of flooding**	**Likelihood of severe damage + loss of function` flood**	**Casualties**	**Societal Disruption**	**Environment**	**Economic**
Client infrastructure						
Harbour facilities						
Dry Bulk						
Liquid Bulk						
Containers						
RoRo & break bulk						
Public infrastructure						
Logistic infrastructure						
Business areas and other land use						

The qualitative assessment is performed by using a scoring methodology as presented in Table 3.2 below. First the probability of damage given a flooding event is evaluated. For this, a probability of 1%, 10% and 100% is used. Secondly the consequences have been assessed using a categorization dependent of each type of consequence.

Table 3.2 Scoring of the probability of damage given a flooding event and the potential consequences

	Low	**Middle**	**High**
Probability of damage given a flooding event	~ 1%	~ 10%	~ 100%
Consequences			
Casualties	None to a few (<5), especially persons at the facility / location	A few to a few (~ 10), also externally	Many (>100)
Societal disruption	Effects are brief and limited to the facility / location	Hindrance and damage within 10 km of the location of flooding	The complete region and\or nation experiences sustained hindrance and damage as result of flooding
Environmental risk / ecological damages	The range and severity of effects are limited and short-term	The range of effects is in the order of km's and limited to a number of weeks	Large area affected and negative effects long-term
Economic damage	< 1 million € damage	A few dozen million € damage	Hundreds of millions to billions € economical damage

During the workshop with a group of experts in the field of flood risk management, crisis management, port operations, and external safety, the vulnerability assessment was performed. During the workshop, the effects of flooding for the abovementioned port facilities were discussed into high detail.

The discussion resulted in a qualitative ranking of the vulnerability of the categories of port infrastructure. The following scoring categories were applied:

Table 3.3 Scoring method

Qualitative score	**Colour**
Low	🟢
Middle	🟡
High	🔴

3.2 Discussion Vulnerability of different categories of port infrastructure

During the workshop the vulnerabilities to flooding of different types of flood infrastructure have been discussed. In addition relationships and interdependencies between categories have been discussed in more detail. A more detailed overview is presented in Annex B. Here, only the most interesting observations and conclusions are mentioned.

As said the potential effects of flooding are numerous. Also, it is expected that chain effects can occur: if electricity fails other components will fail as well, such as cooling of installations, crisis management operations such as hospitals, police stations, ICT related components, communication, etc.. This will than result in delayed crisis management which could prove to cause more casualties than in a situation when electricity would be available. The failure of an electric plant itself does, apart from economic damage, not lead to casualties. Same holds for public infrastructure: especially tunnels and roads could seriously delay the transportation of goods and people during a flood event. In addition to this, crisis management will be difficult if the port areas can not be reached. Assessing the vulnerability of port infrastructure to these 2^{nd} or 3^{rd} order consequences is a difficult task. A Consequence Analysis as used in the chemical industry should be an approach to tackle these difficulties. In such a consequence analysis, hazard types following a broad range of possible events are used to calculate the consequences. During this consequence analysis, the chain effects are worked out in more detail. The case study in Phase B presents an example of such a Consequence Analysis.

With regards to **General port facilities**, it was concluded that no events are expected to lead to major effects or consequences. The most vulnerable components are communications, ICT and electricity, on which most other functions of the port area rely.

The consequences of flooding of **Dry Bulk** areas are primarily the outflow of the commodities and the interruption of business. Effects will include delayed transport of goods and minor environmental damage due to dissolving goods into the river.

The consequences of flooding of **Liquid Bulk** areas are generally assumed to be most significant. Not only are more hazardous goods present at the facilities, also some critical and vulnerable components are identified. These include pipeline on the ground level, systems which rely on the electrical circuits which could fail and storage tanks. The effects could include emission of hazardous goods, as well as delay of business due to shut down of the installation. Environmental damages are also expected if, for instance, oil leaks into the river.

It is generally expected that **Container terminals** will be out of function if flooding occurs. The electrical system has not been designed to water levels exceeding 0.5m. If operations on the container terminals are interrupted, it will take weeks to restart to full capacity. Major effects of flooding in terms of casualties are not expected though. Containers will not float with inundation depths of a few meters. Leakage of some tank containers could lead to environmental damage. It is likely that the provision of goods to the hinterland is severely hindered after a flood event.

For **RoRo & Break Bulk** not many consequences are expected. Very incidentally, hazardous goods are transported, but it is likely that preventive measures will be taken during an extreme storm.

With regards **to Business areas and other terrain use**, especially electrical plants will be very vulnerable. Not only is the port affected if these electrical plants will be out of function, also the nation will be affected.

With regards to **Public infrastructure**, many categories are assumed to be vulnerable to flooding. Roads, tunnels, rails will not be able to transport goods or persons for a considerable time, leading to much societal disruption. Also, electricity lines are assumed to be very vulnerable to flooding leading to large consequences. During the workshop, much attention was given to especially electric components and ICT systems which are necessary for the operation and management of the port facilities. Failure of these systems reduces the functioning of containers terminals, process installations and cooling installation of for instance LNG. It was further concluded that, the plant operators and land users should have already included the possibility of electrical failure and or ICT malfunction in their safety assessments. Flooding adds a small probability to this “standard” risk.

3.3 Results of assessment of vulnerability of port infrastructure

3.3.1 Qualitative assessment

The tables below provide the results of the qualitative ranking as performed using the workshop by a group of experts. The first column includes the port infrastructure categories. The second column provides an overview of most important effects which have been identified to occur during a flood. Experts were asked to qualitatively score the port infrastructure categories according to the conditions set in Table 5 2. Each green, red or orange dot means a score of an expert following the Table 5 3.

Table 3.4 Qualitative assessment of vulnerability: General harbour facilities

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Berthing facilities Quay wall Jetties	Washout due to water run-off Corrosion Failure of berthing function					
Terminal Terrain Roads and railways	Roads and terrain not accessible Washout due to water run-off					
Underground facilities Electricity Communication Cables Pipe lines	Rupture of pipe lines Failure and damage of electricity and ICT Failure and damage of communication					
General facilities Lighting buildings Safety installations Vehicles	Washing away of loose standing objects Lighting failure Safety onsite cannot be guaranteed Damage to buildings					

Table 3.5 Qualitative assessment of vulnerability: Liquid bulk

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Facilities Process installations Pipelines Cooling installation	Cable trays are on ground level => spills + release of toxic goods + interruption of processes. Instability of construction of installation, for instance distillation columns built on footings Rupture / damage of (empty) pipelines Corrosion of (salt) water in installations Power failure => uncontrollable processes					
Storage of goods Oil LNG LPG Toxic gasses: H_2F Vegetable oil	Rupture of (oil) tanks due to high water pressures LNG cooled storaged=> during power failure uncontrolled boil-off (Controlled) shut-down installations during flood threat Release toxic material from storage Gas supply fo electricity / hinterland interrupted					

Qualitative score	Colour
Low	
Middle	
High	

Table 3.6 Qualitative assessment of vulnerability: Dry Bulk

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Facilities Cranes Conveyor belts Silos Sheds	Corrosion Failure and damage of electricity and ICT Instability of buildings on footing					
Storage of goods Ores (zinc, iron, coals, ...)	Wash-out of material (loss of good) Instability of piles Toxic goods in surface water					

Table 3.7 Qualitative assessment of vulnerability: RoRo terminals

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Facilities Cooling installation Sheds	Washout due to water run-off Corrossion of (salt) water Interruption of berthing and (un)loading functions					
Storage of goods	Cars\ trucks float from quays Special goods (for instance nuclear waste containers) pose specific threat					

Table 3.8 Qualitative assessment of vulnerability: Container terminals

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Facilities Cranes Reefer slots	Washout due to water run-off Corrossion of (salt) water Interruption of berthing and loading functions					
Storage containers port terrain	Floating containers (only very high water levels >1m) Reefers shut down Leakage of tankcontainers (by collision of debris)					

Table 3.9 Qualitative assessment of vulnerability: Businesses and other land use

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Electricity plant	Short-cutting \ generation interruption Chain effect of power failure: • rail • communication • Port safety systems • Power failure Zuid Holland => Can be partly resolved by national power network though					
Drinking water plant \ pumping stations	Drinking water supply and pumps not resistant to high water Interruption if water supply => can be partly resolved by national water supply network					
Offices	• Given timely evacuation only material damage to offices • Crisis management and rescue teams might not be able to execute task during flood event					

Qualitative score	Colour
Low	
Middle	
High	

Table 3.10 Qualitative assessment of vulnerability: Public related infrastructure

	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Electricity cables / transformer	Rupture by soil displacement Short cutting Chain effect of power failure: • Rail • Communication • Port safety systems • Power failure Zuid Holland => Can be partly resolved by national power network though					
Drinking water pipelines	• Pipeline rupture due to soil displacement • Failure of drinking water supply => can be partly resolved nationally. In addition, temporary provisions are available					
Roads \ Tunnels	• Obstruction of transportation of goods and personnel • Safety services and essential personal can not reach terrain \ port area					
Rail	Obstruction of transport / removal of goods					
Communication (fixed and mobile)	Interruption of communication by failure of subsoil infrastructure \ relay stations					
Recreation areas \ parks	Temporary out of use by contamination and floating debris					
Waterways	Vessels and barges pose threat to installations and other infrastructure Vessels at the quay float onto port areas					

Qualitative score	Colour
Low	
Middle	
High	

Appendix C provides identical tables as above, but summarizing and elaborating on the discussion during the workshop. The next section discusses the main conclusions from the assessment presented in the above tables.

3.3.2 Main conclusions of qualitative assessment of vulnerability

Based on the scoring of experts, the following overall conclusions can be drawn:

- The distribution of the scoring of vulnerability does not show much variation: for most categories the scoring is quite uniform.
- The probability of consequences in terms of societal disruption shows a scattered scoring: apparently experts do not agree on the exact consequences and the severity of consequences. During the assessment, it was concluded this can partly be explained by large number of possible consequences
- The probability of casualties due to flooding of port infrastructure is in most cases assessed as “Low”, some categories assessed as “Middle”, but in no case “Large”. Apparently most experts agree that the risk of a significant number of casualties is small.
- Most experts agree that the probability of consequences due to flooding is relevant. For almost all land use categories, the probability is assessed as High. Note that during the workshop the assumption was made that up to 1 m of water depth should be taken into account for this

3.4 Ranking of vulnerability of port categories

A final assessment was made to identify most vulnerable components in the port area. Experts were asked to assess the vulnerability to flooding according to terrain use, based in the information presented and the results out of the discussion by experts. The land uses assessed as most vulnerable are thus likely to have considerable consequential damage, given a flooding to a depth of about 1 m, small flow velocities and not taken into account wind and waves.

The scoring was performed using a classification of Low (1), Middle (2) and High (3). Note that this scoring includes all consequence categories.

Table 3.1 Ranking of vulnerability of land use to flooding

	Land use	**Score**	**Total**
1	Public infrastructure	3-3-2-2-2-2-2-2-2-2-1-1-1-1-1	27
2	Liquid Bulk	3-3-3-3-3-3-3-3-2-2	28
3	Containers	1-1-1-1	4
4	Business areas and other land use	3-2-1-1	7
-	RoRo	-	0
-	Dry Bulk	-	0
-	General harbour facilities	-	0

A list of 4 critical terrain use categories was derived out of this scoring by the various attendees. Especially public infrastructure and liquid bulk is assumed to be vulnerable. Containers and business area and other land use are vulnerable to less extent. For RoRo, Dry Bulk and general harbour facilities do not seem to cause considerable consequences during flood events.

4 DISCUSSION AND CONCLUSION OF PHASE A

The main aim of phase A was to provide a first qualitative assessment of the vulnerability of port infrastructure to flooding, following the objective of this study.
Phase A of this study comprised of a literature study, a workshop among experts and out-of-the pocket information by a range of experts. The information gathered and shared among experts was assessed using a qualitative scoring method, providing a first determination of the vulnerability of port infrastructure in unembanked areas to flooding.

During the workshop, many issues were raised and the discussion focussed on the assessment of the vulnerability. Also, experts discussed on potential effects and consequences of flooding of port infrastructure. The conclusions below provide the issues which stood out most. The Appendix includes a more elaborated consequence and effects overview per category infrastructure. The conclusions below are valid under the assumption that a terrain will be flooded to about 1 m. Note that for large parts of the Port of Rotterdam, in the present situation, the frequency of flooding up to 1m depth is very low ($>10^{-4}$). In future situations though (2050, 2100), flooding of more than 1m water depth might occur locally, under the assumption that the unembanked areas have not been raised in the mean time. These flooding conditions would however still occur during very extreme storm conditions, with a low probability of occurrence.

Textbox 4.1 Main conclusions from Part A:

- Liquid Bulk and Public logistic infrastructure are most vulnerable to flooding, especially with respect to societal disruption: effects may be considerable
- The port function of provision of goods to the hinterland is especially vulnerable to flooding
- The number of casualties, given a flood depth of 1m, is expected to be small. Dozens of casualties are expected at most.
- The category public logistic infrastructure is vulnerable to flooding because
  - Power failure affects many other processes
  - ICT very important for other functions such as crisis management during floods
  - Roads, tunnels and pipe lines provide transport of people and goods. This is severely interrupted during floods.

General

During the workshop and in the literature study, it was concluded that the amount of potential effects of flooding in port areas is extensive. Port areas consist of a broad variety of components, buildings, electric systems etc. During the discussion in the workshop, it was concluded that these components have specific characteristics and have different behaviour with respect to flooding by water. Therefore, the potential hazards, consequences and effects are numerous as well. Therefore, it is very difficult to make a non-site specific estimate of the flood risk of port infrastructure given a certain flood depth. The general notion of the broad variety of consequences due to failure of infrastructure is also supported in literature, for instance in TNO (2003) and in Cazzoni et al. (2010). For urban areas this relation is available, see Report C “Vulnerability assessment based on direct flood damages”. The damages can be more or less estimated for urban areas by general characteristics and value of the properties. Also, because not much information has been available to date, practical figures of the flood risk of port infrastructure from experience are still lacking. For economic damages, this has been studied for instance in Pimontel 2005, but for the other damage categories, such as societal disruption, this has not been done.

Effects and Consequences due to flooding of port areas with respect to social disruption and casualties

The different consequence types due to flooding of port areas have been discussed, focusing on casualties, economic consequences, societal disruption and environmental pollution. More focus has been given on the societal disruption and casualties, than on the other categories. The main reason for this is that these two categories are of most interest to the provincial policy document. This does not mean that environmental damages are not of concern. The results of the qualitative assessment can be used in follow-up studies in which environmental damage should be reviewed in more detail.

Societal disruption

It was concluded that especially the port function of provision of goods to the hinterland is hindered during a flooding event. If services and businesses are more and more directly dependent of port facilities, or dependent of the storage of goods in the port area, the effect to society and businesses is large. This holds for all types of goods: container terminals store goods for super markets, dry bulk (coal) is used for the generation of electrical plants throughout the Netherlands and into Germany etc. Especially container terminals are important in the chain of supply to all sorts of businesses in the nation. Therefore the category “public infrastructure” was found to be very vulnerable. If the infrastructure fails, many other types of function will fail in the hinterland. One can think of power failure, termination of ICT services etc.

An interesting research topic would be how long different functions of the economy continue to function if the port is flooded and not operational. A comparison can be madder of the delay time due to flooding and the time needed to provide the commodity to the end-user. For instance how long can coal electricity plants function without the supply of coal through the port of Rotterdam.

It is noted here that also if preventive measures are taken when a flooding is forecasted, such as a shut down of installations, normal operation will stop the supply of goods to the hinterland as well. If a container terminal is shut down due to internal failure by for instance electrical failure, it will take weeks to restart to normal terminal operations. Also gas supply, supply of oil and gasoline is expected to be considerably delayed.

Casualties

It is generally concluded, under the assumptions used in the workshop, that casualties are still expected to be low in most instances, also for high risk installations, mainly because:

- High populated areas are not within close range of the majority of these facilities.
- It is expected by most of the attendees that effective measures are taken within the process installations to prevent explosions or the release of hazardous goods in the normal design and procedures of process installations and storage facilities. In addition, if flooding is expected, plant operators can mitigate the risk by measures to reduce the vulnerability of the plant.
- The frequency of significant flooding (> 1m) for most of the port area is very small. In the future, if the sea level continues to rise significantly, some specific areas would be subject to more frequent flooding with more significant flood depth.

The effects which have been identified should be compared to effects in areas defended by primary flood defences. The reason is that during a storm with an uncommonly extremely high water level, other parts of the area of South Holland are likely affected as well. Although effects of flooding of port areas could be large, the urban areas of Rotterdam or The Hague would experience severe consequences of flooding as well during the same time.

These conclusions have been drawn during the workshop based on several assumptions. More detailed and specific information is needed to confirm these conclusions.

The next phase will present a methodology to assess the flood risk of a chemical plant in areas unembanked by a primary flood defence in more detail. A theoretical case study is used, because site specific information is not used. The results of Phase A are used as input for this case study.

PART B: RISK ASSESSMENT AND RISK EVALUATION OF CHEMICAL INSTALLATIONS IN UNEMBANKED AREAS

5 INTRODUCTION TO PART B

In Part A, a qualitative assessment was made of the vulnerability of port infrastructure to flooding. Part B continues into more detail by defining the flood risk of chemical installations in unembanked areas. In the analysis, information and approaches from flood risk and chemical risk assessment are combined. The results of the assessment of the flood risk of a chemical installation will be discussed in the context of existing risk frameworks. The following steps are made:

Step 1. Flood risk assessment of chemical installations (Chapter 6 and Chapter 7)

The frequency and the potential consequences of flooding of a chemical plant are estimated in this first step. Phase A of this study provided a qualitative assessment, Chapter 6 presents a method to perform a quantitative flood risk assessment. This method has been developed for this study, as no general applied method exists. For this purpose, a hypothetical case study has been used. The case study is not based on factual information from a particular plant in the port of Rotterdam. However, the case study provides a realistic estimate for a new development in the Port of Rotterdam with realistic circumstances and hazard types. The consequences and effects in terms of casualties and societal disruption are estimated. In addition, environmental damage, economic damage as well as cultural damage is considered, following the risk methodology as defined by the Province of Zuid-Holland.

Step 2. Risk evaluation (Chapter 8)

During a second step, the flood risk of a chemical installation as defined in step 1 will be discussed and evaluated in the context of flood standards which are applicable in areas in the Netherlands defended by flood defences. In addition, the flood risk as defined in step 1 will be compared to External Safety standards as they are available in the chemical industry. This will have to indicate whether the risk is substantial or not.

Step 3. Discussion of results and follow-up activities (Chapters 9 and 10)

The study for this part was concluded in a workshop. Findings of the risk analysis have been presented in the meeting as well as the different risk evaluation methods, both for chemical plants and for flood risk assessments of areas defended by primary flood defences. During the workshop, a range of people involved in flood risk management and external safety discussed the outcomes and possible application of this study. The main issues that were discussed are summarized in chapter 9. The main conclusions and recommendations are found in chapter 10.

6 FLOOD RISK ASSESSMENT OF CHEMICAL INSTALLATIONS

6.1 Introduction

This chapter presents a risk assessment methodology for chemical installations used for this study. A uniform methodology to assess the flood risk of a chemical installation is not available. The objective is to develop insight in the order of magnitude of the flood risk of a chemical installation, by performing a quantitative analysis.

The following steps are made:

1. Description of available Risk Assessment methods in the chemical industry
2. Methodology for estimating the additional risk of a chemical installation due to flooding
3. Flood risk assessment: Hypothetical case study
   Worst case scenario, no flooding
   Worst case scenario, flooding
4. Conclusion and discussion

For the flood risk analysis, a case study was prepared based on general assumptions and expert judgement. Starting point is a description of risk methodologies in the chemical industry, which will be taken as a starting point for the assessment. Secondly, a method is presented for a flood risk assessment of chemical industry. This is supported by a description of flood conditions. Results are presented after which conclusions and a discussion are presented. The assumption was made that the chemical installation of interest is fictive: the conditions are realistic but do not represent any particular installation.

6.2 Risk Assessment methods in the chemical industry

The safety of chemical installations is assessed during design as well as during operation of the installation. In the industry, internationally accepted methods are found. These methods are also used in the Netherlands. Very early in the design process, a so called Hazard en Effect Management Process (HEMP) is performed. The HEMP is a structured and systematic analysis methodology involving the Identification, Assessment and Control of hazards and the Recovery from effects caused by a release of the hazards. Part of the HEMP is the set-up of a Health Safety and Environment assessment, providing the risks for people and the environment as result of the industrial operations. During the operation of a facility, a continuous monitoring of the safety of the installation is performed as well. The following steps are made:

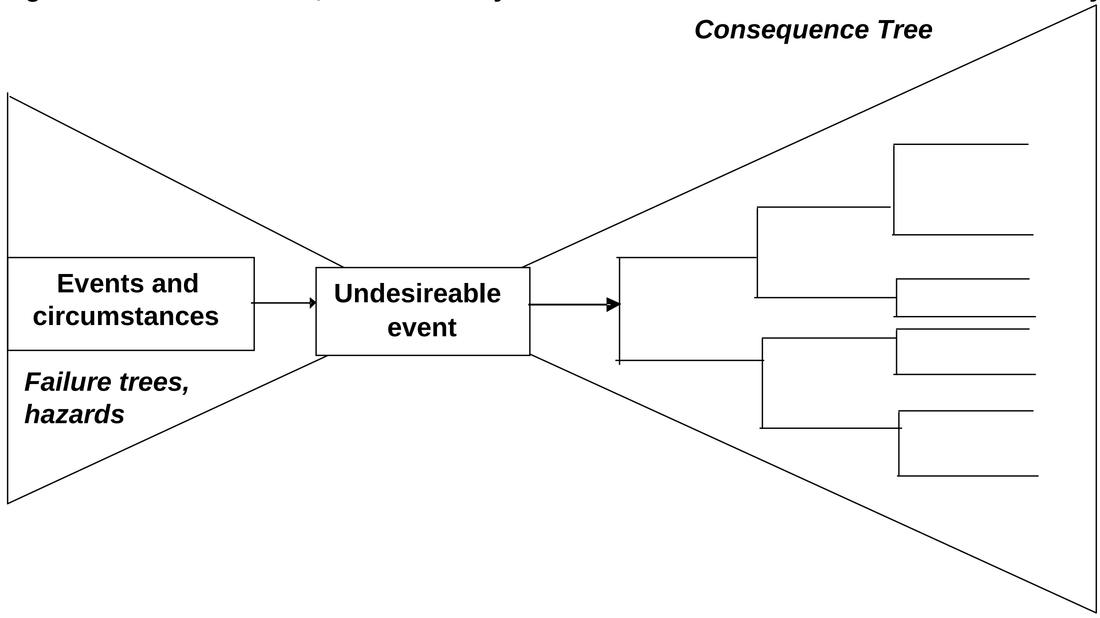
Step 1 - Hazard Identification
A multi-disciplinary team reviews a hazard checklist to identify those hazards which are relevant to the business throughout its total life cycle. This list is the start of the hazard and effects analysis.

Step 2 - Identification of Hazard Scenarios
The experience of the team is used to identify the failure trees or hazard scenarios (top events) which could occur if the hazards being considered were released in a so-called Process Hazard Analysis (PHA).

Step 3 – Risk assessment
For each hazard scenario, the risk is assessed and hazards are prioritized according to their potential consequences and effects (on the basis of realistic worst case assumptions).

During the risk assessment process, most undesirable events, circumstances and consequences are identified. These can be presented in a so-called BowTie model, see Figure below.

Figure 6.1 BowTie model, used in safety assessment methods in the Chemical Industry



A list of the most hazardous and undesirable events is than produced, for which a Consequence Analysis can be made: This Consequence Analysis could consist of (for a chemical plant):

- Description of release scenarios
- Calculation of emission quantities and other consequences
- Identification of potential effects to people, society and environment.

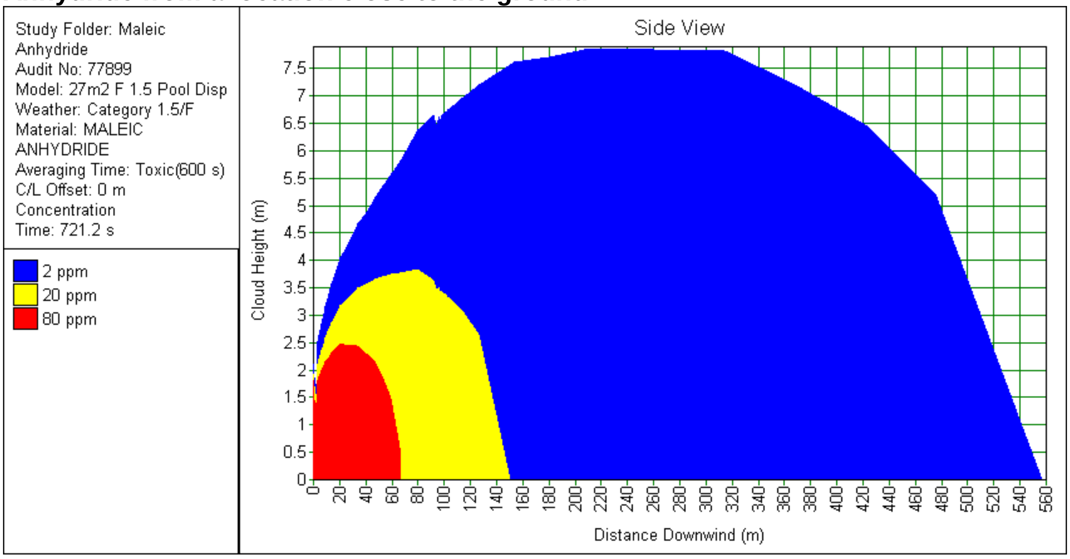
The table below gives an example (in Dutch) of several undesirable events as an example.

Figure 6.2 Example frequencies (in Dutch) of several events causing release of hazardous contents. (RIVM)

	Frequentie (per jaar)
1. Instantaan vrijkomen van de gehele inhoud	5×10^{-7}
2. Vrijkomen van de gehele inhoud in 10 min.	5×10^{-7}
3. Continu vrijkomen uit een gat met een effectieve diameter van 10 mm	1×10^{-5}

The undesirable events are than used to calculate the consequences of the emission scenario. For this numerical modelling is used. In most situations, the dispersion of a chemical substance has to be calculated under given weather circumstances, see for an example below.

Figure 6.3 Side view of the results of a numerical model calculating the emission of Maleic Anhydride from a location close to the ground.



The Consequence Analysis than provides expected concentration rates and exposure time of the surroundings to the hazardous goods. This information is than used to estimate the effects of the emission of the goods.

The effects of emissions of hazardous goods and materials on human life and health are quantified using so called IDLH levels and ERPG levels.

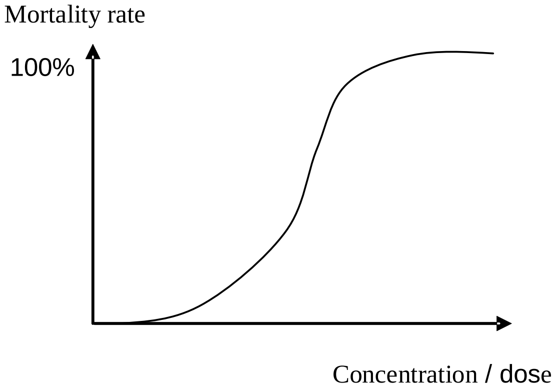
Extreme toxic hazardous substances can be classified as IDLH. IDLH is an acronym for Immediately Dangerous to Life or Health, and is defined by the US National Institute for Occupational Safety and Health (NIOSH) as exposure to airborne contaminants that is "likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment." Examples include smoke or other poisonous gases at sufficiently high concentrations.

The ERPG levels are based on Emergency Response Planning Guidelines (ERPG). This is a system of guidelines, developed by a committee of the American Industrial Hygiene Association, that are intended to provide estimates of concentration ranges where one might reasonably anticipate observing adverse effects as described in the definitions for ERPG 1, ERPG 2, and ERPG 3, as a consequence of exposure to a specific toxic substance.

- ERPG 1 level is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.
- ERPG 2 level is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.
- ERPG 3 level is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.

In the case study, these IDLH and ERPG levels will be used to identify the effects of human health: also the health effects are used to estimate a potential fatal health effect, as a result of toxic emissions. The estimate of the number of casualties is used to evaluate the flood risk of a chemical installation in terms of the Individual Risk (IR) and Group Risk. Chapter 10 will go into more detail on this.

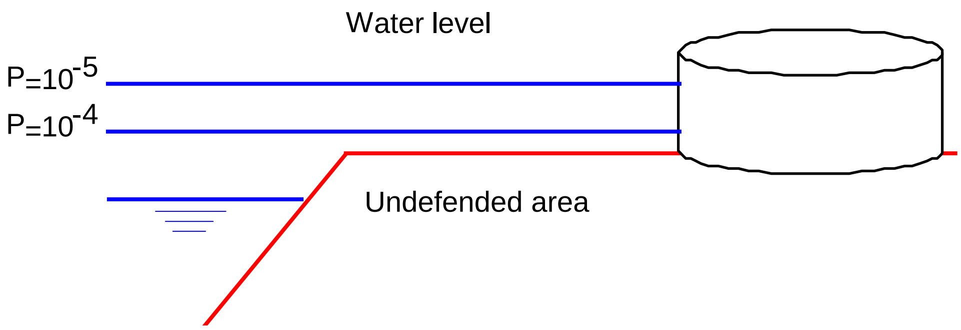
Figure 6.4 Relation of concentration or dose of toxic material, resulting in an estimate of the probability of death of an exposed person



6.3 Methodology for estimating the additional risk due to flooding of a chemical installation

In this paragraph, the methodology of quantifying the additional risk due to flooding for chemical installations is explained. During normal day-to-day situations, unembanked areas will not flood. Only during very occasional storm events, the water level could exceed the ground elevation of the unembanked areas, and inundation occurs. The inundation depth is a difference between the storm high water level and ground elevation. Higher storm water levels will result in higher inundation depths, see Figure below. It is noted that in general it is assumed that port areas have been constructed on high elevations. Therefore, the probability of flooding remains very low.

Figure 6.5 Flooding of areas not defended by primary flood defences



High water levels will likely result in more damage. Hence the probability of consequential damages, given flooding, will also increase with flood depth. Also the magnitude of consequential damages might increase due to higher water levels, for instance because more hazardous components in a chemical plant are inundated and hence suspect to fail.

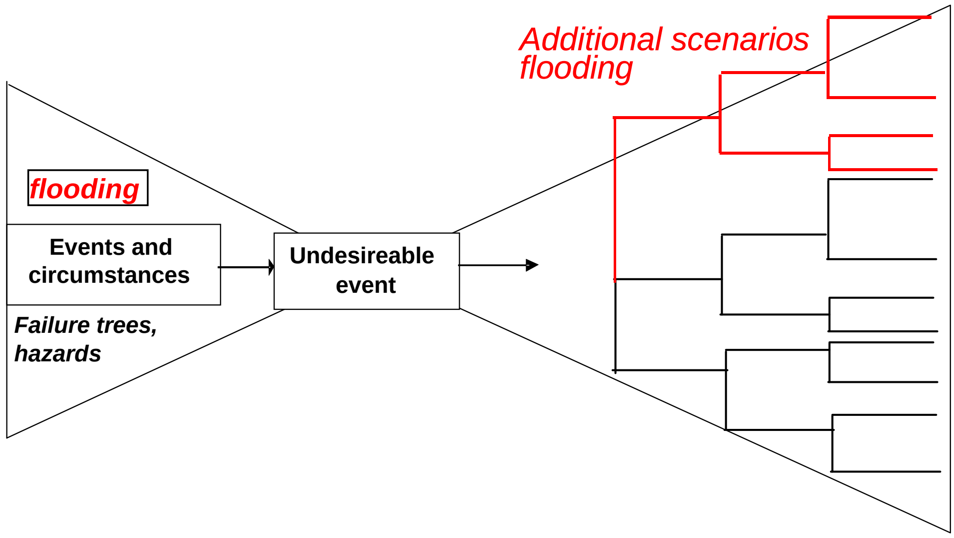
Inundation of chemical installations in unembanked areas results in additional scenarios. Thus, additional undesirable events have to be identified. The workshop of Part A is an example of an expert meeting which could identify those undesirable events. In the workshop, many different failure mechanisms have been identified, see Annex B for an elaborate overview.

The circumstances of a scenario occurring as result of flooding of the chemical installation will also be different than a scenario occurring during “normal” operations, i.e. without flooding.

In this case study, it is assumed that the worst-case situation under normal conditions is also a worst-case situation for a situation including flooding. In other words, these conditions are assumed to be the most severe conditions which could occur under any circumstance as result of failure of an element in the chemical installation. The consequences and effects of a worst-case situation are assumed to be most damaging to people, environment etcetera. Hence, looking at the worst-case scenario in situations including flooding will also provide insight into the most severe consequences due to flooding. Note that during flooding, the worst-case situation, in terms of consequences and effects, is not necessarily the most likely situation to occur. For example, one can think of a chemical plant for which the worst case scenario is defined as release of goods during unloading of a vessel at the quay. It is however very unlikely that this event takes place during flooding, as no vessel will be unloading. Other hazard types might be more likely to occur during flooding for such a chemical plant, which would have less severe impact.

For this study we will use the worst-case situation though, because it is believed this gives insight in the consequences and effects as a first estimate. Hence the approach thus provides an upper bound approach rather than a best-estimate. During a more detailed flood risk assessment, it should have to be checked whether other hazards are important in a flood risk assessment. The results and list of failure mechanisms have been developed during Phase A of this study and have been included in Appendix B. This list can be used as a starting point.

Figure 6.6 Bowtie model of the risk of flooding of chemical industry in unembanked areas. The additional hazards, as well as additional consequences are incorporated in the general risk assessment.



The following steps are taken in the case study to quantify the additional risk due to flooding of a chemical plant, using the risk assessment methodology of a chemical plant as starting point:

- Define a worst case scenario under “normal” plant operations, i.e. a worst case *without flooding*. Also define the effects and consequences. These worst case scenarios and effects and consequences are known for an existing installation. (Section 7.1)
- Describe the specific **circumstances** under which a worst case scenario during flooding might occur. (Section 7.2)
- Assume that the worst case scenario *without flooding* is also the worst case scenario *with flooding*. Estimate the consequences and effects of the worst case scenario *with* flooding by using information of the specific circumstances under which flooding occurs and estimate the impact of these circumstances on the consequences and effects as defined for the worst case scenario *without flooding*. (Section 7.3)

Determine the additional risk due to flooding, using the worst-case as a reference situation. (Section 7.4)

In the case study of the next chapter, examples are given of two Consequence Analyses studies, without flooding. These analyses are compared with two cases, in which the assumption is made that flooding does occur. For cases with flooding, the cause of the hazard event is different than in a case without flooding (for instance accident in installation). This is however for a first estimate of the actual flood risk of no importance. The consequences of the case with flooding are compared with worst cases without flooding. A table is presented which presents the following information:

1. Identification of the scenario
2. Frequency of occurrence of the scenario
3. Specific circumstances which are assumed to be valid for the scenario
4. Consequences
5. Effects

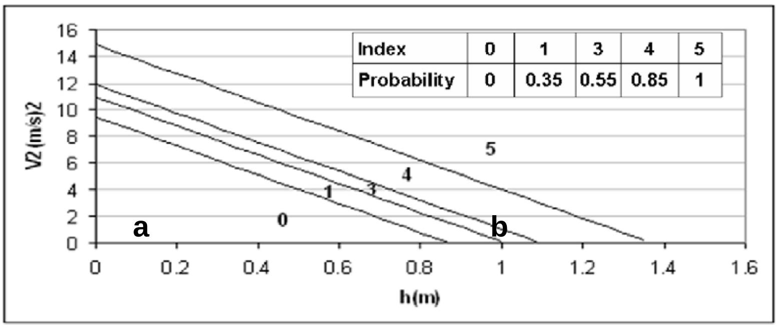
For the case study, the situation with flooding is set next to a situation without flooding. Both cases can than be compared. The next page presents a text box in which a similar methodology has been presented in literature.

Textbox 6.1 Campedel, A. et al (2008). A framework for the assessment of the industrial risk caused by floods. In Safety, Reliability and Risk Analysis: Theory, Methods and Applications – Martorell et al. (eds) 2009.

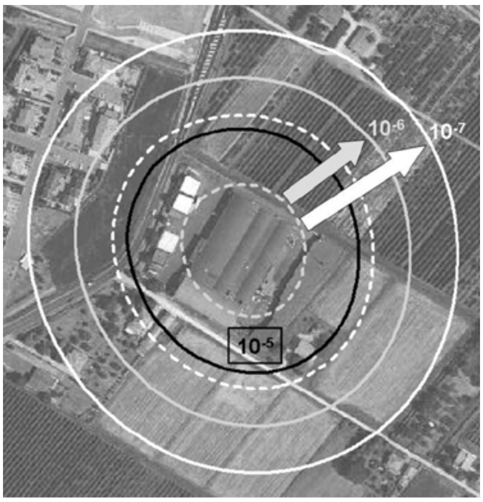
The paper *"A framework for the assessment of the industrial risk caused by floods"* provides a similar approach to estimating the flood risk of chemical installations. The following steps were made in the study, similar to the steps made in this research:

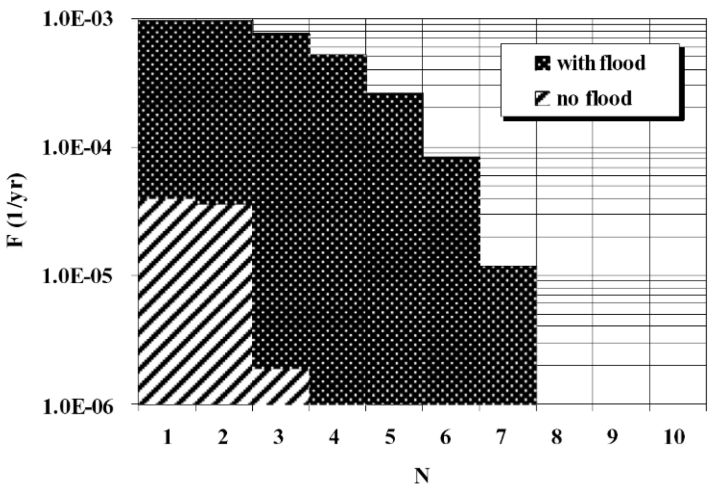
- Characterization of flood events
- Identification of equipment items more vulnerable to flood event and assessment of the final scenarios associated
- Damage probability of the critical equipment items

The last step determines the damage probability given flooding. The figure below shows these relationships. The velocity *squared* is given on the vertical axes and the water depth on the horizontal axis. The probability of a hazardous event is than found by looking at the region in which the velocity and flood depth combination lies (1 to 5). A probability is than found for these regions. For the study as presented in this report, velocities are rather small (< 0.5 m/s) and the water depth is assumed to be 0.1m or 1m. Velocity squared (vertical axes) is < 0.25 m/s. Flooding of 0.1m falls than in region 0 ("a" in figure), and flooding of 1m lies in region 3 ("b" in figure). Probabilities are 0 and 0.55 respectively.



A case study was performed as well. A water depth of 1m during flooding was assumed with low flow velocities. The frequency of this event was assumed 10^{-3}. A release probability of 55% was assumed based on the figure above, which has been based on unclear assumptions with regards to release of goods in industrial site. Results of the study are presented in the graphs below. The individual risk contour line is shown in the left panel, indicating exposure of the surroundings to a fatal hazard. Societal risk is graphically represented by an FN-curve that shows the exceedance probabilities of the potential numbers of fatalities (P(N≥n)) on double log scale. A societal risk graph is presented on the right hand side, indicating the additional probability of a hazard involving more than 1 person.





A significant increase of the total probability was observed in the personal risk contour (left panel) as well as in the group risk contour (right panel). The study concludes that for chemical installations in regions with considerable flood events, the additional risk to surroundings by the effect of flooding is large.

7 FLOOD RISK ASSESSMENT: HYPOTHETICAL CASE STUDY

In this chapter, the method that has been proposed in Chapter 6 is applied to a realistic case study. First, worst case scenarios are assumed in section 7.1. After this, the specific circumstances for extreme storm situations are presented in section 7.2. The additional scenarios due to flooding are presented in section 7.3 after which effects and consequences can be derived in section 7.4. The chapter ends with conclusions based on the results of the case study as well as conclusions with regards to the methodology.

7.1 Definition of worst case scenarios used for case study

The following undesirable events are identified which could occur under "normal operations", i.e. no flooding, as well as a result of flooding. Two situations are presented as a reference Hazard Analysis. These worst case scenarios are used as starting point for the flood risk assessment of the chemical plant. The case studies are selected to represent realistic installation types which can be found in the Port of Rotterdam.

- Airborne emissions of Maleic Anhydride from a 27 m^2 pool at ground level.
- Rupture of a 3" nozzle from a hexafluorpropene tank

Figures below present the emission scenarios of a hexafluorpropene tank. The characteristics of this emission calculation are used to identify the possible consequences and effects of the hazard.

Figure 7.1 Top view emission scenario of a hexafluorpropene tank

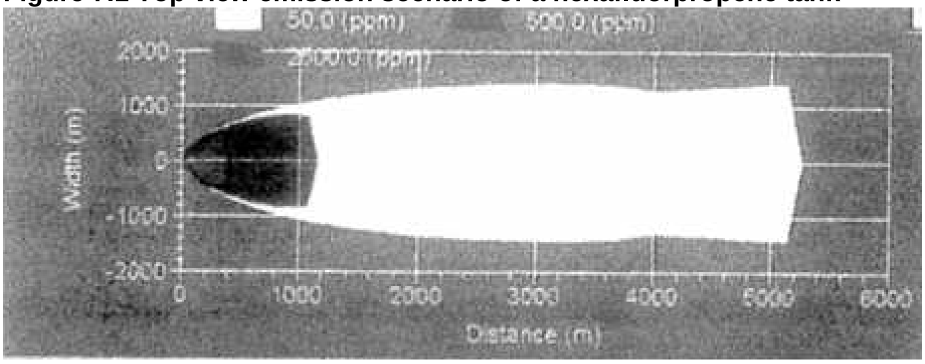
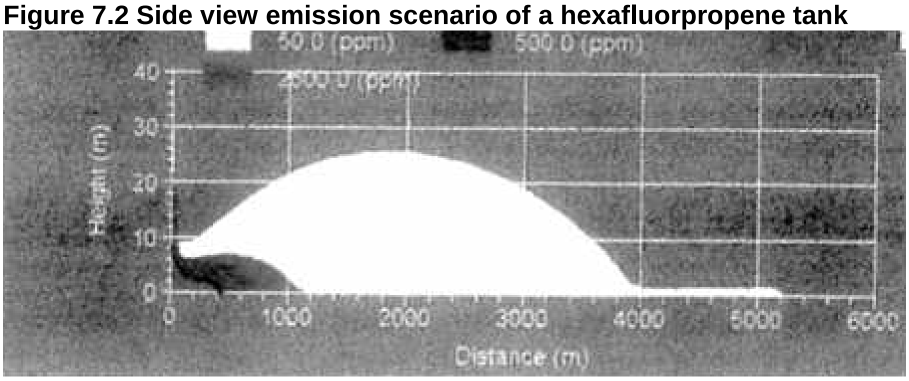


Figure 7.2 Side view emission scenario of a hexafluorpropene tank



7.2 Specific conditions and circumstances during flooding

Chapter 2 gives an overview of specific circumstances under which flooding of unembanked areas can be expected. For the risk assessment in the case study the following assumptions are made, based on the assumption that we look at newly build installations. Also we assume that we look at a future situation, and hence take into account sea level rise to 2050 for new developments.

- Flooding with a frequency of 10^{-4} per year is estimated as ~ NAP + 5.60 m in 2050.
- Flooding with a frequency of 10^{-5} per year is estimated as ~ NAP + 6.50 m in 2050.
- Ground level elevation of a chemical installation is assumed to be NAP + 5.50 m. This corresponds to the elevation for new developments of the Maasvlakte 2 areas.

The ground elevation in combination with the expected extreme water levels result in the following inundation depth, for a given frequency:

- Inundation with a frequency of 10^{-4}: 0.1 m
- Inundation with a frequency of 10-^{5}: 1.0 m

In addition, the following circumstances are identified which are taken into account in the consequence analysis:

- Current velocities are assumed to be small, see Chapter 2: 0.25 m/s - 0.5 m/s.
- Wind speed is assumed to be moderate to very high: ~35 m/s, >12 Bft. The correlation between extreme water levels and wind speeds is almost 1, meaning that extreme flood elevations only occur if wind speeds are very high.
- Waves can occur onsite when inundation depth is sufficiently large, maximum wave height equals about half the water depth locally.
- In case of flooding, it is very likely that measures have been taken, as an extreme storm can be foreseen 2-5 days in advance. Measures include shutdown of the installation, evacuation of persons from the site and other measures.
- During a storm, the water will inundate and run-off the terrain during high tides. This means that during 1 storm event, the industrial site is inundated twice. Also, the water runs of twice taken emitted or released toxic waste with it.

Note that these assumptions are made for newly developed areas, i.e. Maasvlakte 2. This study does not focus on existing areas. For these areas, inundation depths might be larger as the terrain elevation is lower. All other circumstances are equal.

Figure 7.3 Ground level elevation of the Port of Rotterdam area. Red areas are elevated areas, dark blue indicates low lying polders.

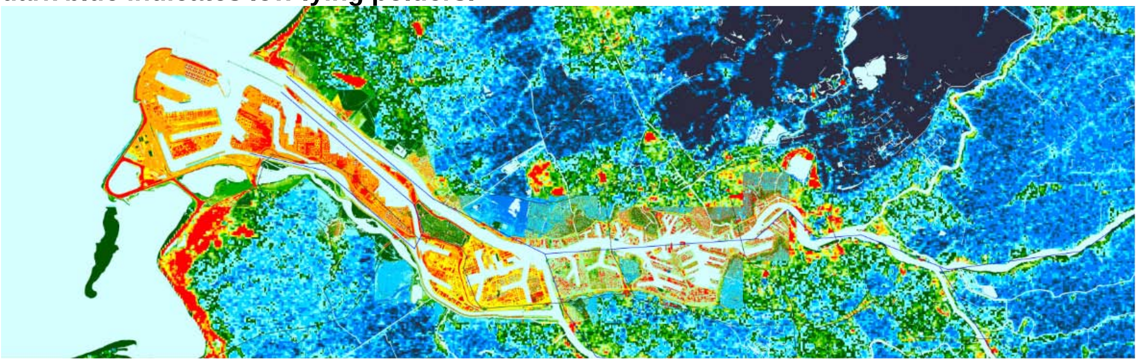
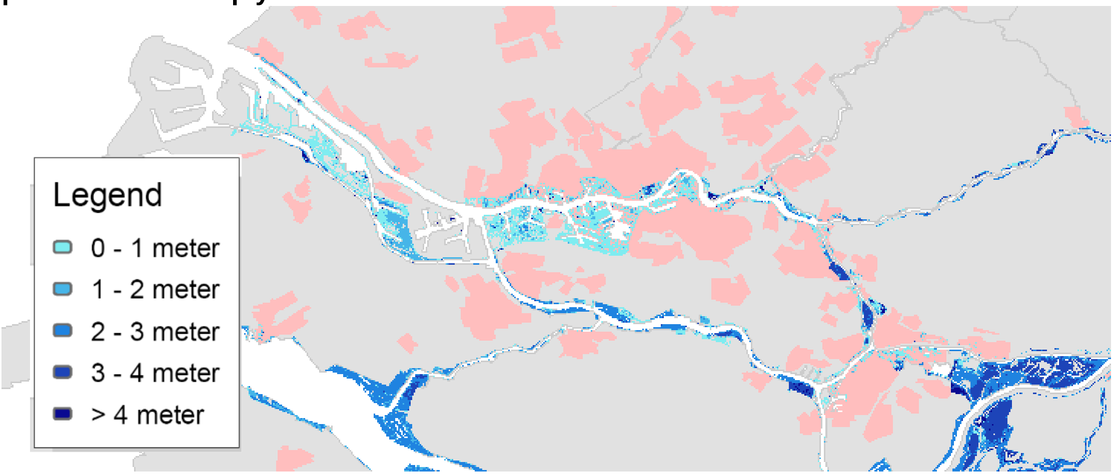


Figure 7.3 Inundation depth in 2050 and 1/10,000 year frequency. Maasvlakte 2 has not been plotted on this map yet.



7.3 Additional scenarios due to flooding for the worst case

It is assumed that during flooding, a hazardous event will take place, which is identical to the worst-case scenario, as presented in section 7.1. The cause leading to the event is however different. Also, the effects and consequences might be different. Next section presents effects and consequences in scenarios with flooding and scenarios without flooding. For this particular case study the following causes where identified, leading to these worst-case scenarios.

a) Low water levels (~ 0.1 m) can cause buoyancy effects of empty or gas-filled pipelines. Destabilization due to erosion by local high velocities may also result in local scour holes underneath pipelines supported on ground level. The consequences include multiple pipeline rupture, resulting in airborne emissions and water pollution. Water pollutions may spread by water (provided that the density is lower than the density of water) or when the toxic goods are dissolved in water may react with water. In both cases, toxic substances will evaporate. As a result airborne emissions may reach high concentrations over large areas, due to the fact that the water distributes the material over large areas.

b) For higher water levels (~ 1 m) there may be additional damage of pipe lines, tanks and vessels due to floating objects and debris. Waves and wind may result in bumping behaviour of floating objects resulting in serious damage. The amount of leakage can exceed the consequences due to multiple pipe rupture, because also elevated storage facilities and process installations are subject to flooding.

The probability of these scenarios to occur, given flooding, is assumed to depend on the flood depth. Flood velocity is not taken into account in this study, because we assume that for the typical application of unembanked areas, higher flood depths will also lead to higher velocities during flooding and run-off, and hence a higher probability of failure is included in the estimate of probability. The conditional probabilities below have been based on the information from the first workshop.

Flood depth 0.1 m: 1%
Flood depth 1 m: 10%

Text box 7.1 presents the failure probability as a function of water level and velocity. The probability of failure following this relation would be 0% for 0.1 m and 55% for 1 m. For water levels >1m, the probability will further increase. It can be assumed in the Port of Rotterdam, preventive measures have been taken to a certain extent as the high water can be forecasted and the facilities are warned on beforehand. These prevention procedures have been (although only recently) defined for industrial companies in the Port of Rotterdam (within the program Waterproof). Knowledge on impact of these procedures on the total risk of flooding does not exist though, due to a lack of experience. The study in textbox 7.1 assumed catastrophic dyke breaches without any warning. The relative high release probability as assumed in the study from textbox 7.1 is assumed to be too high for the fore ying study. The damage probability of 55% seems too large for the Rotterdam situation. An overview of all scenarios, the frequency of occurrence and the specific circumstances are summarized in the table below.

Table 7.1 overview of all scenarios, the frequency of occurrence and the specific circumstances

	Worst cases excluding flood		**Flood cases**		
Process Hazards Analysis	Maleic Anhydride	Hexafluorpropene		Flood depth 0,1 m	Flood depth 1 m
Frequency (once in x years)	1.0E+04	1.0E+04	Frequency (once in x years)	1.0E+04	1.0E+05
	-	-	Likelihood of conditions specified below in case of flooding	1%	10%
Total frequency	1.0E+04	1.0E+04	Total frequency	1.0E+06	1.0E+06
Primary cause	tank rupture, pool of 27 m^2	3" nozzle rupture			
Wind	1,5 m/s	1,5 m/s	Wind	12 Beaufort from sea	12 Beaufort from sea
			Waves	only on edges and low points	< 0,5 m limited by depth
			Tides	2 extreme tides	2 extreme tides
Emission Period	2 hours leakage time; large scale emissions < 1 hour due to solidification	12 minutes	Period	10 hours (total storm duration up to 50 hours)	10 hours (total storm duration up to 50 hours)
Measures			Measures		
Warning x days in advance	none	none	Warning x days in advance	2-5	2-5
Procedures available	yes	yes	Procedures available	yes	Yes

7.4 Effects and consequences of a worst case scenario including flooding

For this case study, several types of consequences were identified. A consequence is defined as an event happening as a direct result of flooding. These consequences were discussed in an expert meeting during the workshop of Phase A. In this particular case study, 2 hazard events are assumed. Information in this case study is derived from in-house experience of a safety assessment of a chemical installation. Although these are realistic scenarios, a more detailed and case specific analysis is required. Effects are defined as the impact of an event on people, environment, business etc. The consequences of flooding were used to determine the effects in terms of casualties, injuries, societal disruption, environmental damages, and economic damages.

Consequences of an emission scenario during flooding

Single or multiple pipe rupture is assumed to be a large risk resulting from flooding. This scenario can be caused by a combined impact of tidal variations, flooding and water run-off over large areas. In case of flooding, the simultaneous impact of emissions on a lot of locations and the impact of release of toxic substances in the river might scale up risks to a high level, resulting in health effects at a large distance from the event. Pipe or nozzle rupture will result in airborne emissions and water pollution. A less frequent case is damage to piping, tanks and vessels by floating objects.

If the released hazardous goods are spread out by the water running off the industrial site (if the density of the released goods is lower than the density of water) or when the goods can dissolve in the water and generate heat by the chemical reaction, toxic substances can evaporate. As a result airborne emissions may reach high levels over large areas; e.g. ERPG 2 level over a distance of 5 km or more from the event. Toxic substances can evaporate, both direct and indirect from the water surface. As a result airborne emissions may reach high levels over large areas. The duration of high airborne emission levels should be compared with the ERPG duration limit of 1 hour. When the duration exceeds 1 hour, the health effects are likely to increase.

Effects of an emission scenario during flooding

The number of people affected by these emissions depends on the population density in the affected area. In an average urbanized area the population density equals about 2000 persons per km^2. People experiencing a cloud to an ERPG 2 level experience or develop serious and potentially irreversible health effects when exposed for a period longer than 1 hour. Depending on the water level and wind conditions, the duration of the exposure could exceed 1 hour.

The two consequences of two cases of Maleic Anhydride and Hexafluorpropene are compared with the two flooding cases. The table on the next page presents the consequences and effects of the worst-case scenarios including flooding and without flooding. By setting the consequences and effects next to each other, one can define whether flooding has a worsening effect or not. Doing so, one can see whether flood risks are substantial in the total safety assessment of a chemical plant. Also, a quantitative estimate can be made for the scenarios with flooding, using the known worst-case scenario without flooding as a starting point. From the analysis, it was seen that for the two hazard scenarios in case of no flooding, the rupture of a 3" nozzle shows the most effects. Therefore the flooding cases are compared to this worst case only. Annex F shows the complete table including the Maleic Anhydride case.

Table 7.2 Comparison of effects of cases including flooding to the worst case without flooding (in yellow, intensified effects and consequences are highlighted) based on existing safety assessment reports of a chemical installation (see Section 7.1).

	No Flooding	**Flooding**	**Flooding**
	Worst-case (nozzle rupture)	consequences compared with worst case excluding flood (grey column)	consequences compared with worst case excluding flood (grey column)
Process Hazards Analysis	Hexafluorpropene	Flood depth 0,1 m	Flood depth 1 m
IDLH effects downwind	no offsite effect	no offsite effect	no offsite effect
Number of people in IDLH area	2 operators	less (site evacuation)	less (site evacuation)
ERPG 3 offsite effects downwind	0,1 km^2	no offsite effect (strong wind)	no offsite effect (strong wind)
Number of people in ERPG 3 area	10	n.a.	n.a.
ERPG 2 offsite effects downwind	8 km^2	less to comparable	Comparable (large cloud + water contamination)
Number of people in ERPG 2 area	1000	100	2000
Duration of ERPG 2 concentrations	< 1 hour	> 1 hour	1 day (leak difficult to stop)
Total impact to public health	exposure time within ERPG 2 limits	100 people in area with ERPG2 concentration, duration exceeding 1 hour, resulting in irreversible health effects	2000 people in area with ERPG2 concentration, duration far exceeding 1 hour, resulting in irreversible health effects
Claims resulting from injuries	10 x E6 Euro	10 x E6 Euro	200 x E6 Euro
Consequences for society	minor	minor	minor
Environmental effects	significant contamination of air, limited water pollution	significant contamination of air, water and soil	significant contamination of air, water and soil
Cultural damage	minor	minor	minor
Damage to nature	minor	limited;	along the river up to 10 km from event
Economic damage			
- public property damage	minor	limited;	fouling by oil
- downtime	2 months	comparable	5 months
- in site property damage	5 x E6 Euro	comparable	50 x E6 Euro
- business interruption	50 x E6 Euro	comparable	comparable
- consequential damages	2 weeks for logistic adjustment for delivery of products from other sources	comparable	comparable

The effects as quantified in the table above are used to estimate the casualties which can be expected due to flooding of a chemical installation in unembanked areas. Although immediate deaths (IDLH) are not expected, the significant health effects could still result in casualties. Therefore, an estimate was made of the potential casualties based on the affected persons and health effects. It is assumed that a limited number of casualties are expected in both cases, order of magnitude 10 people. This number will be used in the next chapter.

7.5 Conclusions flood risk assessment case study

The case study was intended to estimate the order of magnitude of the flood risk of a chemical installation due to flooding. A methodology has been proposed for this study, which follows standard procedures in the chemical industry. Using emission calculations from a known worst-case scenario in combination with knowledge about flood circumstances, a judgement on the effects and consequences was made. The following conclusions can be drawn, based on this hypothetical however realistic case study.

- The number of expected immediate casualties as result of flooding of the installation as presented in the case study will not increase due to flooding. This means that the number of offsite casualties for this case study is limited to nil. This also means that flooding does not increase the effects of the release of hazardous goods with respect to casualties.
- The health effects of the worst-case scenario including flooding might however be worse than the health effects without flooding (~100 health effects, compared to ~10 health effects): the toxic material can be distributed by water to distant locations. In addition, the scale of simultaneous damages is expected to be larger due to flooding of the whole industrial site. These factors are fundamentally different from a worst case situation in which the hazardous goods are contained on the dry soil in a situation without flooding.

The table below presents the results of a quantitative estimate of casualties, affected persons, economic damage and cultural damage. These estimates are based on the considerations above.

Table 7.4 Overview of effects on casualties, affected persons, economic damage, environmental damage and cultural damage based on the case study (taken from table 7.2)

	Worst Case Scenario **No flooding**	**Worst case scenario** **Including flooding**
Casualties	None / limited	None / limited
Affected persons (health effects)	1000 (~10 health effects)	1000-2000 (~100 health effects)
Economic damage	10-100 million euro (plant, down time, claims)	Idem
Environmental damage	minor	Significant
Cultural damage	None	None

The following additional remarks are made with regards to the conclusions:

- The area which is affected by releases and emission of hazardous goods during a flooding event increases due to distribution by water running off the industrial site: the toxic water can flow from the site towards urban areas. This results in more severe effects for a case including flooding.
- However, the effect of a large wind speed is to be taken into account as well. Wind has a dispersive effect on emissions; hence the “worst-case” scenario under normal operations mostly occurs under low wind speed conditions. Contrary to this, flooding will occur under high wind speeds. This has a positive effect on airborne emissions reducing the consequences and effects of release. This results in less severe effects for a case including flooding.
- An industrial site will likely be (partly) evacuated during flooding, as a flood event can be predicted with a prediction time of 2 days – 5 days in advance. Also mitigating measures are taken when a flood is forecasted. This results in less severe effects for a case including flooding.

8 RISK EVALUATION

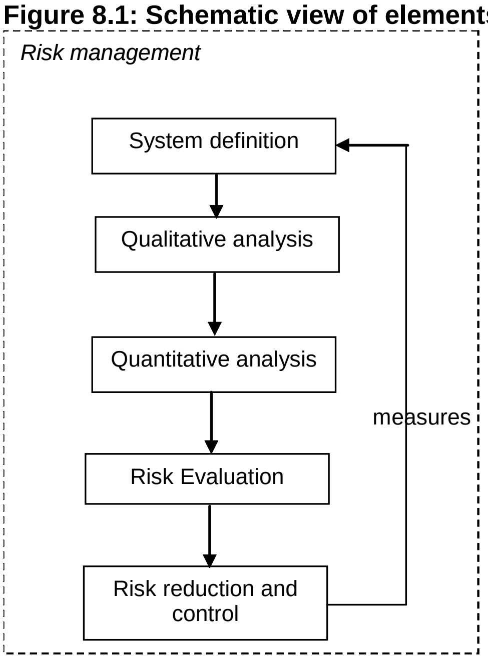
In this section the additional risks due to flooding of chemical facilities in areas unembanked by flood defences is discussed in the context of risk evaluation frameworks.

8.1 Background: risk evaluation

Different elements can be recognized in risk management (see also figure 10-1).

- System definition: Definition and description of the system, its elements and the scope and objectives of the analysis.
- Qualitative analysis: Hazards, failure mechanisms and scenarios are identified and described.
- Quantitative analysis: The probabilities and consequences of the defined events are determined. The risk is quantified in a risk number or graph as a function of probabilities and consequences.
- Risk evaluation: With the results of the former analyses the risk is evaluated. In this phase the decision is made whether the risk is acceptable or not.
- In addition, risk management also includes the element ‘risk reduction and control’:
- Risk reduction and control: Dependent on the outcome of the former phase measures can be taken to reduce the risk. It should also be determined how the risks can be controlled, for example by monitoring, inspection or maintenance.

Figure 8.1: Schematic view of elements in risk management



This section deals with risk evaluation. In the risk evaluation phase it is determined what level of risk associated with a certain activity is acceptable. Or, in other words, it is attempted to answer the question “how safe is safe enough?” (Starr, 1967). The results of the quantitative risk analysis provide the input for risk evaluation and decision-making. Several political, psychological and social processes play an important role in the evaluation of the risk, making it a subjective process. Thereby it is different from the previous phases in risk management (system definition, qualitative analysis and risk estimation) which are focussed on making an (objective) calculation of the risk.

To support decision making societal views on acceptable risk levels can be expressed in quantitative risk limits or regulatory safety goals. These indicate the acceptable probability of an event with certain consequences (e.g. by means of an FN limit line) or the acceptable level of personal risk. Such limits reflect the societal value judgement regarding an activity in a quantitative risk limit. However, other approaches are available, e.g. formal decision theory and more process-based approaches, for risk evaluation – see (Jongejan, 2008) for further background.

A few relevant issues regarding risk evaluation are outlined below:

- Judgement and acceptance of risks associated with certain (new) techniques or activities involves a societal trade-off between risk costs and benefits, or pros and cons. The consequences of the selection of certain risk limits (e.g. costs and number of installations that have to be closed or moved) will be important
- The level of generally accepted risk is related to the perception and voluntariness of an activity. It was first shown by (Starr, 1967) that the public is willing to accept larger risks from voluntary and beneficial activities than from involuntary activities. For example, people will accept a higher risk when they go mountain climbing (app. A 1/100 or 1/1000 probability of getting killed per year for active climbers) than from a chemical or nuclear installation in their surroundings (risk will be smaller than 10^{-6} per year) – see also (Vrijling et al., 1998).

Based on these points it is clear that:

- Risk limits cannot be proposed from a purely technical perspective (only). The characteristics of the activity under consideration, the costs and benefits of interventions and the interests and responsibilities of the various stakeholders have to be taken into account.
- Risk limits cannot be copied from one domain to another.

Nevertheless, comparison of different risk levels and perspectives on acceptable risk can be useful for the further development of policies related to risky activities.

8.2 Perspectives for risk evaluation

In this section different perspectives and frameworks are summarized that could be relevant for the evaluation of the risks for port infrastructure in unembanked areas.

Existing safety standards and perspectives from different fields of application have been analysed. These include the standards for external safety, existing and proposed safety standards for primary flood defences, the frameworks that have been proposed for Maasvlakte 2 and by the province of South Holland.

The table on the following page gives an overview of the frameworks and their main characteristics. These include:

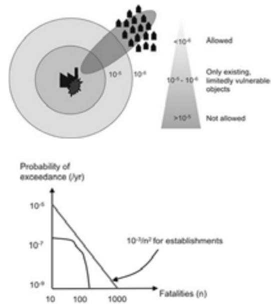
- The name of the framework;
- The field of application (external safety, flood risk, others);
- The risk and consequence categories taken into account (e.g. serious health effects, loss of life, damage, environmental damage or societal disruption);
- The existence of quantitative safety standards / risk criteria and their form;
- The purpose of the framework and safety standards;

Information on the parties involved and their roles:

- The party that proposes and imposes the standards;
- The party that is responsible for managing the risk and reducing the risk if it exceeds the standards / risk criteria;
- Remarks regarding the applicability of the framework to chemical installations in areas unembanked by flood defences.

The first 4 frameworks are the most relevant for the present study and will be worked out in more detail in the following sections.

Table 8.1 Different Risk Evaluation Frameworks. The first 4 frameworks are discussed in more detail in the following sections

Framework / perspective	**Takes into account**	**Applied to**	**Quantitative standards – format**	**Purpose**	**Standards / guidelines, Imposed / proposed by**	**Managed by**	**Remarks regarding applicability**	**Source**
Draft Policy proposed by province of South Holland (FRAMEWORK 1)	• Loss of life (and injuries) • Societal disruption • Economic damage to individuals and companies • Environmental damage • Damage to cultural values (metrics proposed in HKV report)	All developments in areas unembanked by flood defences in province of South Holland (excluding coastal areas)	No, only draft ideas for standards for individual risk and societal disruption *(note by Haskoning: some unusual risk metrics have been proposed, e.g. nr. Of exposed days / ha / yr)*	Provide guidance for flood protection and development in unembanked areas. Policy is draft and will be tested for a year.	Province South Holland	Province South Holland, measures have to be implemented by (often private) developers of areas / facilities	Relevant. Framework mainly focused on urban functions, no specific attention for chemical installations or other port infrastructure	Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland - Voorlopige Nota (GS ZH, 2009)
Existing standards for flood defences (FRAMEWORK 2)	Occurrence of flooding due to exceedance of extreme water levels. Safety of the flood defence (return period of hydraulic boundary conditions and strength of the flood defence)	Primary flood defences	Yes - Prob. Of exceedance of extreme water levels	Ensure safety of primary flood defences and areas behind the defences	Central government	Various government organizations (water boards, central government, provinces)	Difficult: prob. Of exceedance of design water is not a useful concept for chemical installations)	Wet op de waterkering (1996)
External safety (FRAMEWORK 3)	Loss of life -> individual and societal risk	Hazardous installations	Yes – IR, SR standards 	Limit the risks to external parties for hazardous installations	Central government	Private parties responsible for the installation	Seems relevant, as additional risk could possibly have to be evaluated within this framework (see discussion in section 11.4)	Besluit Externe veiligheid inrichtingen (BEVI 2004)
Safety frameworks by plant owners (FRAMEWORK 4)	accidents with lethal or adverse health effects – see example in appendix	Hazardous installations	Yes - Probability of accidents with lethal or adverse health effects – see example in appendix	Limit the risks to internal and external parties for hazardous installations	Owner of the hazardous installation	Private parties responsible for the installation	Relevant	Industry standards, e.g. by DuPont, Shell (confidential)
New concepts for flood protection standards	Flooding probability, derived based on: • Economic risk (CBA) • Individual risk • Societal risk	Primary flood defences	Not yet- format will be a flooding probability per dike ring.	Ensure safety of primary flood defences and areas behind the defences	Central government	Various government organizations (water boards, central government, provinces)	Flooding probability itself is not directly applicable, but concepts of economic, individual and societal risk could be useful for evaluation.	Concept nationaal waterplan / beleidsnota waterveiligheid (Min V&W, 2009)
Maasvlakte 2	Requirement for safety of flood defences and flooding probability of Maasvlakte 2, based on: • Economic risk (CBA) • Individual risk • Societal risk The above factors were derived from the TAW / Vrijling framework • In add. Environmental risk has been considered	Terrain height of Maasvlakte 2	No – method proposed by TAW / Vrijling, resulting in an optimal / acceptable terrain height	Ensure safety of people, objects and values on Maasvlakte 2.	Proposed by Port of Rotterdam; standards formally set by Rijkswaterstaat	Minimum terrain height set by Havenbedrijf. Private parties can choose to heighten terrain height further to reduce risk	Approach and concepts seem applicable. Values are not directly transferable.	Veiligheid tegen overstroming van Maasvlakte 2 - (HbR, 2005)
Draft study by the ministry of Transport, Public Works and Water Management	Broad investigation of bottlenecks in unembanked areas. Considering: • economic risk • loss of life • processes and policy aspects Loss of life (individual and societal risk) explicitly mentioned as risk indicators	Flood risk in unembanked areas	No – no primary responsibility of central government for unembanked areas	Broad investigation of bottlenecks in policy development for risks for unembanked areas.	Not by central government	-	Does not give criteria for risk evaluation that can be applied to port infrastructure	Inventarisatie knelpunten waterveiligheid buitendijks (Arcadis voor DG Water, 2009)

8.3 Evaluation of the additional risk due to flooding of chemical installations

8.3.1 Introduction and approach

In this section the additional risk due to flooding of chemical installations in the port area is discussed in the context of different risk evaluation frameworks.

As input for this elaboration the risk estimate from section 7.4 is summarized below.

- The scenario concerns Rupture of a 3” nozzle from a hexafluorpropene tank
- The probability of occurrence of this scenario is estimated to be in the order of magnitude of 2.10^{-6} per year. This estimate is motivated as follows:
  - The conditional probability of this scenario for a 0.1m water depth is 1%. The probability of occurrence of this water depth is about 10-4 per year.
  - The conditional probability of this scenario for a 1m water depth is 10%. The probability of occurrence of this water depth is about 10-5 per year.
  - The total probability of occurrence is found by multiplying the probability of a water depth and the conditional probability for the scenario. Addition of the two previous estimates results in an estimate of 2.10-6 per year.
- The consequences are summarized in the table below. In a conservative estimate it is estimated that the number of casualties is in the order of magnitude of 10 people.

Table 8.2 Overview of effects on casualties, affected persons, economic damage, environmental damage and cultural damage based on the case study

	Worst Case Scenario **No flooding**	**Worst case scenario** **Including flooding**
Casualties	None / limited	None / limited
Affected persons (health effects)	1000 (~10 health effects)	1000-2000 (~100 health effects)
Economic damage	10-100 million euro (plant, down time, claims)	Idem
Environmental damage	minor	Significant
Cultural damage	None	None

This information has been used for a first order estimate of the (additional) individual and societal risk. The additional societal risk concerns a scenario with a probability of 2.10^{-6} per year and 10 fatalities.

The (additional) individual risk level is determined by a) the probability of an accident scenario; b) the probability of getting killed at a certain location. The scenario probability is estimated to be 2.10^{-6} per year. The probability of getting killed is dependent on the distance to the installation and the exposure to effects. This probability decreases with the distance to the installation. In principle, a consequence and mortality analysis would be required, but is not available. Therefore the probability of getting killed for a person living in the vicinity during and accident is conservatively estimated to be 10% or lower. By combining both numbers the additional individual risk is estimated to be 10^{-7} per year.

Selected frameworks
Based on the remarks regarding the applicability of different frameworks and discussion with the client on relevant policy developments a number of frameworks have been selected for further elaboration. These include:

- Framework 1: Policy framework by the province of South Holland: this framework is specifically developed for unembanked areas in the Rijnmond area. The chemical installations in the port area are located in the unembanked area.
- Framework 2: Comparison with the risks of flooding of dike ring South Holland: it is relevant to compare the flood risk in unembanked areas with the risks of (embanked) dike ring areas.
- Framework 3: External safety regulations in the Netherlands: chemical installations are part of the external safety policy
- Framework 4: Safety frameworks by plant owners: relevant as chemical companies evaluate their own risks from different sources.

The risk estimates are discussed in the context of these frameworks in the following paragraphs.

8.3.2 Framework 1: Policy framework by the province of South Holland

The policy framework proposed by the province of South Holland concerns the evaluation of the risks of new developments in areas unembanked by flood defences in province of South Holland.

In the policy and the underlying documentation it is proposed to take a number of consequence categories into account. The order of magnitude of the consequences for the case study has been described for every category:

- Loss of life (and injuries): In the technical report (HKV, 2009) the individual risk is proposed as a metric for evaluation and a threshold value of 10^{-6} per year is proposed. The calculated additional risk is in the order of magnitude of 10^{-7} per year and smaller than the threshold value.
- Societal disruption: for the scenario hundreds to thousands of people could be affected and experience health effects. Thereby the societal disruption is likely large.
- Economic damage to individuals and companies: the economic damage to the company is estimated to be in the range 10 – 100 million Euros. This is significant damage, but mainly to the company itself.
- Environmental damage: depending on the materials and chemicals that are released substantial pollution is expected.
- Damage to cultural values: no damage is expected.

For comparison the judgment of the risks for chemical facilities from phase A is included below. This corresponds to the above evaluation.

Figure 8.2: Overview of the judgement of the (additional) risks of chemical facilities from phase A (also see section 5.2)

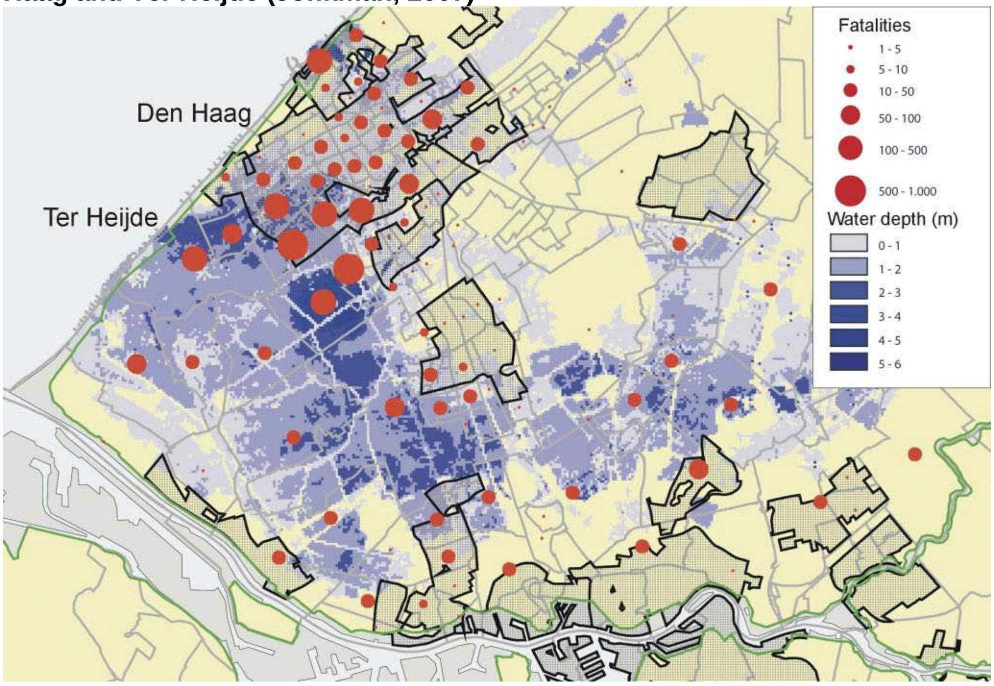
	Effect of flooding	Probability of damage given a flooding event	Casualties	Societal disruption	Environment	Economical damage
Facilities	Cable trays are on ground level => spills + release of toxic goods + interruption of processes. Instability of construction of installation, for instance distillation columns built on footings					
Process installations	Rupture / damage of (empty) pipelines					
Pipelines	Corrosion of (salt) water in installations					
Cooling installation	Power failure => uncontrollable processes					

Overall, it is expected that societal disruption and economic damage (for the company itself) will be the most relevant consequence types for the case study within the policy framework of South Holland.

8.3.3 Framework 2: Comparison with the risks of flooding of dike ring South Holland

This section concerns the comparison with the risks of flooding of dike ring South Holland. An extensive risk study on the flood risks to people for this dike ring was executed, see (Jonkman, 2007; Jonkman et al., 2008) for details. South Holland is one of the largest flood prone areas in the Netherlands. The area has 3.6 million inhabitants and it is also the most densely populated area in the country and includes major cities. As an example the results in terms of flooding and casualties for a more severe coastal flood scenario with breaches at two locations (Den Haag and Ter Heijde) is considered. In this case an area of approximately 230 km^2 could be flooded with more than 700,000 inhabitants. It is expected that the possibilities for evacuation of this area are limited because the time available for evacuation (approximately one day) is insufficient for a large-scale evacuation of this densely populated area. Eventually it is calculated that this flood scenario could lead to more than 3000 fatalities. Figure 8.3 shows the flooded area and the spatial distribution of the number of fatalities estimated with the method described above.

Figure 8.3: Fatalities by neighbourhood and flooded area for the scenario with breaches at Den Haag and Ter Heijde (Jonkman, 2007)



This approach can also be used in the context of flood risk assessment by evaluating different flood scenarios and their probabilities and consequences (Jonkman et al., 2008). Figures 8.4 and 8.5 show the calculated levels of societal risk and individual risk. The probability of death for a person in South Holland due to flooding, the so-called individual risk, is small and in most areas lower than 10^{-6} or 10^{-7} per year. The probability of a flood disaster with many fatalities, the so-called societal risk, is relatively large in comparison with the societal risks in other sectors in the Netherlands, such as the chemical sector and aviation. For example, it is estimated that the probability of an event with 1000 fatalities is about 10^{-4} (1/10,000 per year). For purposes of comparison the (additional) societal risk for the case study is indicated in the societal risk graph. It shows that the additional societal risk of the case study is much smaller than the societal risk for the dike ring. This is no surprise as the number of potentially affected people in the dike ring is large, but much smaller for the individual installation. The (additional) individual risk for the case study is of the same order of magnitude as the individual risk in the dike ring. To date, no policy has been defined with regards to an accepted standard for the individual risk flood risk nor a standard for group risk. These standards are being developed in the coming years.

Figure 8.4: Societal risk estimate for flooding of South Holland

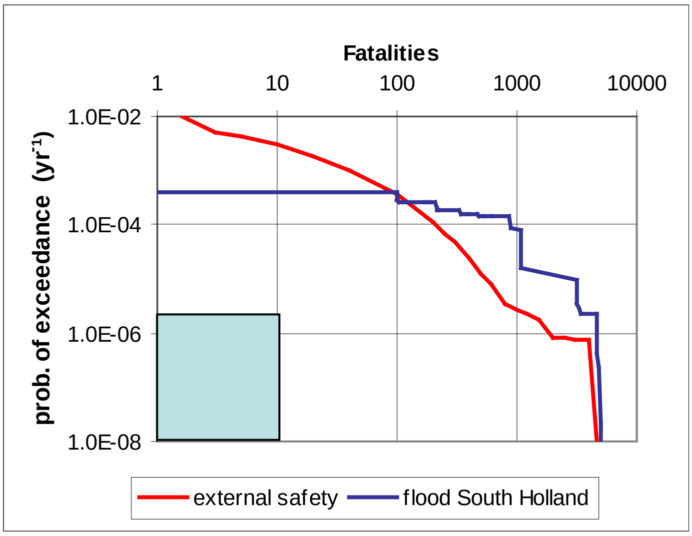
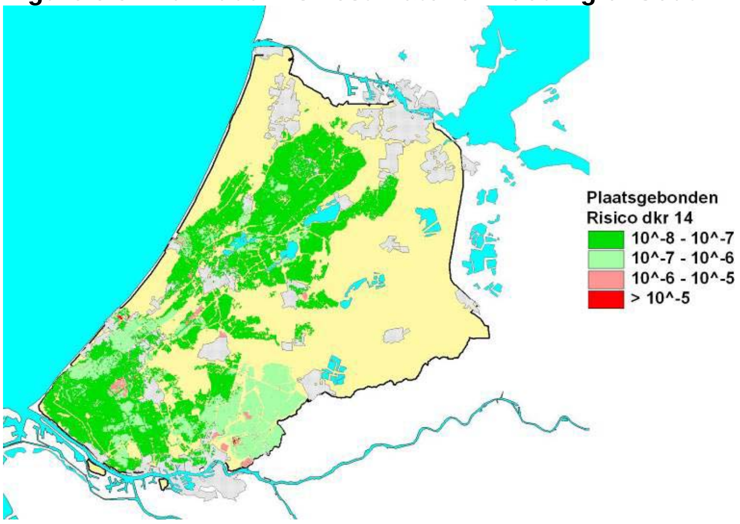


Figure 8.5: Individual risk estimate for flooding of South Holland



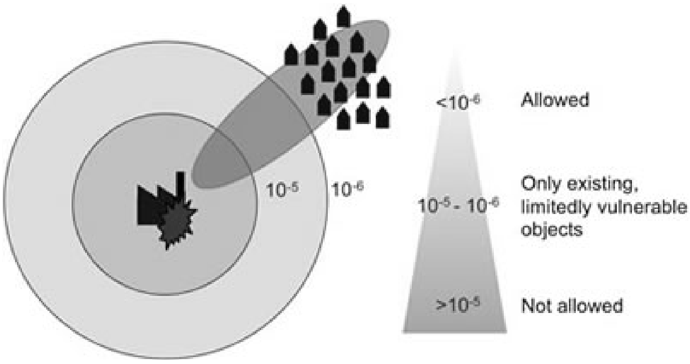
8.3.4 Framework 3: Comparison with external safety standards

Introduction to external safety / the Dutch major hazards policy

Dutch major hazards policy deals with the risks to those living in the vicinity of major industrial hazards, such as chemical plants and LPG-fuelling stations. The cornerstones of the Dutch major hazards policy are (i) quantitative risk analysis, (ii) individual and societal risk as risk-determining parameters and (iii) quantitative acceptability criteria for evaluating levels of individual and societal risk (Ale 2002; Bottelberghs 2000). Individual risk is defined as the probability of death of an average, unprotected person that is constantly present at a given location.

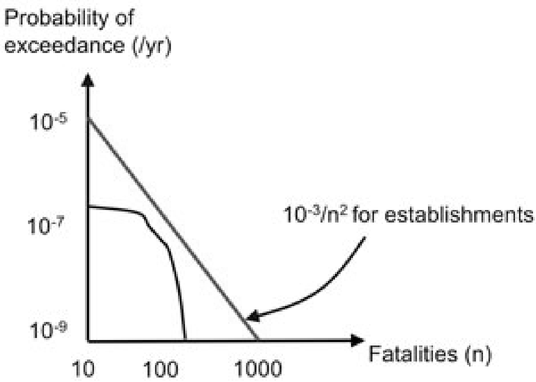
Individual risk criteria are reference levels for evaluating individual risks. The individual risk criteria were given a legal status in 2004 by the External Safety Decree. These limits to individual risk prevent disproportional individual exposures. Permits for property developments or plant modifications are denied if vulnerable objects would then be located within the 10^{-6} contour (Fig. 8.5).

Figure 8.5: Individual risk contours around a hazardous establishment and the area affected by an individual accident scenario



An individual risk criterion alone cannot prevent the too frequent occurrence of multi-fatality accidents. As shown in Figure 1, the area affected by an accident can differ considerably from the area that is defined by an iso-(individual) risk contour. When individual exposures are low, there could still be a chance that a single accident kills a large number of people. While a vast number of small accidents can go by without hardly being noticed, multi-fatality accidents can shock a nation. Psychometric studies have indeed shown that “dread”, or catastrophic potential, is an important factor in explaining risk perceptions (Slovic 1987). To prevent the too frequent occurrence of large-scale accidents, societal risk criteria were implemented in the Netherlands. Societal risk is graphically represented by an FN-curve that shows the exceedance probabilities of the potential numbers of fatalities ($P(N\geq n)$) on double log scale (Fig. 8.6).

Figure 8.6: The Dutch societal risk criterion for hazardous establishments and a fictitious FN-curve.



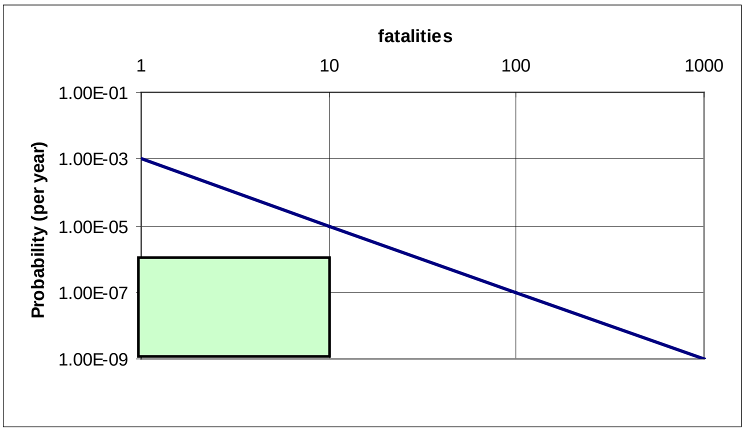
The Dutch societal risk criterion of 10-3/n2 per installation per year was initially developed for LPG-fuelling stations. It was later applied to all Seveso establishments. Similar societal risk criteria thus apply to hazardous establishments of different character and size, despite considerable differences between the marginal costs of risk reduction in different cases (see Jongejan (2008) for further discussion).

Additional risks due to flooding of chemical facilities

The estimates individual and societal risk levels are compared with the limits for external safety. Figure 8.7 shows a comparison between the (additional) risk for the case study and the societal risk limit for installations (indicated in green). It is clear that the risk is smaller than the limit for installations. It is noted that in fact the risk due to flooding should be added to the normal risk. In this context it is noted that both the axes of the FN curve are logarithmic, the more to the right on the horizontal axis the smaller the visual contribution of an additional event with 10 fatalities becomes.

Regarding the individual risk it is estimated that the additional contribution from flooding (order of magnitude 10^{-7} per year or smaller) is below the individual risk limit of 10^{-6} per year.

Figure 8.7: Comparison between the societal risk limit (blue line) and the additional risk due to flooding (green).

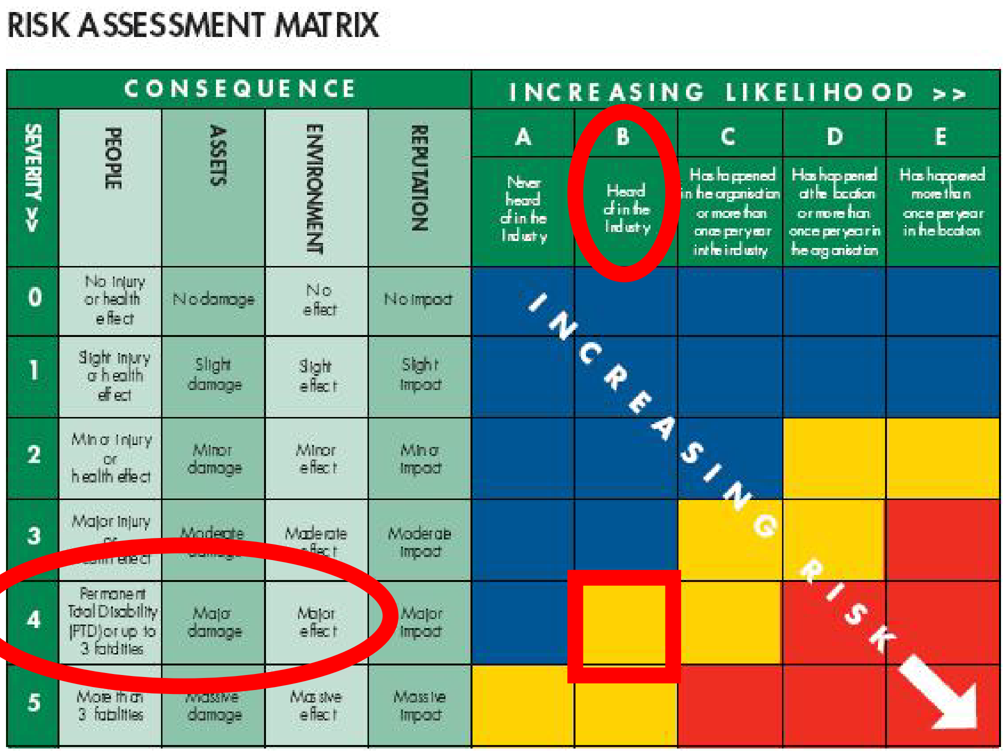


8.3.5 Framework 4: Discussion in the context of safety frameworks by chemical industry

Companies within the chemical industry have adopted their own safety and risk policies to ensure the safety of their companies, installations, employees and the surroundings of the company. The risk of the installation is evaluated by considering the probability / frequency of accident and the consequences.

An example of such a “risk assessment matrix” is given in figure 8.8. It considers a qualitative description of the accident frequency (horizontal axis) and several consequence categories on the vertical axis. By combination of the two, the overall risk can be positioned in the matrix. Depending on the position of the quantified risk, it can be judged how the risk should be treated and this is a basis for further analysis for the need of risk reduction measures. In the figure the (additional) risk of the chemical installation has been indicated. It is recommended to involve companies on the discussion on the evaluation of this type of risk and the judgment for a further need of risk reduction measures.

Figure 10-8: Risk assessment matrix (source: http://www.eimicrosites.org/heartsandminds/userfiles/file/RAM/RAM%20PDF%20brochure%20sample%20pages.pdf , accessed Feb 2010) and judgement of the additional risk due to flooding of chemical installations



8.4 Discussion regarding risk evaluation

A number of closing remarks are made following the analyses in this section.

- In general, it is expected that the additional risk of flooding of chemical facilities is relatively small for sufficiently high elevated areas unembanked by flood defences (> NAP + 5.5 m). The flooding and consequent accident frequency is relatively small.
- The (additional) risks in these areas are small relative to the risks of flooding of embanked areas, such as South Holland, and are expected to be acceptable for most cases within the frameworks of external safety policy and chemical companies.
- Overall, it is expected that societal disruption and economic damage (for the company itself) will be the most relevant consequence types for the case study that should be further evaluated within the policy framework of South Holland.
- Eventually, if it is concluded in the risk evaluation that if the current risks are not acceptable, additional risk reduction measures should be taken. These could consist of:
    - Structural measures: such as raising the terrain to reduce the flooding probability, or a (more) flood resistant design of the facility
    - Measures related to the management of the facility: e.g. a shutdown of the plant or the movement of dangerous goods in a threatening situation or a timely warning and evacuation of people living in the vicinity.
- During a high water or storm surge a large part of the Maasvlakte could be flooded and multiple facilities are affected simultaneously. In this study, the risk for a single (hypothetical) facility has been assessed and assessment of the cumulated risk for multiple installations is recommended.
- The (additional) risks of chemical facilities due to flooding will be dependent on the characteristics of the substance that is affected, the interaction between the substance and water, and the role of the weather conditions (wind, temperature, etc.). Note that this is different from “normal” flood risk assessments were location specific risk assessments are not made, see results of the Zuid-Holland flood case.
- The case referred to one type of scenario and facility. Other substances and facilities could lead to different scenarios and risks, which could in some cases be more severe. Therefore it is needed to consider the additional risks of flooding of chemical installations on a case-by-case basis.

9 DISCUSSION PART B

9.1 Introduction

This chapter summarizes the main issues that were discussed during the second workshop. The objective of the workshop was to share the information from Phase A and the knowledge developed in Phase B. The following presentations were made during the workshop:

- Results of Phase A: Vulnerability assessment of port infrastructure in unembanked areas.
- Methods, and results for the flood risk assessment for the chemical industry in the case study (Chapters 8&9)
- Discussion of these results in the context of risk evaluation frameworks from External Safety Standards and Flood Risk management. The policy as set by the Province of South Holland was taken as reference for this evaluation. (Chapter 10)

Following this, a discussion was held with various experts and stakeholders to evaluate the risk as presented during the presentations and as presented in this report. In the following sections the discussion is summarized. The list of workshop attendees is included in Annex D.

The findings from the discussion are thematically grouped as follows:
- Technical issues regarding the method for risk assessment and the assumptions (section 11.2)
- Issues regarding the further application and implementation of the flood risk assessment for chemical facilities (section 11.3)
- Issues regarding risk evaluation and policy development for unembanked areas (section 11.4)

Where possible, recommendations and follow-up actions are included in the next section.

9.2 Technical issues regarding the method for risk assessment and assumptions

- **More realistic estimates are needed:**
    - The probability of a hazard to occur, given flooding of a chemical installation, has been estimated using expert judgement. For a realistic risk estimate it is necessary to increase the accuracy of the probability estimates. It is noted that the probability estimate could differ for different types of installations and types of products and goods.
    - The dispersion of chemical and toxic goods by water during a flood event has been assessed by means of expert judgement and has not been reviewed in high detail for this study. Further research into this topic would be needed to come to realistic estimates of effects and consequences. It would be interesting to assess one simple case study for which dispersion of toxic goods during a flood event is calculated in more detail using existing dispersion models.
- **More cases and installation types**: More insight into the flood risks for existing installations in the Port of Rotterdam is needed. The study only looked at a hypothetical case study for one installation only. This should be extended to more installations and substance types and look at a specific installation and situation in more detail.
- **Indirect damages** such as interruption of business, damage to society by failure of port functions is not worked out in detail. The topics were discussed during the first phase of the study, but a more detailed study would be worthwhile.
- **Terrain elevations**: the study focused on newly built terrains in Rotterdam and assumptions were made with regards to terrain elevation and flood depth. The existing areas have not been reviewed yet. Hence, terrain elevations, flood depth and flood risk might differ in these areas.

9.3 Further applications and implementation of the flood risk assessment for chemical facilities

- **A practical approach** is necessary for the assessment and evaluation of the risks. Many issues and topics can be mentioned but in the end an evaluation of the risk is required. This can also be done based on limited but reliable information, endorsed by a group of experts and stakeholders. The results of this study and in particular the results of the workshop of Phase A can be used for this.
- **Involve companies**: In this study companies have not been involved. In a follow-up study it is a necessary step to involve companies that have industrial installations in unembanked areas. Involvement of the sector will result in a more accurate risk assessment. The impact and economic damage to companies can also be taken into account.
- **Simultaneous flooding of multiple installations**: Accumulation of risks is a point of concern. The case study assessed the risk of a single installation. It is however likely that during a flood event more installations will flood. If a risk assessment should be performed in more detail for the Port of Rotterdam, the accumulation of risks should be taken into account.
- **Risk estimate for Rijnmond:** For policy development it is important to know the size of the additional risk due to flooding of chemical facilities. It should become clear whether it is a small risk or a larger systemic risk to the whole area. Which areas are particularly vulnerable and should be reviewed in more detail? For instance the Botlek region and Vondelingenplaat are partly urbanized and would experience a higher threat than other areas.

- **Flood risk included in current external safety approach**: It was mentioned during the workshop that in an external safety assessment, it is already required to include significant risks due to external impact (plane crashes, train accident, terrorism). It should be investigated if flood risks should be taken into account under this category. Flooding could be included as an additional hazard scenario in the External Safety Assessments of the chemical industry in unembanked areas. For this, clear standards with respect to circumstances of the event are then required (e.g. flood depths, normative wind speeds, flood duration, waves, etc.)
- **Risks to installations within embanked areas**: During the workshop it was discussed that the additional flood risks for installations within embanked areas could also be relevant and significant. Two major reasons for this is that a) if dike breaches occur the effects (depth, velocity, rise rate) are likely far more severe in the polders; b) it is difficult to take mitigating measures in the plant due to the sudden nature of dike breaches. It is recommended to make a similar risk assessment for chemical installations in areas defended by primary flood defences.
- **Emergency management**: The insights developed in this study could be relevant for emergency management. If a significant threat is foreseen in the port of Rotterdam for a specific chemical industrial location, than crisis management could take this knowledge into account to protect these vital objects.

9.4 Risk evaluation and policy development for unembanked areas

- **Climate change and adaptation:** The effects of climate change have not been included explicitly in this study. It could be relevant to take into account in the risk assessment and, even more importantly, in the planning of new facilities. The concept of adaptation of industrial installations was proposed by one of the participants. The adaptive capacity of chemical facilities could be considered. Future developments such as sea level rise could be accounted for by applying various measures, such as raising of vulnerable parts of an installation, local bund walls or additional measures to mitigate the risks during a crisis situation.

- **Additional terrain height Maasvlakte 2:** The method developed in this study could play a role in assessment of the need for additional terrain height for vulnerable installations on Maasvlakte 2. The new port development Maasvlakte 2 has been designed to a height of NAP + 5m. It was decided that for infrastructure an extra height of 0.5 m is necessary. Developments with hazardous material have to acquire a permit. During the acquisition procedure, the required terrain height is than to be determined based on additional safety assessment of the expected flood risk. It is suggested in the workshop that also for new developments in other unembanked areas, a flood risk assessment should be part of the permit procedure.

- **Responsibilities and problem ownership:** As there are different responsibilities and stakeholders for developments in unembanked areas, it is not a good idea to “copy” policies from external safety of flood defence of embanked areas. Further policy development for unembanked areas should take account of the interests, tasks and responsibilities of the stakeholders.
- **External safety or provincial policy?:** A follow-up question would be whether a flood risk assessment should be included in the policy of the Province of Zuid-Holland, or should it be included in the External Safety Assessment of the chemical industry? Or even both? It is mentioned that flood risk assessment should be included in a Safety assessment procedure in the industry, for instance in the standard HAZOP procedures.
- **Environmental permit:** Flooding is not part of the environmental permit procedure of the chemical industry at the moment. It should be investigated whether or not this is desirable. At present, RIVM is already doing an initial study into this matter. Results of this study will be shared in a later phase.
- **Responsibilities:** If standards for flood risk management will be applied to the industrial developments in unembanked areas, who is than financially responsible if adaptations have to be made? This consideration should be taken into account when the flood risk of installations is evaluated. Additional investments in flood risk are made by the government (construction of dykes, flood structures). For installations, investments should be made in the plant operations.
- **Individual risk**: An external safety standard for the individual risk of 10-6 is also mentioned in the risk methodology document of the Province of Zuid-Holland. If an industrial facility complies with individual risk from external safety, it could imply that it also complies with the Province of Zuid-Holland standards. This might offer opportunities for linking these policies. It was noted that for a single installation this would hold, but for a group installation the effects can be worse due to accumulation of risk. How to deal with this has not been defined yet.
- **Existing situations:** One question that was raised was whether the risks that were studied are also relevant for existing developments. The provincial policy focuses mainly on new developments.
- **Follow-up:** Attendees were also asked which parties should continue with this the knowledge development and take the lead in stimulating this. Governmental parties, The Province of South Holland, the Rotterdam Port Authority, DCMR and Rijkswaterstaat were mentioned as potential lead parties.

10 CONCLUSIONS AND RECOMMENDATIONS PART B

This chapter presents the main conclusions with respect to the work carried out in Phase B, for which also conclusions of Part A were used as input. The conclusions are made with respect to the risk analysis as followed in this study (Chapters 8 and 9) and the risk evaluation of Chapter 10. The studies objectives were formulated as follows:

- What is the vulnerability of port infrastructure in unembanked areas to flooding?
- How do we evaluate this vulnerability to flooding in comparison to other (flood) risks?

The vulnerability of port infrastructure in unembanked areas is given in Part A in a qualitative manner and in Part B in a quantitative manner. Following this, the evaluation of vulnerability was performed using the case study of a chemical installation in Chapter 10.

Special attention is given to the conclusions with respect to the Provincial Policy Document which has been released recently, as the results and conclusions of this study will be read within that context as well. Lastly, general recommendations with respect to the study are given, which stand out most from the conclusions from this study.

10.1 Conclusions

10.1.1 Conclusions flood risk analysis

The conclusions below have been derived from the case study as presented in Chapter 7. Conclusions on the overall flood risk of port infrastructure should be derived based on installation specific information, preferably of all, industrial sites in the Port of Rotterdam rather than one single case study. These conclusions give a first estimate though which are regarded to be representative for this overall flood risk. Considerations have been included in the recommendations in section 12.3.

- The expected number of immediate casualties as a consequence of flooding of a single installation as presented in the case study will not increase due to flooding. This means that the number of offsite casualties is limited to nil. This also means that flooding does not increase the effects of the release of hazardous goods with respect to immediate casualties.
- Following the reasoning during the case study, the health effects of the worst-case scenario including flooding are worse than the health effects without flooding: the toxic material can be distributed by water to distant locations. This is fundamentally different from a situation in which the hazardous goods are contained on the dry soil in a situation without flooding.

10.1.2 Conclusions flood risk evaluation

- In general, it is expected that for sufficiently high elevated unembanked areas (> NAP + 5.5 m), the additional risk of flooding of chemical facilities is relatively small compared to the day-to-day risks of the industry. This is due to the fact that the frequency of flooding and consequent hazard frequency is relatively small, due to the elevated terrain heights.
- The (additional) risks are small compared to risks of flooding of embanked areas, such as South Holland, and are expected to be acceptable for most cases within the frameworks of external safety policy and chemical companies.
- Overall, it is expected that societal disruption and economic damage (for the company itself) will be the most relevant consequence types for the case study that should be further evaluated within the policy framework of South Holland.

10.2 Conclusions of this study from the perspective of the Provincial Policy:

Below, the conclusions with respect to the Provincial Policy document are highlighted. In the policy and the underlying documentation, it is proposed to take a number of consequence categories into account. Based on the first order estimates in this study, the order of magnitude of the consequences for a single case study, in which a chemical industrial site is taken, has been described below for every category.

- **Casualties**: In the technical report (HKV, 2009) the individual risk is proposed as a metric for evaluation and a threshold value of 10^{-6} per year is proposed. The estimated additional risk in this study for a single plant is in the order of magnitude of 10^{-7} per year (or smaller) and thus smaller than the threshold value.
- **Societal disruption**: for the scenario hundreds to thousands of people could be affected and experience health effects. Thereby the societal disruption is likely large.
- **Economic damage to individuals and companies**: the economic damage to the company is estimated to be in the range 10 – 100 million Euros. This is significant damage, but mainly to the company itself.
- **Environmental damage**: depending on the materials and chemicals that are released substantial pollution is expected.
- **Damage to cultural values**: no damage is expected.

The results indicate that the expected number of casualties will be limited for a single chemical plant. Societal disruption will however be large due to a number of health effects.

The following general conclusions can be made concerning the results and lessons learned during this study, which can be used in the evaluation of the draft Provincial Policy document.

- **Including external safety methods in flood risk assessment and policy**: given the complexity and specific considerations which apply to the determination of safety of (industrial) port infrastructure to flooding, it should be considered how, and whether, to include flood risk of the port in the Provincial policy. Should a methodology as presented in this study be used in addition to the present policy document, or should this be integrated? In addition, will a flood risk assessment of port infrastructure be a responsibility of the government or would it be more realistic to include this in the existing External Safety procedures of the industry? These questions should be followed up with relevant stakeholders. The recommendations and conclusions of this study can be used as input.

- **Gaining insight into overall flood risk of the Rotterdam port area by including all port infrastructure rather than a single installation**: It is relevant for the evaluation of the Provincial Policy to gain insight into the flood risk of unembanked areas with respect to all port infrastructure and industry in Rotterdam, rather than a single installation. The cumulation of effects by simultaneous flooding of industrial sites has not been studied yet. For this the flood risk of all installations should be considered as during a flood event it is likely that all installations in the port of Rotterdam will experience flooding. It is concluded that this is an important issue to estimate the flood risk of the whole port area of Rotterdam.

- **Applicability of the Provincial Policy methodology to the port area**: the methodology given in the Provincial Policy for unembanked areas does not include flood risks of port infrastructure or industrial areas. Therefore, the method is not easily applicable to these areas. For instance, in industrial risk assessments, it is common practice to take health effects into account as a result of release of hazardous goods (including chain effects) and casualties as a consequence of this. The Provincial Policy flood risk method does not take this into account explicitly. Casualties are calculated based on a water level and a mortality function. The societal disruption due to failure of port functions has not been quantified in high detail for this study. The Provincial Policy document provides a methodology in which the number of days, per hectare, is calculated for people affected. The applicability of these indicators to port infrastructure is to be studied yet. These (knowledge) gaps with respect to industry and infrastructure is found in the flood risk methods for other (defended) areas in the Netherlands as well. Results and conclusions with regards of the method used in this study can be used to evaluate the possibility and desirability of including evaluation of port infrastructure in the policy document.

- **Knowledge sharing for successful implementation**: During this study, and especially during the 2 workshops, it was observed that the common knowledge base for integrating flood risk assessments and industrial safety assessments is not well developed. In order to successfully implement the Provincial Policy taking into account the flood risk of the industrial port areas, it seems vital to share knowledge between people involved. Without this background knowledge, it will be a difficult task to comprehensively evaluate, on common grounds, the risk of flooding of port infrastructure.

10.3 Recommendations

Below the most important recommendations are presented. These are categorized by

- the risk methodology as developed during this study,
- the application of the risk methodology and
- the evaluation of the risk methodology for policy purposes.

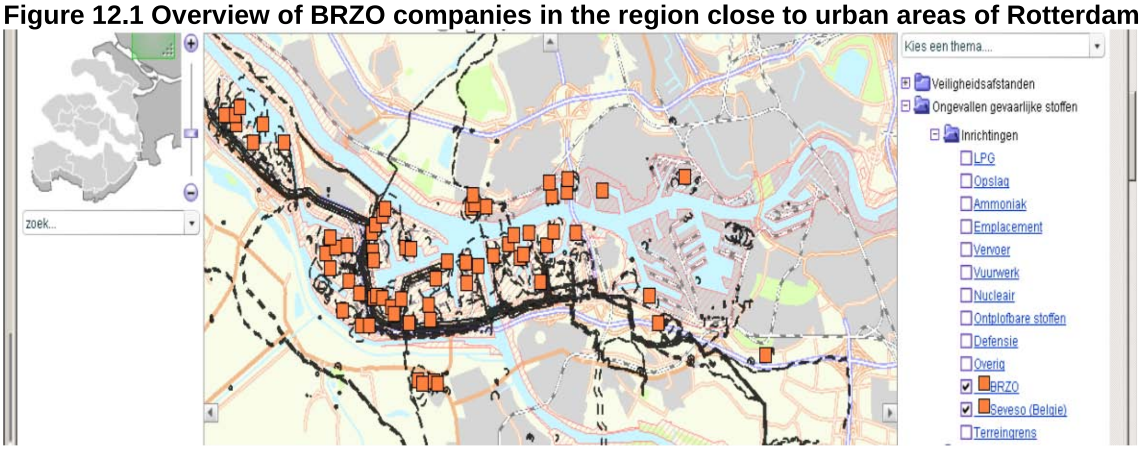
10.3.1 The risk methodology:

- The risk methodology presented in this report should be worked out in more detail. For this, more scenarios need to be included for more hazard types by including more steps in the methodology. It is for instance likely that a wide range of different installation types will have a wide range of hazard events. All event types will have a range of return frequencies.
- Also, a method which includes flood risk in an early stage of a safety assessment of a chemical installation could be considered.

10.3.2 The application of the risk methodology:

- During a high water or storm surge, a large part of the port of Rotterdam could be flooded and multiple facilities are affected simultaneously. In this study, the risk for a single (hypothetical) facility has been assessed and assessment of the cumulated risk for multiple installations is recommended. The concentration of chemical companies in the unembanked areas is high.
- The case study referred to one hypothetical type of scenario and facility. Other substances and facilities could lead to different scenarios and risks and could in some cases be more severe. Therefore it is needed to consider the additional risks of flooding of chemical installations on a case-by-case basis. Preferably, companies should be responsible for this or should play a major part in this because they have the best information.
- It is interesting to present an overview of risks in the port area of Rotterdam. This can be done by defining hotspots in terms of risk for various areas. These hotspot regions will be those areas that are close to urban areas and include hazardous installations. The information provided on www.risicokaart.nl could be a good starting point.

Figure 12.1 Overview of BRZO companies in the region close to urban areas of Rotterdam.



- For this study, newly developed areas have been taken into account in the risk assessment and evaluation, using flood depths representative for the new port development Maasvlakte 2. It is recommended to perform a similar risk analysis to existing areas more land inwards.
- In this study, the main focus was on casualties and societal disruption. The effects to the environment were studied in less detail. The Provincial Policy is not primarily focussing on environmental damage. Note that for embanked areas, an approach to estimate environmental damage due to flooding does not exist. In addition no standards are set for environmental damage to date and hence it will be difficult to define. Nevertheless, given the fact that the case study indicates that significant environmental damage is expected during a flood event, and given the fact that this topic is not well studied, more research is recommended.
- Same recommendation is valid for economic damages. The economic damage to the industry and society, due to flooding, has not been studied in this project to high extent. Quite some literature exists with respect to this topic though, but could be made more specific for research topic of this project.

12.3.3. Risk evaluation and policy development

- At this moment, it is not clear how responsibilities are defined in flood risk management of chemical installations in unembanked areas. Related to this, it is not clear how flood risks should be evaluated: is it a public task of the Province of Zuid Holland (or the municipality of Rotterdam or national government)? Or do flood risks have to be included in external safety regulations in these specific cases? It is recommended to define this in more detail with relevant stakeholders.
- One of the most interesting conclusions during both workshops was that all persons involved were very content about the sharing of knowledge. Experts from different fields of expertise discussed this topic on equal grounds. It is strongly recommended to continue this discussion in the community by combining expertise of port infrastructure, external safety, flood risk management and policy development. This will provide more understanding of the topics as it has been noticed during this study, that external safety methods, risk assessment and risk evaluation are no easy topics for a general public.

10.3 General closing remark

As could be concluded from the above points and the discussion of chapter 11, there are many questions and issues that require further attention and knowledge. An important remark during the workshop was made that this project and the workshops can be seen as a first step in the development of this relevant knowledge and policy field. The combination of knowledge from different fields (external safety, flood risk management) and backgrounds (policy and experts) is what is needed in that process. The professionals that have participated in the workshops and this project will form an important network in this respect. Hopefully initiatives will develop in the nearby future which will continue down this road. This can be the government by means of the Province of Zuid-Holland, but also the chemical industry. One conclusion was that the knowledge from this study should be consolidated and made available to different parties. The information, knowledge and experience developed for this study should be used in the evaluation of the Policy document of the Province of South Holland.

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Appendix A Unembanked areas in Rotterdam region


ROTTERDAM
MAASSLUIS
VLAARDINGEN
SCHIEDAM
ROZENBURG
WESTVOORNE
ROTTERDAM
CAPELLE AAN DEN IJSSEL
KRIMPEN AAN DEN IJSSEL
NEDERLEK
NIEUW-LEKKERLAND
RIDDERKERK
ALBLASSERDAM
ALBRANDSWAARD
BARENDRECHT
HENDRIK-IDO-AMBACHT
SPIJKENISSE
PAPENDRECHT
SLIEDRECHT
HARDINXVELD-GIESSENDAM
ZWIJNDRECHT
OUD-BEIJERLAND
BINNENMAAS
S-GRAVENDEEL
DORDRECHT

Appendix B Vulnerability assessment of port infrastructure

LITERATURE STUDY

Introduction to the literature review

Starting point for this study is a literature review in order to:

- Give the present day knowledge with respect to vulnerability assessments of port infrastructure. Also appreciation of the relevant policy documents for this study is provided.
- Gather information for estimating the flood risk of port infrastructure in Phase B.
- Use information at hand for input in the workshop of Phase A in which an overall vulnerability assessment is made of port infrastructure.

For this study, the following relevant literature has been reviewed.

- Province of Zuid Holland (2008) “Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland”
- HKV en Arcadis (2009) “Risicomethode buitendijks: Methodiek ter bepaling van risico’s als gevolg van hoogwater”.
- Pimontel (2005) “Economische Schade ten gevolge van Overstroming“
- Delft Cluster (2003) Consequences of Flooding
- Port of Rotterdam (2005) “Veiligheid tegen overstroming Maasvlakte 2”.
- TNO (2003) “Bescherming Vitale Infrastructuur: Quick-scan naar vitale producten en diensten”
- Cazzoni et al. (2010), “Industrial accidents triggered by flood events: Analysis of past accidents”, Journal of Hazardous Materials 175 (2010) 501–509

Additional information has been give by DCMR, especially results of the Waterproof program. This information has been used as input for this study and is not reviewed explicitly. The main conclusions and findings from literature have been used as input for the 1st workshop in which a first assessment of the vulnerability of port infrastructure has been made. The section below gives a summary of the relevant literature as reviewed for this study.

Province of Zuid Holland (2008) “Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland”

The report “Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland”, by the province of Zuid Holland, is a policy document for flood risk assessment of developments in unembanked areas. The province has a public task to protect the population and economy against flooding. The policy will be effective after a trail period, which ends at the end of 2010. The document provides a methodology to be used by municipalities, water boards and private project developers. The main goal of the policy document is to:

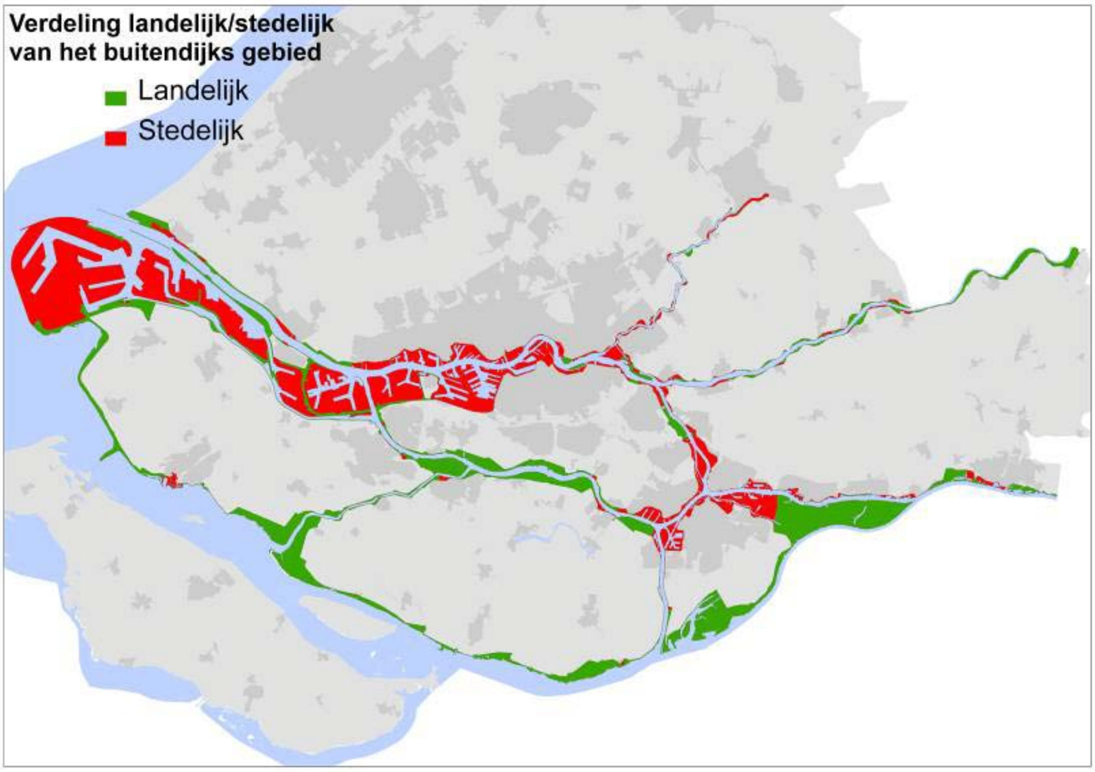
- Define the provincial interests and responsibilities
- Provide a risk based methodology for balancing developments and flood safety in areas outside the primary flood defences
- Provide clarity into the role and responsibilities of the Province towards end users

The policy document is only applicable when provincial interests are concerned. The Province interest is to:

- prevent significant societal disruption
- prevent fatalities and casualties

Other effects of flooding (environmental damages, cultural risk and individual economic risk) are assumed to be mitigated and regulated by the municipalities or other land users.

Figure Overview of urbanized (in red) and agricultural land outside the primary flood defence



The risk method is only directed if the provincial interests are of concern. The following considerations are used by the Province for developments of unembanked areas:

Table Assessment scheme of vulnerability of functions with respect to high water

Vulnerability of function	Probability of high water	Authorization of development	Instrument
High	High	yes, provided that	Application of the risk methods to substantiate\demonstrate the effectiveness of mitigating measures.
Low	Low	Yes	Application of the risk methods to substantiate\demonstrate the local interest is balances the flood risk.
Low	High		
High	Low		

If substantial flood risk is expected by developments in the unembanked areas and standards are exceeded (yes, provided that), than developers and municipalities have to prove that the plans sufficiently mitigate for flood risks. Otherwise (yes) the municipalities are responsible for permission of developments of unembanked areas.

One of the prime issues which will have to be defined in the following years is the standards to which the above method has to apply.

The report indicates vital objects and functions, according to www.risicokaart.nl:

Vital infrastructure:

- evacuation routes (roads and tunnels);
  - rail roads;
  - cables en pipelines;
  - airports
- Buildings for non self-reliant people:
  - retreat\hostel;
  - education institution
  - hospitals;
  - day care centre;
- Hazardous goods objects \ functions
  - For these functions it is necessary to evaluate whether flooding causes release of hazardous goods or flooding causes casualties or societal disruption.
- Housing

The implementation of this proposed methodology is supervised by the Province on these vital objects.

HKV & Arcadis (2009) "Risicomethode buitendijks: Methode ter bepaling van risico's als gevolg van hoogwater".

General

This document provides a methodology for assessing the risk of flooding of unembanked areas. The document is an appendix to the "Buitendijkse ontwikkelingen benedenstrooms Zuid-Holland".

The following damage and consequences categories are identified:

- Casualties
- Societal disruption
- Environmental damage;
- Cultural(-historical) damage;
- Ecological damage;
- Individual economic damage
  - Direct damage;
  - Direct damage as result of business interruption;
  - Indirect damage.

For the first 2 categories, the standard to which the developments in unembanked areas have to apply, have been quantified. For the other categories, no standard has been set.

Table Standards and categorization of consequential damage due to flooding of unembanked areas

	Damage categories				
	Provincial Interest		Local interest (test)		Local interest
	Casualties	Societal disruption	Environment*	Culture	Economical damage
	Individual casualty [probability/ha/year]	[Yearly expected number of affected-days/ha/year]	[Yearly expected environmental-damage/ha/year]	Yearly expected Cultural-damage/ha/year	Yearly expected economical damage per hectare per year
Standard	10^{-6}	100.000	?0,5?	?*50.000*?	?10.000?

The methods to quantify the consequences in terms of increased risk following the above categories are worked out in the sections below.

Casualties

The report presents a common methodology to estimate the number of casualties as result of flooding (the so-called HIS-SSM methodology, see Jonkman et al. (2008)). The number of casualties is calculated as a function of water depth and current velocity. The location depended Individual Risk (PR) is used to quantify the casualties expected from flooding.

The location depended Individual Risk is defined as the probability that an average unprotected person, permanently present at a certain location, is killed due to an accident resulting from a hazardous activity

An External Safety standard for the location-depended Individual Risk is used of 10^{-6}. Note that the dimension used is [probability/ha/year].

Societal disruption

The study presents a new methodology for estimating the societal disruption due to flooding. In this method it is assumed that a public function fails due to high water. This estimate is a translation of physical, social and emotional hindrance due to a flooding event. The following factors are of importance for this estimate:

- Area of service (number of people);
- Seriousness factor societal disruption (max 1, min 0)
- Duration of disruption (days)

My multiplication of these factors an estimate is found for societal disruption. The dimension of this estimate is than “affected-days/year”.

Environmental damage

Environmental damage is defined as the negative impact to the environment due to chemical and biological contamination of air, water and soil due to flooding. The casualties as result of environmental contamination are not taken into account here, but should be taken into account when evaluating casualties. The environmental damage depends on the following aspects:

- Size of the contaminated area
- The seriousness of the contamination seriousness factor environment
- The duration of the contamination

The environmental damage is found by multiplication of the above factors. The risk (defined as frequency times damage) is than found by multiplying the flood frequency by the damage estimated due to the flood event.

Cultural risk

Cultural risk is defined as damage to cultural-historical buildings in the area as well as objects which function as a cultural object to society such as theatres, libraries etc. This is not taken into account in this study given the low cultural values of the port area.

Economical damage

Economic damages are estimated using the approach and methodology as provided in the HIS-SSM module. The follow damage types are taken into account:

- direct damage
- direct damage due to business interruption
- indirect damage due to flooding

The damage depends on the type of land use. The damage is calculated using a damage factor. This is a function of water depth and is a number between 0 and 1. This damage factor is multiplied by the total damage.

Relevance for this study

The method as presented in this document sets a standard for the assessment of flood vulnerability of unembanked areas. The document is used in the evaluation of the flood risk assessment in Phase B (Chapter 10).

Delft Cluster (2003) "Casualties resulting from flooding of industrial sites. (DC-10)"

Aim of this part of the study was to get insight into the number of possible casualties that could be expected as a con-sequence of flooding of industrial sites. First a literature study was carried out using a database containing more than 17000 industrial accidents.

- From the literature study it could be concluded that only high-energy floods (i.e. high flow velocities) (were reported to) cause calamities (like fire and explosions) with casualties. Floating of tanks was observed in certain cases, and in addition to (storage) tanks, pipelines were vulnerable objects. No effects of toxic sub-stances released and subsequently dispersed as a result from floods are reported.
- Secondly, a calculation of the expected number casualties was carried out for a simulated flooding event near the city of Krimpen aan de Lek in the Netherlands, using generally recognised principles and models applied during quantitative (safety) risk assessment studies (software programme EFFECTS version 5). Only one site, where sufficient amounts of dangerous substances were stored, was found to be located such that a significant release could be expected. This was a location where 86 tons of ammonia (NH3) was present. Under unfavourable atmospheric conditions release of this volume could result in over 2000 casualties, and many more people needing medical attention. More realistic conditions, under which a dyke breach could be expected, could result in about 55 casualties. Although flood conditions might be such that a re-lease could occur, local (safety) measures taken significantly reduce the probability of occurrence of such a scenario. Although the effects of chemical releases can be estimated, the likelihood of the occurrence of such events should be investigated further in a probabilistic approach.

The relevance for this study is found in the case study which is found in Delft Cluster (2003). Results will be used as input for the Workshop of Part A.

- Floating of tanks and pipelines are vulnerable objects
- Especially high velocities cause calamities. The flood characteristics for unembanked areas outside primary flood defences are such that high velocities are not expected. Hence, the probability of a calamity is much lower if flooding occurs.

Delft Cluster (2003) "Publication Consequences of floods for civil infrastructure (DC-2)".

In this study only the products and services that are dependend on any type of physical infrastructure (including lifelines and excluding buildings and housing) have been researched. The vulnerability of the components of these products and services are identified in terms of their likelihood of incurring permanent damage or being temporarily out of service during the flood. The dependencies of products and services on the products or services which are likely to fail immediately when a flood occurs have directly been taken from. It can be concluded that the failure of these products and services directly leads to the interruption of all telecommunication services and interruption of the drinking water supply. Also the damages in terms of loss of human life or wounded, animal suffering, environmental impact, material damages, disruption of normal activities and damages to the economy has been described (partly given by the TNO report). It appears that the damage is such that in the first place, the number of casualties, material damages and economic setback weigh more than the damage to activities, the environment and to animals. By following the approach described in this report the exact sequence of repercussions leading to a particular failure of a service or type of damage should clearly emerge, making it possible to identify elements in the physical infrastructure which could be improved in order to reduce the effects of flooding in the future.

Figure Products and services which are likely to fail immediately due to a flood (From Delft Cluster (2003)) "Publication Consequences of floods for civil infrastructure (DC-2)" Table 3.)

Electricity
Fixed telecommunication
Internet
Water quality
Surface water control
Road transport
Railway transport
Air transport
Internal shipping

Figure Extent of damages due to products and services directly affected by flooding (From Delft Cluster (2003)) "Publication Consequences of floods for civil infrastructure (DC-2)" Table 5.)

	People	Animal suffering	Enviromnment	Material damage	Immaterial	Economy - large businesses	Economy - small businesses
Electricit	H	H	H	H	H	H	H
Fixe					H	H	H
Mobil	H					H	
Radio/navigati	H						
Satellit	H					H	
TV							
Internet						H	H
Water	H	H			H	H	H
Water							
Surface water	H		H	H			
Road				H		H	H
Railway				H		H	
Air							
Internal							

Table 5 Extent of damages due to products and services directly affected by flooding.

Relevance for this study

It appears that especially communication and electricity are especially suspected to be strongly affected by flooding, and in addition has a major impact on different consequence categories. The table below presents an assessment of the vulnerability of public infrastructure, prepared by a group of experts (in which L = Low, M = medium and H = high (function loss)) See for a list of participants Delft Cluster (2003) DC-2). A similar assessment is made for this study, in which the results below are used as input

Figure Basic components of the physical infrastructure on which critical products and services are dependent and classification of the likelihood of damage of function loss during a flood

			Basic components of related infrastructure					
				Likelihood of			Likelihood of	
Sector	Product or service	Nr.	Links	Damage	Loss of function	Nodes	Damage	Loss of function
Energy	Electricity	1	High voltage power lines	-	L	Power plants	-	-
			Low voltage power lines	M	L	Transformers	M	H
			Underground cables	M	M	Electrical switchgears	M	H
						Circuit breakers	L	L
	Methane	2	Pipelines	L	L	LNG tanks	L	L
						Undeground storage reservoirs	L	L
						Compressors	M	M
	Oil	3	Pipelines (?)	L	L	Docks or terminals	L	L
						Storage tanks	L	L
Tele-communication	Fixed	4	Fiber optics	L	M	Relay stations	M	H
			Coaxial cables	L	M	Microwave towers (obsolete?)	L	L
	Mobile	5	Fiber optics	L	M	Towers	L	L
			Coaxial cables	L	M	Masts	L	L
						Antenna frames	L	L
	Radio/navigation	6				Radio towers	L	L
						Beacons	L	L
						Lighthouses	-	-
	Satellite	7				Satellite antenna's	L	M
	TV	8	Coaxial cables	L	M	Radio towers		
	Internet	9	Fiber optics	L	M	Relay stations	M	H
			Coaxial cables	L	M			
Drinking water	Water supply	11	Water mains	L	L	Desalination plants	L	L
						Water towers	L	L
Surface water	Water quality	16	Sewage pipes	M	H	Water treatement plants	M	M
			Canals	L	H			
	Surface water control	17	Dikes	M	L	Pumping stations	L	L
			Dams	M	L	Locks	L	H
			Canals	L	H	Sluices	L	H
						Acquaducts	L	M
Transport	Road	26	Motorways	L	L	Tunnels	M	H
			Highways	L	M	Bridges	M	L
			Local roads	L	H	Viaducts	L	L
			Lighting systems	M	M	Traffic lights	M	H
						Level crossings	M	H
						Petrol stations	M	H
						Toll stations	M	H
	Railway	27	Railway lines	L	M	Crossings	L	H
			Power lines	L	H	Junctions	L	H
						Stations	L	H
						Bridges	M	L
						Tunnels	M	H
						Viaducts	L	L
	Air	28				Airports	M	M
						Landing strips	L	H
						Hangars	M	M
	Internal shipping	29				Locks	L	M
						Harbours	L	H
						Terminals	L	M
	Shipping	30				Harbours	L	L
						Terminals	L	L
	Pipes and mains (other than for electricity, gas, water and telecom.)	31	Pipelines			Terminals	L	M

Table 2: Basic components of the physical infrastructure on which critical products and services are dependent and classification of the likelihood of damage or function loss during a flood.

Pimontel (1995) "Economische Schade ten gevolge van Overstroming"

The internship report of Pimontel prepared for Delft University of Technology in cooperation with the Rotterdam Port Authority provides a quantified estimate of economic damage to port areas to be expected due to flooding. Economic damage is calculated as a function of

- water depth,
- the total damage calculated as the total value lost if all property is lost, and
- damage factor, which indicates the fraction of property lost during flooding.

Examples of the damage to business area and infrastructure per ha is given below, in which d is the depth of flooding

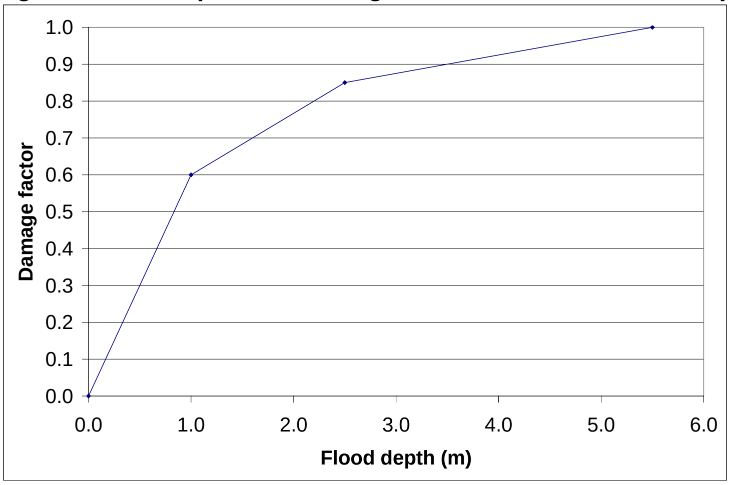
Business area	0.1*d	d = [0,1)
	0.06*d+0.04	d = (1, 3]
	0.39*d-0.95	d = (3, 5]
	1	d > 5
Infrastructure	MIN (0.28*d, 0.18*d+0.1, 1)	

For different types of port infrastructure and land use (dry bulk, box containers, and liquid bulk), a damage function and total damage is given as a function of area (per hectare) as well. The same approach is provided in the HIS-SSM module developed for evaluation for damage estimates of flooding events. However, more land use and industrial land uses are included in the report of Pimontel. It would be interesting to include these conclusions into the HIS-SSM module as well.

Relevance for this study

For this study, a qualitative approach is proposed in the risk methodology in Part B. For further application, the method provided in this literature reference is found to be easy applicable to most types of land use. However, the method requires that the damage factor and total damage is known. This requires detailed site specific information. A damage factor relation to flood depth is not available for casualties or societal disruption.

Figure 3.5 Example of a damage factor related to flood depth



Port of Rotterdam (2005) “Veiligheid tegen overstroming Maasvlakte 2”.

During the planning phase of Maasvlakte 2, the required terrain height for the new port developments was derived. During this assessment, an optimal elevation of 5,0 m was found. The study reviewed economic consequences, environmental consequences, potential casualties and societal risk. Both individual risk as group risk was taken into account. It was concluded, that for casualties and societal risk, an elevation of 5,0 m is highly sufficient. The final height of approximately NAP + 5.0 m was primarily based on economic considerations. Apparently, the required terrain height derived from an economic assessment exceeds the terrain height needed for casualties and societal disruption.

Relevance for this study is found in the general conclusions with respect to the flood risks of chemical industry in the port of Rotterdam. A first conclusion is drawn that the risk due to flooding of these installations with respect to casualties or societal disruption is not significant.

TNO (2003) “Quick scan Vitale Infrastructuur”

This report presents the findings of a study into vital services and product in the Netherlands society. The study was commissioned by the Dutch Government to increase the resiliency of the Dutch society. A package of measures was set-up to increase the availability and reliability of vital services and vital products.

In the study a comprehensive overview is given into different types of consequences due to interruption or failure of vital infrastructure. This is irrespective of the accident type (flooding, fire, terrorism etc.) The figure below provides (in Dutch) an overview of the products and services which are especially vulnerable to different types of consequences categories: persons, animal welfare, environment, material damage, and immaterial damage.

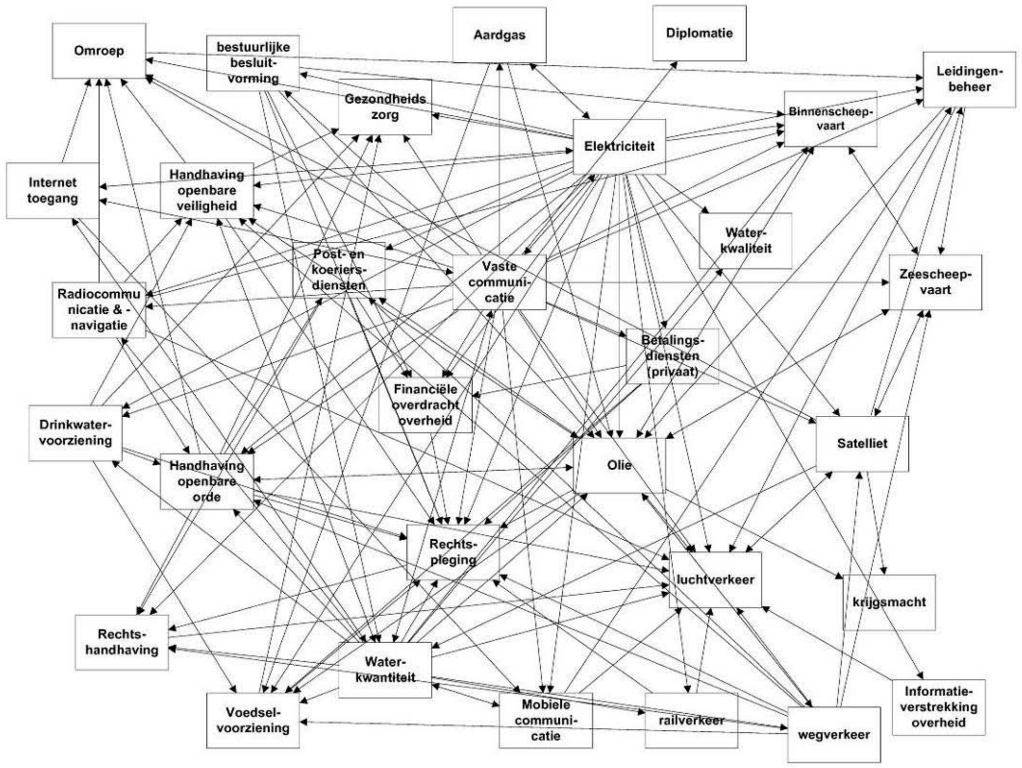
Another very important conclusion is drawn with regards to the interrelations of different products and services. The figure below presents a very complex network of interrelations of a variety of products and services. It is concluded that products and services are far more related to and depended of each other than on first hand thought.

First order consequential damage and effects due to malfunction of a vital function ("TNO Quick scan Vitale Infrastructuur").

Product of dienst	Personen	Dierenleed	Milieu	Materieel	Immaterieel
Elektriciteit	H	H	H	H	H
Aardgas	M	M	-	L	M
Olie	-	-	-	H	L
Vaste communicatie	M	-	-	M	H
Mobiele communicatie	H	-	-	L	M
Radiocommunicatie & -navigatie	H	-	L	?	L
Satelliet	H	-	L	L	L
Omroep	-	-	-	L	-
Internet toegang	-	-	-	M	-
Post- en koeriersdiensten	L	-	-	L	-
Drinkwatervoorziening	H	H	?	L	H
Voedselvoorziening	H	L	-	L	H
Gezondheidszorg	H	-	-	L	H
Betalingsdiensten (privaat)	-	-	-	L	M
Financiële overdracht overheid	-	-	-	-	L
Waterkwaliteit	-	L	?	L	-
Waterkwantiteit	H	M	H	H	H
Handhaving openbare orde	M	-	?	L	H
Handhaving openbare veiligheid	H	L	?	M	H
Rechtspleging en detentie	L	-	-	?	H
Rechtshandhaving	L	-	-	?	H
Diplomatie	-	-	-	-	-
Informatieverstrekking overheid	-	-	-	-	-
Krijgsmacht	-	-	-	-	-
Bestuurlijke besluitvorming	-	-	-	?	-
Wegverkeer	-	-	-	H	M
Railverkeer	-	-	-	H	L
Luchtverkeer	-	-	-	L	L
Binnenscheepvaart	-	-	-	L	-
Zeescheepvaart	-	-	-	L	-
Leidingenbeheer	-	-	-	-	-

Nihil	-
Laag	L
Midden	M
Hoog	H
Onbekend	?

The complex relation between vital products and services in the Netherlands society



As a result of this very complex and intertwined network, a number of chain reactions are expected when one important service or product is interrupted.

Relevance for this study:

The study provides an overview of vital products and services of the Netherlands society. This information can be used to identify whether these products and services are found a port area. For instance, electricity is found to be very critical component in the network of products and services: power plants are located in port areas mainly because these are close to infrastructure for the transportation of coal.

The study also highlights the complex structure of Consequence Analysis: many products and services are highly dependent on each other, so chain effects are likely to occur. These chain effects are however very difficult to define.

Cazzoni et al. (2010), "Industrial accidents triggered by flood events: Analysis of past accidents"

During the final stage of this study, this study has been released. The study primarily focuses on hazard identification of past flood events, and studies the event types and consequential damages. Industrial accidents triggered by natural events (NaTech accidents) are a significant category of industrial accidents. Several specific elements that characterize NaTech events still need to be investigated. In particular, the damage mode of equipment and the specific final scenarios that may take place in NaTech accidents are key elements for the assessment of hazard and risk due to these events. In the present study, data on 272 NaTech events triggered by floods were retrieved from some of the major industrial accident databases. Data on final scenarios highlighted the presence of specific events, as those due to substances reacting with water, and the importance of scenarios involving consequences for the environment. This is mainly due to the contamination of floodwater with the hazardous substances released. The analysis of process equipment damage modes allowed the identification of the expected release extents due to different water impact types during floods. The results obtained were used to generate substance-specific event trees for the quantitative assessment of the consequences of accidents triggered by floods.

Relevance for this study

Due to the fact that this paper was released after the fore lying report was written, the conclusions were not taken into account in this study. However, the approach as presented in this scientific paper is almost similar to the method as presented in the fore lying study although only historical cases were analysed. The notion of the need for substance-specific event trees for the quantitative assessment of the consequences of accidents triggered by floods was also used in the fore lying study.

Table 3
Description of structural damage modes experienced by tanks and process equipment during flood events. The release category associated to the damage is also estimated.

Modality of flood impact	Type of structural damage	Release category
Slow submersion	Collapse for instability (catastrophic failure)	R1
	Complete failure of connected piping	R2
	Failure of flanges and/or connections	R3
Moderate-speed wave	Failure of flanges and connections	R3
	Damage of connections due to floating objects	R3
High-speed wave	Impact with/of adjacent vessels	R1
	Roof failure and/or shell rupture	R2
	Complete failure of connected piping	R2
	Failure of flanges and connections	R3

- The instantaneous release of the complete inventory, defined as R1 release category.
- The continuous release of the complete inventory in a limited time lapse due to the full-bore rupture of large diameter connections or due to shell ruptures, defined as R2 release category.
- Minor leaks from the partial rupture of connections or from the full-bore rupture of small diameter pipes, defined as a R3 release category.

Appendix C Vulnerability assessment of port infrastructure

Introduction and categorization of port infrastructure

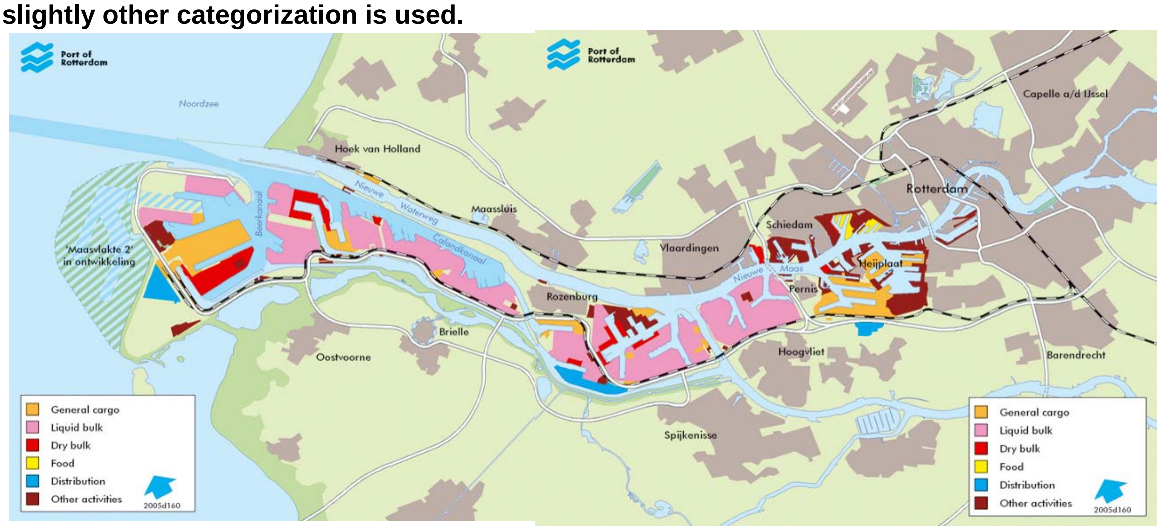
This chapter provides a comprehensive inventory of most important port infrastructure which is present in the Port of Rotterdam. It is not intended to include a detailed list of port infrastructure. The inventory is intended to provide inside into types of infrastructure which are vulnerable to flooding and hence should be taken into account in an assessment. As such, the inventory has been used as input for the workshop of Phase A and used to discuss the possible consequences with the attendees. A subdivision has been made into categories of port infrastructure, according to land user category:

Client related infrastructure
- General harbour facilities
- Dry Bulk
- Liquid Bulk
- Containers
- RoRo
- Business areas and other land use

Public related infrastructure
- Public logistic infrastructure

General harbour facilities are applicable to most of the cargo types and are therefore treated as a separate category but applicable to all cargo types. The figure below gives, although using a slightly different categorization, overview of land use types.

Figure 4.1 Overview of port area use according to www.portofrotterdam.com. In this study a slightly other categorization is used.



The section below gives an overview of the components and characteristics of the port infrastructure, per category. These components have been used in the assessment of vulnerability of the port infrastructure.

Inventory list of port infrastructure

- General harbour facilities

This category includes all harbour facilities which can be found on all port areas, not related to a specific commodity or land use.

- Dry Bulk

Dry bulk consists of all goods which are stored in large quantities on open terrain, silos or storage sheds. The goods typically consist of coal, iron ore etc. Facilities on the port facilities include unloading facilities and transportation equipment. Large Industrial installations for processing of these goods are not assumed for this commodity. The following items have been used for the vulnerability assessment:

- Liquid Bulk

Liquid bulk consists of both storage and industrial processing of liquids and liquefied gasses. Liquids include LNG, LPG, oil products, toxic gasses such as hydrogen flour (H2F), ammonia etc. Additional infrastructure to unload, transport and store the goods is also taken into account.

- Containers

Container terminals mainly consist of stacking and (ICT) infrastructure to transport the containers, such as straddle carriers unloading cranes etc. In the assessment, different types of containers have been reviewed, such as reefers, tank containers and box containers.

- RoRo

RoRo terminals are designed such that goods are transported directly from a vessel to the quay and storage sheds or storage terrains. The type of goods and commodities which are transported using RoRo terminals varies from small goods such as cars, food, electrical equipments. Also large structural components of for instance wind mills are transported. Occasionally, goods also comprise of military equipment, toxic waste, nuclear waste etc.

- Public logistic infrastructure

This type of port land use consists of all areas which are on the property of the Port Authority of Rotterdam, but have a public function and\or are not directly used by clients of the Port Authority.

- Business areas and other land use

This category consists of all land users which are not directly related to the function of the port, but make use of unembanked areas outside the primary flood defence owned by the Port Authority. An electrical plant or drinking water facility is part of this category.

The table on the next page presents the items per category which were taken into account in the vulnerability assessment during the workshop.

Table 4.1 Overview of port infrastructure in the Port of Rotterdam used in the vulnerability assessment

Client related infrastructure		
	General harbour facilities	
	Berthing facilities Quay wall Jetties Terminal Terrain Roads and railways Underground facilities Vehicles	Electricity Communication Cables Pipe lines General facilities Lighting buildings Safety installations
	Dry Bulk	
	Facilities Sheds Cranes Silos	Storage of goods Conveyor belts Ores (zinc, iron, coals, ...)
	Liquid Bulk	
	Process installations Storage of goods Oil LNG	LPG Toxic gasses: H_2F Vegetable oil
	Containers	
	Facilities Reefer slots	Cranes Storage containers port terrain
	RoRo	
	Facilities Cooling installation	Sheds Storage of goods
	Business areas and other land use	
	Electric plant Drinking water plant \ pumping stations	Offices
Public related infrastructure		
	Public logistic infrastructure	
	Rail Road Pipelines	Drinking water Waterways Electricity power grid

General Harbour facilities		
Consequences categories		**Effect of flooding**
Berthing facilities		
	Quay wall Berthing facilities/bollards, quick release hooks Fenders Jetty Approach trestle Berthing facilities/boulders, quick release hooks Mooring Dolphins Berthing dolphins	Flooding will temporarily inundate the berthing facilities. During this time, the infrastructure is out of use, but severe damage is not expected. Some damage might be expected due to washout of structures. Also corrosion of all kind is expected leading to material damage.
Harbour/terminal areas	Pavement Roads Rail tracks	Inundation of infrastructure on the terminal areas will not result in major damages. The effect of salt sea water might result in some corrosion but the effect is estimated as low. Possible damage is also expected due to debris, especially by floating containers or break bulk. The infrastructure will however be out of order for the period of flooding.
Underground Facilities	Pipes Electricity Telecommunications	The consequential damage of failure of electricity and\or communication could have severe implications. Especially transformers, and switchgears could be damaged and loose their function. During crisis situations this would have an impact on the port area, and to a smaller extent the public domain of the security of the port area cannot be guaranteed. Damage to electrical systems in the foundation of the construction Reduced efficiency of “bedrijfshulpverlening”, fire dept. etc. More time needed to fight fire etc, consequential damage will be larger.
	Gas pipes Compressed air Steam Oil (products)	The probability of damage of underground transportation and storage facilities for gas and oil is very low, due to the reason that for most areas it is assumed that these are under the groundwater table. In addition, underground storage facilities are in general not very large so consequential damages are estimated as low.

General Harbour facilities		
Consequences categories		**Effect of flooding**
	Storage tanks	
General facilities on port area		
	Illumination facilities, light masts Substations Access control, gates, guard houses etc. Administration buildings Cars Trucks Rail wagons Barges Storm water treatment Control rooms Reefer slots	A number of facilities will be out of order due to flooding. Special attention is given to port security. During the Waterproof study, malfunction of ICT and electricity was assessed as posing vulnerability because the port safety can not be guaranteed. It is quite likely that if the port terminal is flooded that some of these functions will cease. Special attention should be given to tank wagons and barges in the port area, potentially containing hazardous goods.

Dry Bulk		
Consequences categories		**Effect of flooding**
Facilities		
	Cranes Ship loaders/excavators Conveyor belts Silos Storage sheds	Flooding will temporarily inundate the facilities. During this time, the infrastructure is out of use, but severe damage is not expected. Some damage might be expected due to washout of structures. Also corrosion of all kind is expected.
Commodities		For all commodities, it is likely that wash out of material occurs. In addition, instabilities in the stacks might lead to collapses. Loss of material will lead to environmental damages (depending on commodity) as well as loss of material and value. It is likely that in the design of the dry bulk facilities, heavy rainfall has been taken into account, so the likelihood of loss of function is estimated as low to medium
	Coal	Washout \ instability
	Ore (Iron, Zinc, etc…)	Washout \ instability
	Grain	Washout \ instability
	Soya	Washout \ instability

Liquid Bulk		
Consequences categories		**Effect of flooding**
Facilities	Process installation Pipe lines Cooling installations	Liquid bulk is processed in all different types of facilities on the port areas. The following threats are indicated: - (especially large) pipeline rupture - undermining of foundation of distillation columns or other process installations - storage tank flooding or collapse - power failure The collapse of facilities might result in the outflow of oil and related products. For oil this means that the spills will likely flow into surface waters. If significant storage areas are affected, the distribution for public needs might be affected. Supply of oil or gasses to consumers is cut when pipelines are ruptured, or in case of an emergency shutdown, supply is cut. A specific risk is identified, that in the normal safety assessment, pipeline rupture is included. However, the effect of water on the goods in the pipeline might not be part of the safety assessment (yet). Distillation columns are designed for a wind of max 12 Bft, combination of waves and water pressure might cause the collapse of columns. Due to the very safe designs, a water level of <1m is not assessed as dangerous. More research might be necessary, or incorporation of this event in a Consequence Analysis of the plant operators might be desirable. A controlled shutdown of the industrial plants will result in high economic damages. Also uncontrolled shut down might result in other damages such as gas releases in large quantities => health risks or environmental damage is possible. Specific risks are found for LNG or other gasses which are highly inflammable and are stored in cooling facilities. Boil off of LNG is necessary to keep temperature low and to keep pressure low. A constant flare of LNG is necessary; most flares are not designed for constant flaring. Nevertheless, in the normal safety operations, instant boil-off or flaring of LNG is part of the normal safety assessment. More importantly, safety consideration define that hazardous goods should be contained in the facilities as long as possible. Shut-down of an installation can be done within one day.

Liquid Bulk		
Consequences categories		**Effect of flooding**
		Power failure can lead to different undesirable consequences. However, also power failure is part of the normal terminal safety assessment. The combined risk of power failure and of the presence of 1 m of water is not in the present safety assessment. The control mechanisms are not functioning if the electricity shuts down. Possibility of jamming of product lines (some products can only be transported when heated)
Storage of goods	Oil Gas LPG Toxic gasses: H_2F Vegetable oil	In extreme situations, severe flooding of LNG tanks or pipelines can cause explosions. The following threats are indicated: - undermining of foundation - storage tank (esp. terp tank) and silos flooding or collapse - power failure In the future, part of the public gas supply will come from the port area. Therefore, the supply of gas from the port area will be more and more vital. Tanks that are not designed for corrosive environments (for example non stainless steel) will suffer from contact with salt water (when empty). The collapse of facilities might result in the outflow of oil and related products. For oil this means that the spills will likely flow into surface waters. If significant storage areas are affected, the distribution for public needs might be affected. It is not known whether the buns which are constructed around large storage facilities are only designed to withstand the products within the bun, but are also able to prevent water flooding the storage tank. Empty, or almost empty, storage tanks seem to exhibit the highest risk. If the water pressures outside of the tank gets to high, during high water, than the storage tank could collapse.

Containers	
Consequences categories	**Effect of flooding**
	Flooding of container yards is mainly affects the control mechanisms and electricity and ICT facilities which are present on the container yard. Many containers are not water proof. Containers with hazardous goods are a potential environmental risk. Especially the power circuit will cease to function. It can be expected that all electronic infrastructure above 10kV will cease to function. This is only valid for electronic infrastructure above 0.5m. The electronic infrastructure below this reference is designed for heavy rainfall. The AGVs will not function. Reefers have a power connection on the top on the container => the connection will not cease. Reefers will only be shut down if the general electricity supply fails. Tank containers are designed such, that they are very unlikely to fail during flooding. Also floating debris does not seem to be a significant thread. Some cases are reported of burning containers on ships due to contact of goods with water. These occasions are rare so these are not expected during flooding either Floating containers. Floating of containers occurs only if the water level is at the height of 1 container. This will not occur in the present situation. Wind during storm events might be a larger risk. During failure of the electronic grid of a container terminal, the process ceases completely and it will take an order of weeks to restart the process. This will result in some societal disruption, because much business and logistics in the Netherlands, Germany etc. rely on the import of goods. The extent of this is not known within the group but it is estimated that the effect would be significant.

RoRo & break bulk		
Consequences categories		**Effect of flooding**
	-	This type of harbour infrastructure comprises consumer goods such as cars and trucks. Also other of goods might comprise more vulnerable goods, such as nuclear tanks, flights. During the workshop, it was concluded that only very occasional goods could pose a significant risk. However, during an upcoming storm event the products will likely be transported out of the port to prevent damage.

Logistic infrastructure	
Electricity	Several power plants are located in the Rotterdam Port area. These power plants have been designed such that redundancy is guaranteed to a great extent. The effect of failure of a large plant, or a number of smaller plants is large. Recent power failures have highlighted the consequences of these power failures. The apache incident of some years ago shows this. During 2003, cooling water was not available in the Netherlands because of a very warm summer. This lead to serious instable situations in the grid. Nevertheless, this can be solved quite quickly in a day or so, bearing in mind some delay due to stormy weather (normally this would be about a few hours). The TNO report XXX also shows that the effect to societal disruption of outfall of electricity is large. This will have a significant impact during a crisis: • Rail roads will not function • Communication will not function • The safety of ports cannot be guaranteed if the safety system is connected to the grid All power lines are highly elevated in the Netherlands. These power lines are much more vulnerable to wind speeds and not so much to high water levels. The number of affected people due to power failure is enormous. Also, a lot of crisis management infrastructure would potentially malfunction (communication etc.) Another site effect is the safety issue: electrical safety systems connected to the electrical grid would malfunction if not backed by a secure back-up system. Also ICT systems of plant operations and installations would potentially malfunction. This was identified during the TMO Waterproof study (DCMR).
Drinking water	Underground pipelines lie under the groundwater table with a minimum of 75cm. This is done to prevent freezing of the contents and or freezing of pipelines itself. The risk of buoying of pipelines is therefore very limited. The highest risk of rupture of a pipeline is “verweking” of a dyke during a flood. Rupture of a water pipeline will result in a reduced supply of drinking water. There is a continuous probability of water pipeline rupture and the system has a guarantee of supply (75%). Therefore, a reduced supply will be likely to occur after a large rupture rather than complete closure. In addition, also noodwatervoorziening is available. Drinking water facilities are in general not designed to withstand high water; it is estimated that with 10cm of water on the facilities, major failure of the facility will be the result. This is due to the fact that the basement of the facility will likely be flooded. Most drinking water facilities are therefore highly elevated when they are not protected by a levee. Same holds for pumping stations. These stations are located very low, because of the necessary head difference needed for pumping of water. The purification plants have been constructed on Delta height. Pipelines run underground. Potential damage is foreseen if high water levels cause verweking of dykes and collapse of pipelines is foreseen.

Roads	If roads are flooded, traffic is not possible. The movement of goods in and out of the port area is interrupted. The movement of goods to the hinterland is jammed leading to shortages and disruption of business. More important, evacuation is not possible. Also the accessibility of the port area is significantly reduced. If tunnels are flooded, they can not be used. Secondly, during a flood, the tunnel will destabilize and might be damaged for a longer time. Hindrance of evacuation and crisis services is expected. This is regarded as a serious threat.
Communication	Communication fails directly of fixed communication lines are ruptured, local masts are damaged or telephone lines are broken. Communication proves to be vital in crisis management. Depending on the type of infrastructure, the likelihood of flooding is low to medium.
Rail	If railways are flooded, train traffic is not possible. The movement of goods in and out of the port area is interrupted. The movement of goods to the hinterland is jammed leading to shortages and disruption of business.
Pipelines	Underground pipelines are located under the groundwater table with a soil cover of a minimum of 75cm. This prevents freezing of the contents and or freezing of pipelines itself. The risk of buoying of pipelines is therefore very limited.
Waterways	It is expected that the seagoing vessels will be denied access of the port of Rotterdam in time. Secondly, the safest place is at sea for a vessel. During rising water, sea going vessels are not expected to be damaged significantly if located at the quay Inland waterway shipping however is fixed to the quay. Strong winds are also troublesome for this type of ships. During flood and strong winds, this type of ships are potentially floating towards other vital infrastructure (such as pipelines or structures).

DAMAGE	**Consequences categories**		**Effect of flooding**
Business areas and other land use			
	Electricity plant		See public infrastructure
	Drinking water facility \ pumping stations		Drinking water facilities are in general not designed to withstand high water; it is estimated that with 10 cm of water on the facilities, major failure of the facility will be the result. This is due to the fact that the basement of the facility will likely be flooded. Most drinking water facilities are therefore highly elevated when they are not protected by a levee. Same holds for pumping stations. These stations are located very low, because of the necessary head difference needed for pumping of water.

Appendix D Workshop A

Location: Port Authority of Rotterdam
Date & time: 11 November 13:00-17:00

Experts present during the workshop:

Name	**Company \ organization**	**Expertise \ background**
Aernoud Willeumier	Rotterdam Port Authority	Containers Break Bulk and Logistics
Ronald Backers	Rotterdam Port Authority	Liquid Bulk
Joop Verdoorn	Rotterdam Port Authority	Public infrastructure
Paul Crooijmans	DCMR	External safety \ environmental safety
Jan Konter	Private consultant.	Expert flood safety Maasvlakte 2
Bas Jonkman	Royal Haskoning	Flood risk management
Joost Lansen	Royal Haskoning	Flood risk management
Rinske van der Meer	Rotterdam Port Authority	Flood risk management
Joost Bos	Royal Haskoning	Port infrastructure
Henk de Visser	Royal Haskoning	Industrial installations and external safety
Hans Iserief	Royal Haskoning	Workshop leader
Alan Dirks	Rotterdam Port Authority	External safety
Gerard Laanen	Director Departementaal Coördinatiecentrum Crisisbeheersing (DCC) van het Ministerie van Verkeer en Waterstaat	Crisis management
René van der Helm	Departementaal Coördinatiecentrum Crisisbeheersing (DCC)	Crisis management
Jan Huizinga	HKV Lijn in Water	Flooding \ safety

The program of the workshop was as follows:

1. Welcome
2. Presentation on background study and objective of the workshop
3. Presentation and discussion on consequences of flooding of areas not defended by primary flood defences per type of port infrastructure
4. Assessment of the vulnerability of the different types of port infrastructure
5. Qualitative ranking of vulnerability by experts
6. Outlook to follow-up study and defining recommendation
7. Closure

The results of this workshop have been integrated in this report in chapter 5 & 6.

Appendix E Workshop B

Location: Port Authority of Rotterdam
Date & time: 5th of February 9:00-13:00

Experts present during the workshop:

Name	**Company \ organization**
Jan Konter	Rotterdam Port Authority
Adri van der Hoeven	Rijkswaterstaat Zuid-Holland
Elmi Vermeij	HKV lijn in water
William Veerbeek	Unesco IHE
Nick van Barneveld	Gemeente Rotterdam
Bas Jonkman	Royal Haskoning
Joost Lansen	Royal Haskoning
Rinske van der Meer	Rotterdam Port Authority
Henk de Visser	Royal Haskoning
Evert van der Meide	Provincie Zuid-Holland
Alan Dirks	Rotterdam Port Authority
Durk Riedstra	Rijkswaterstaat Waterdienst
Wim de Vries	DG Water
Paul Crooijmans	DCMR
Robert Verhoeven	HKV lijn in water

The program of the workshop was as follows:

1. Welcome
2. Presentation on background study and objective of the workshop
3. Presentation policy document of the Province of Zuid Holland directing at flood risk in areas undefended by primary flood defences
4. Presentation of the results of Phase A
5. Presentation of the results of the case study of flood risk of chemical installations
6. Comparison of the risk assessment in the case study with standards in flood safety management and external safety.
7. Discussion with respect to the following topics:
   - How do we compare the flood risks of port infrastructure with other flood risk methods, for instance the flood risk assessment method for polders and external safety methods
   - How do we evaluate the risk of port infrastructure, based on the case study, with respect to the policy document of the Province of Zuid Holland
   - Identification of knowledge gaps and follow-up research questions

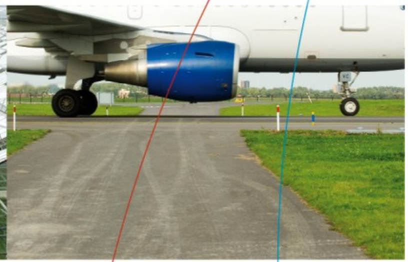
9. Closure

The results of this workshop have been integrated in this report in chapter 10 & 11.

Appendix F

	No Flooding	No Flooding	Flooding	Flooding
		Worst-case	consequences compared with worst case excluding flood (grey column)	consequences compared with worst case excluding flood (grey column)
Process Hazards Analysis	Maleic Anhydride	Hexafluorpropene	Flood depth 0,1 m	Flood depth 1 m
IDLH effects downwind	no offsite effect	no offsite effect	no offsite effect	no offsite effect
Number of people in IDLH area	0	2 operators	less (site evacuation)	less (site evacuation)
ERPG 3 offsite effects downwind	no offsite effect	0,1 km^2	no offsite effect (strong wind)	no offsite effect (strong wind)
Number of people in ERPG 3 area	n.a.	10	n.a.	n.a.
ERPG 2 offsite effects downwind	0,01 km^2	8 km^2	less to comparable	Less to comparable (strong wind)
Number of people in ERPG 2 area	4	1000 (river in between)	100	2000
Duration of ERPG 2 concentrations	< 1 hour	< 1 hour	> 1 hour	1 day (leak difficult to stop)
Total impact to public health	exposure time within ERPG 2 limits	exposure time within ERPG 2 limits	100 people in area with ERPG2 concentration, duration exceeding 1 hour, resulting in irriversible health effects	2000 people in area with ERPG2 concentration, duration far exceeding 1 hour, resulting in irriversible health effects
Claims resulting from injuries		10 x E6 Euro	10 x E6 Euro	200 x E6 Euro
Consequences for society		minor	minor	minor
Environmental effects		significant contamination of air, limited water pollution	significant contamination of air, water and soil	significant contamination of air, water and soil
Cultural damage		minor	minor	minor
Damage to nature		minor	limited;	along the river up to 10 km from event
Economic damage				
- public property damage	minor	minor	limited;	fouling by oil
- downtime	2 months	2 months	comparable	5 months
- in site property damage	1 x E6 Euro	5 x E6 Euro	comparable	50 x E6 Euro
- business interruption	10 x E6 Euro	50 x E6 Euro	comparable	comparable
- consequential damages	minor logistic adjustment: products from other sources	2 weeks for logistic adjustment for delivery of products from other sources	comparable	comparable



To develop the scientific and applied knowledge required for
Climate-proofing the Netherlands and to create a sustainable
Knowledge infrastructure for managing climate change

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