Updated and improved method for flood damage assessment: SSM2015 (version 2)

Deltares

Updated and improved method for flood damage assessment: SSM2015 (version 2)

Karin de Bruijn
Dennis Wagenaar
Kymo Slager
Mark de Bel
Andreas Burzel

1220043-003

Deltares

Title
Updated and improved method for flood damage assessment: SSM2015 (version 2)

Client	Project	Reference	Pages
Rijkswaterstaat Water, Verkeer en Leefomgeving	1220043-003	1220043-003-HYE-0012	115

Keywords
Flood damage, flood impacts, flood damage assessment, HIS-SSM, SSM2015 Netherlands

Summary
This report discusses the updated and improved method for flood damage assessment in the Netherlands. The data used in the previous standard flood damage and fatality assessment model was outdated and the method did not comply with the latest knowledge on flood impact assessment. Both the method and the input data in the method needed updating and improvements in order to allow the damage assessments which are needed for the current policy decisions. New data, models and insights were available which enabled improvements in the HIS-SSM method. Therefore, an improved method based on the actualised data has been developed: the SSM2015 method.

This report explains the need for improvement of the Standard Damage and Fatality assessment model (HIS-SSM), it describes and motivates the improvements and it shows the effects of the new method on the resulting flood damages. The report focuses on damage to businesses, residences and infrastructures, but also briefly considers other damage types.

This report does not aim to describe new software or modelling techniques, but is limited to the method and data for flood damage assessment.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	Dec 2015	Karin de Bruijn	KdB	Marcel van der Doef		Marcel van Gent	

State
final

Contents

1 Introduction

1.1 Background

Currently, flood risk management in the Netherlands is changing from a flood probability based approach to a risk based approach. To support this transition, accurate data on flood probabilities, flood patterns and flood impacts are needed. In the Netherlands flood impacts of large scale floods from the main water courses are assessed with the ‘Standard Damage and Fatality Model’ (In Dutch: Standard Schade en Slachtoffer Model) (HIS-SSM) (Kok *et al*., 2005). This model was developed between 2000 and 2005. Currently, the data, the method and the tool itself need improvement. Such an improvement is possible because new data, hardware, technology and new knowledge are available.

Since the need for improvement of HIS-SSM has been recognized before, research on improvements has already been carried out: Kind (2011) studied HIS-SSM and proposed a correction factor to correct for inflation and missing damage categories. De Bruijn et al. (2012a en b) proposed improvements to be able to work on a smaller spatial scale in the non-protected areas in the Rotterdam-Rijnmond area. Jongman et al. (2012) made an international comparison of damage functions and Veerbeek (2010) studied damage to residential buildings. Gauderis (2012) proposed improvements for the assessment of damage to businesses. Furthermore, research on damage functions in the Netherlands and abroad and a damage function library is ongoing (Wagenaar, 2014; Wagenaar et al., 2016) and De Bruijn et al. (2014) delivered version 1 of the report on the SSM2015 method motivation (this report is version 2 of the same document). However, all this research has led to ad-hoc adjustments and not to changes in the Standard Damage and Fatality model.

In 2013, therefore, we started to develop a new Standard Damage and Fatality Model: SSM2015. The model was delivered to WVL in 2015. In 2013 we focused on an update of the data and research on the maximum damage values and functions and did a proposal to improve them. In 2014 and 2015 next to improvements on the method and discussions with experts, the software design of the new tool was made and tested. Both a webapplication and stand-alone version were developed. During the entire process of improvement, development, testing and acceptation, communication with users, institutions and other relevant groups was important.

This report provides the resulting proposal for improvement of the damage functions and maximum damage figures and for data updates resulting from the research of 2013-2015.

1.2 Aim

The aims of this report are:

- To explain the need for improvement of HIS-SSM;
- To explain possibilities for updating of the data in HIS-SSM and the effects of the updating on the resulting damages;
- To propose improvements in maximum damage figures and damage functions for those damage categories which are relevant for the total damage and where HIS-SSM requires improvements.

This report does not aim to describe new software or modelling techniques, but is limited to the method and data which has been incorporated in the software in 2014 and 2015.

The new Standard Damage and Fatality Analysis tool (SSM2015) for the Netherlands will contain:
- Up to date data on land use, number of inhabitants, and objects in the Netherlands
- Damage functions and maximum damage figures which are motivated, discussed with experts and which can be traced back to data sources, or clear assumptions.
- And an indication of the reliability of the outcomes and uncertainty bounds (this has not been implemented yet at the moment (December 2015).

The envisioned users of SSM2015 are technical people of the consultancies, research institutes, universities and governmental organisations. They should be able to use SSM2015 for damage analyses which support cost-benefit analysis of flood risk management measures, for analyses of effects of measures and for damage and/or risk mapping activities.

1.3 Approach

To improve the current damage assessment method in HIS-SSM version 2.5 (referred to as 'HIS-SSM' in this report), we identified those categories which either contribute most to the total damage, or where improvements are considered most urgent. This resulted in a focus on damage to businesses, residences, infrastructure and the land use category 'urban area'. In chapter 7 other categories are briefly discussed as well.

For each damage category we carried out four steps:
1. We analysed the data sources, damage functions and maximum damages used in HIS-SSM and the rationale behind those.
2. We studied other damage modules (HAZUS, FLEMO, Multi Coloured Manual) (see below) and studied relevant literature.
3. We proposed improvements for those categories for which better data or new knowledge is available and significant reasons were found for improvements. For some categories, changes in damage figures and functions are needed to be able to use more recent data sources (with, for example, other category definitions).
4. Finally, we tested the proposed changes with a flexible experimental damage model on the flood-protected part of the island of Dordrecht and on the Netherlands as a whole. This test procedure is explained in section 1.4.

Since 2000 knowledge on damage to residences, businesses and infrastructure has increased. This new knowledge helps to motivate and improve the HIS-SSM functions and data.

To improve the damage functions we used the following studies and damage models:
- **Gauderis (2012)** - This study proposes a modified method to determine new maximum flood damage figures for businesses.
- **FLEMO** (Kreibich, 2010) – Kreibich describes a German flood damage model, based completely on empirical data on 1000 reported cases after the Elbe flood of 2002. In this flood event water depths were generally around 1 or 2 meters, but also water depths of 3 m have been registered. The Elbe 2002 event caused substantial damages on infrastructure in Germany. Damage to infrastructure and related reconstruction costs of that event are documented comprehensively (e.g. Müller, 2010).

- **HAZUS** (FEMA, 2009) – In this American flood impact model, damage to businesses is based on expert judgement mixed with empirical data. In this American flood impact model, damage to residences is based on over 100,000 insurance claims modified so it can be used for policy analysis.
- **MCM** (Penning-Rowsell, 2005) - This British model is based on a detailed, systematic expert judgement approach.
- **Rhine Atlas** (ICPR, 2001) – This second German model is based mostly on expert judgement taking into account an earlier German damage database (HOWAS).
- **Tebodin** (Sluijs, 2000) – This is a Dutch study, based on a detailed, systematic and well documented expert judgement approach of damage to industries.
- **IHE** (Billah, 2007) – The systematic expert judgment approach as used in MCM applied to Dutch residences
- **COMRISK (2007):** The ‘COMRISK subproject 7’ focussed on a flood risk assessment for the Danish Wadden Sea. This project provides detailed assumptions on reparation and reconstruction costs for different road types (Comrisk, 2007).
- **Australian assessment guidance (2004):** Guidance on the assessment of (potential) flood damage to infrastructure based on floods in the seventies in Australia (DNRM, 2002).

In the chapters 4 to 7 available data is discussed per damage category.

1.4 Testing the effect of improvements on Dordrecht and the Netherlands

To test the effect of the changes made, they were tested on the protected part of the Island of Dordrecht and on the national water depth map of the Netherlands. The results of the proposed method were compared with the results of HIS-SSM. Dordrecht was selected as test area since on this island different land use types are found and also inundation depths may vary from shallow to very deep. Each improvement was tested individually and the effect of all changes together was also determined. The results for the improvements in each damage category group are discussed in the chapters 4 to 7.The results of all improvements together are discussed in chapter 8.

Dordrecht

The island of Dordrecht (dike ring 22) is located in the centre of the Netherlands and is protected for floods that can occur 1/2000 per year. The study area has a size of approximately 50 km^2 and is clearly divided into two parts by the Wieldrechtse Zeedijk: a semi-rural southern part and a high-urban northern part including the old centre of the city of Dordrecht (see figure 1.1). Three important national roads (A16, N3, N217) cross the area.

Figure 1.1 Topographic map (left) and aerial photograph of study area (right)

Figure 1.2 shows the elevation of the study area. In this figure the buildings are not filtered out. The roads and secondary embankments are clearly visible as higher elements in the landscape. The area north of the Wieldrechtse Zeedijk lies much lower than the area south of this embankment. Figure 1.2 also shows the potential flood depth map (based on a set of flood simulations all corresponding with design conditions in the river branches surrounding Dordrecht). The map shows that the northern part of the area (north of Wieldrechtse Zeedijk) may become deeply flooded, while water levels south of this embankment are generally less than 2 m. This northern part with large potential water depths contains the city of Dordrecht and most industries. The southern part is mainly used for agriculture.

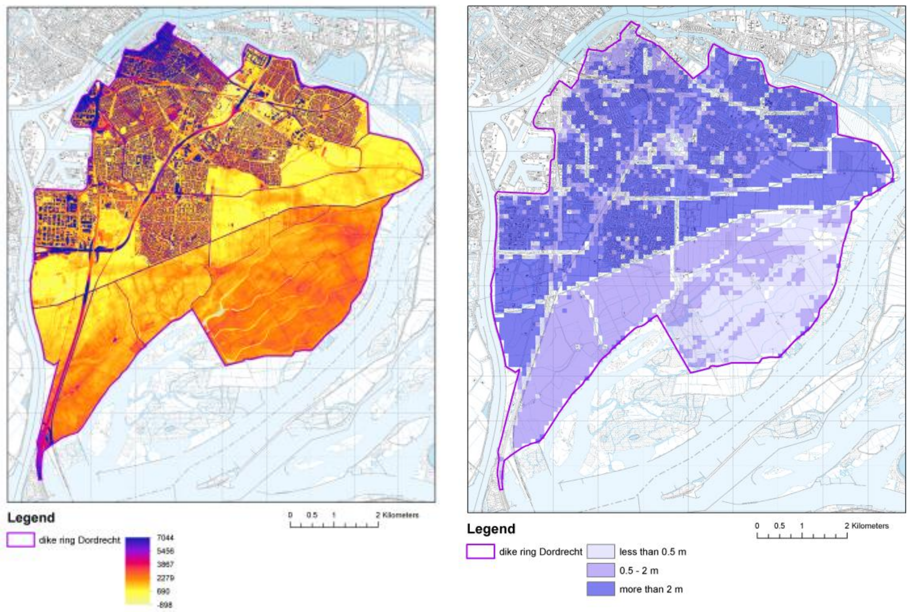


Figure 1.2 Elevation map (left) and maximum flood depth map corresponding with breaches in the main defences and river water levels at design conditions (1/4000 water levels in the river branches) The embankments are designed to withstand these water levels. The value of each cell represents the maximum water depth found in any of the simulations (right).

Test on the Netherlands

In chapter 8 a final test has been made in which all proposed changes are applied to the water depth map of the Netherlands. The resulting flood damages are compared with damages resulting from the HIS-SSM application on the same water depth map.

1.5 Report layout

Chapter 2 describes the standard method of HIS-SSM and discusses its strong points and the needs for improvement. Chapter 3 gives an overview of the improvements made in SSM2015 and chapters 4 to 7 discuss the improvements in more detail for respectively businesses, residences, infrastructure and other categories. Chapter 8 illustrates and discusses the results of the improvements together and the applicability and completeness of the proposed method. It also proposes a method to assess the uncertainty in the outcomes of the method. Finally, chapter 9 provides summarizing conclusions and recommendations.

2 The need for improvement of HIS-SSM

2.1 Overview theory flood impact assessment

Flood impacts are defined here as all negative impacts that floods have from the moment the water inundates dry land until full recovery has occurred. We do not consider positive flood impacts here[1]. Floods may impact society in many ways. They may physically damage objects, destroy products, hamper the use or operation of buildings, locations, or businesses, cause a disruption in utility and transport services which may endanger people and hamper businesses. They may also threaten lives. All these flood impacts can be categorised into a few main groups based on (De Bruijn, 2005) (table 2.1):

- The link with the flood: (physical damage due to the force of the water, or business interruption due to the inability to use locations or machines or to operate businesses).
- The location where damage occurs (within the flooded area: direct damage, outside the flooded area: indirect damage).
- The possibility to express the damage in monetary values (tangible and intangible damage).

Table 2.1 Negative flood impact categories (Based on De Bruijn, 2005)

<table>
<tr><th colspan="2">Category</th><th>Tangible</th><th>Intangible</th></tr>
<tr><td rowspan="2">Direct (in flooded area)</td><td>Physical damage</td><td>Capital loss (houses, crops, cars, factory, buildings)</td><td>Victims, ecosystems, pollution, monuments, culture loss</td></tr>
<tr><td rowspan="2">Business interruption*</td><td>Production losses, income loss</td><td>Social disruption, emotional damage</td></tr>
<tr><td>Indirect (outside flooded area)</td><td>Production losses outside the flooded area, unemployment, migration, inflation</td><td>Emotional damage, damage to ecosystems outside the flooded area</td></tr>
</table>

*Business interruption is often referred to as indirect damage. We use indirect damage for damages outside the flooded area only, which is consistent with the definitions used in HIS-SSM.

Physical damage severely depends on the flood characteristics, while the degree of business interruption due to floods also depends on the economic situation and structure. The methods used to assess physical flood damage, therefore, differ from those used to assess business interruption.

To assess physical flood impacts unit-loss methods are generally used which link flood characteristics to damage of individual objects. Instead of objects also area-units of land use classes may be used. The relationships between damage and flood patterns are for each object type or land use type provided in damage functions (also referred to as ‘vulnerability curves’).

For the assessment of business interruption, methods such as regional econometric models or analysing trends in time series data over a longer period, or input-output models may be used (De Bruijn, 2005). Input-output models consider the economy as a network of series of connected activities or nodes between which goods, people and information flow.

---

[1] *In the Netherlands’ flood-protected area the positive flood impacts are expected to be negligible compared to the negative flood impacts.*

Each activity must have inputs of materials, labour and so on and produces goods, services and waste products. Both inputs and outputs are conveyed to and from all nodes of activity along linkages, which are themselves specialised (Parker et al., 1987). A flood may either cut and interrupt some of these linkages or affect facilities. If there is enough redundancy or transferability the consequences will be small. If floods cause a significant decrease in production, a decline in investment and further decrease in production may occur. This is called a multiplier effect. At the other hand, recovery activities may enhance the level of output and investment which have a positive multiplier effect (Islam, 2000). Input-output models are difficult to make and to keep up-to date. They are very region and time specific.

The indirect flood impacts vary strongly from case to case. The Thailand floods in 2011 caused very large indirect flood impacts, while the 2002 floods in Germany did not. In Thailand very unique production facilities were affected which caused a shortage of input products in factories across the world. In Germany a large area along the Elbe was affected. However, this area was only a small fraction of the area of the economic system where it belonged to. Not many critical production facilities were affected and effects mainly occurred within the flooded area and a small area of the surrounding region.

This report and the damage model discussed focus mainly on direct flood impacts and the link between flood patterns and flood damages.

2.2 HIS-SSM

2.2.1 Overview of the method

In the Netherlands the Dutch Standard Damage and Fatality Model (HIS-SSM) is used to assess flood impacts in the Netherlands. All flood damage estimates for the Dutch local, regional and national governments should be made with this model. It calculates direct damage (including damage due to business interruption) in the flooded area, it provides the number of inhabitants of the flood-area and estimates the number of potential fatalities. It also provides a (very rough) estimate of the indirect impacts outside the flooded area. The model is designed to assess flood impacts corresponding with large-scale floods from the main water bodies in the Netherlands.

The model contains detailed data on land use, objects (residences, cars, businesses) and the number of inhabitants. The damage to these objects is assessed by linking the potential damage of these objects and the flood parameters in damage functions. The most important flood parameter used is the water depth. Next to the water depth, users may also provide maps indicating the maximum flow velocity and water level rise rate over the first 1.5m of water depth[2]. A detailed overview of the damage categories and damage types which are assessed in HIS-SSM is provided in annex A. Figure 2.1 provides an overview of the method of HIS-SSM.

[2] *The water level rise rate is only used to assess the number of fatalities.*

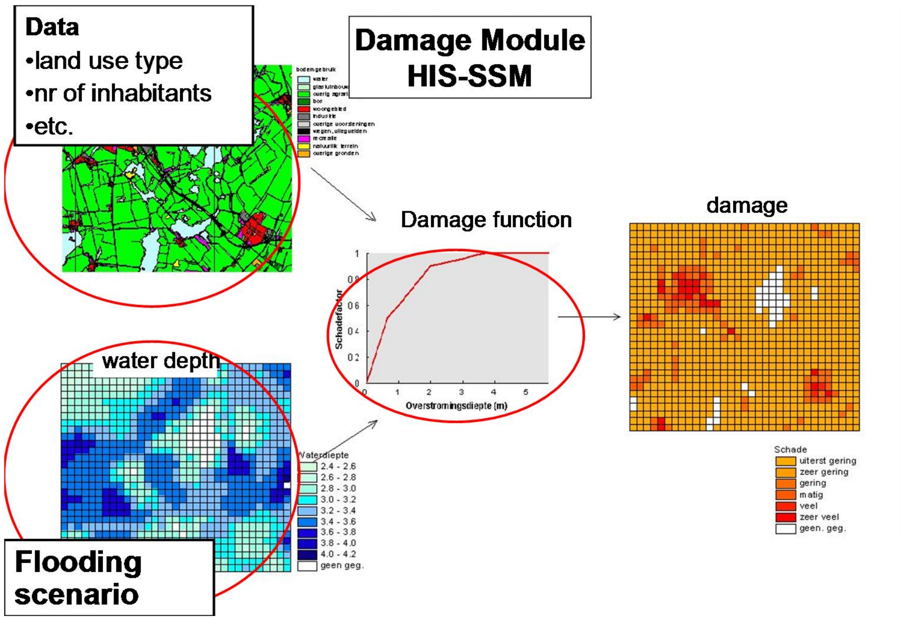


Figure 2.1 Structure of HIS-SSM

2.2.2 The need for improvements and updates of the damage model

The changes in flood risk management and in the corresponding questions resulted in an increased importance of flood impact data and in a need for more spatially distributed data (De Bruijn et al., 2011; Kind, 2013; Morselt & Evenhuis, 2008). The new flood risk management policy in the Netherlands requires more than just a 'total damage figure' per flood event. There is a tendency to draw damage maps and to study the effect of measures such as raising of ground level and flood proofing which requires accurate damage maps. Potential inaccuracies may be averaged in the total figure for a large area, but they will disturb the damage map or the effect of measures such as local ground level raising.

The most important limitations of the HIS-SSM method are:

- *Applicability:* HIS-SSM was made to analyse large-scale floods from the large rivers and from the coast. It is not directly applicable to local floods in the unprotected areas (e.g. near Rotterdam) (De Bruijn et al, 2012; Slager et al., 2013), or for floods with small water depths and small extents in other areas.
- *Actual data and figures*: The object data in the tool is not up-to-date: data on the number of inhabitants and residences has not been updated since the year 2000, the data on businesses is from 2005. To take into account changes since 2000/2005 sometimes corrections are used (e.g. 2.24 in the WV21[3] project, no correction in VNK2). Since these corrections are not used in all projects and not always in the same way, results of different projects have become incomparable. Prices and damage figures are related to the year 2000. They are adapted in HIS-SSM with a correction of 2% per year, but this 2% does not correspond with actual inflation rates.

[3] The factor of 2.24 is used to correct for missing damage categories, economic growth and inflation. The factor serves to convert damage figures calculated with HIS-SSM for the year 2000 to damage figures in 2011.

- *New insights* on damage figures and functions have not been incorporated in the standard damage module since 2005 (except for one important change in the fatality functions).
- *Scale*: HIS-SSM calculates damages on a spatial resolution of 100m cells. This scale cannot be adapted in HIS-SSM. This scale is not sufficiently detailed for small-scale floods or for inhomogeneous areas.
- *Flexibility:* The strong aspect of the tool is that all calculations are made with the same damage functions and object data and are thus all based on comparable assumptions. The drawback of this strong aspect, is that it is difficult for users to change damage functions and data, e.g. for analysis of damage of adapted houses or for future land use maps.

HIS-SSM is not applicable in unprotected areas, because the underlying object data is not very detailed. Residences, businesses and numbers of inhabitants are all provided per 6 Postal Code (PPC) and placed in the centre of a 6 PPC area. In the unprotected areas, these 6 PPC areas are large and very inhomogeneous: some parts may become flooded, other parts will not and some parts may be water permanently (e.g. harbours, or ponds). The location of the centroid of the 6PPC area then determines whether all residences, businesses and people in the 6 PPC are affected, or none. Besides, in areas where water depths are small the uncertainty in the damage is very large. Furthermore, the duration of flooding is generally much shorter in the unprotected areas. If no correction is used for this short duration, damage to business interruption will be overestimated.

To overcome these issues the outcomes of HIS-SSM have been corrected in several projects (see e.g. Kind, 2011) or ad-hoc improvements on the damage functions are made (see e.g. De Bruijn et al., 2012 and Slager, 2013). These corrections and improvements may result in differences of approach and assumptions used by different experts and thus in incomparable results. Therefore, the new standard method SSM2015 has been developed.

3 Overview of the improvements in SSM2015

3.1 Introduction

The new standard method 'SSM2015' is based on the same idea as HIS-SSM: It is based on a unit-loss method in which damage per category is assessed by multiplying a damage factor with the maximum flood damage for that category. The damage factor is a value between zero and 1 and depends on the flood parameters (generally: water depth) (see figure 2.1).

This chapter gives an overview of SSM2015: It summarizes the damage categories which are distinguished, the damage types considered (physical damage and/or business interruption) for each category, the input flood parameters required and the starting points and definitions used. The chapters 4 to 7 discuss the improvements made per damage category in more detail.

3.2 The damage categories distinguished in SSM2015

For SSM2015 a different set of flood damage categories is suggested than was used in HIS-SSM. The changes in categories are required because of the update of data of businesses and residences (the new data refers to other categories, see chapter 4 and 5) and the improvements in the classification of railroads (see chapter 6). Table 3.1 provides the list of categories which is presented in the output. The use of BAG[4] data instead of Dun & Bradstreet data for the damage assessment of businesses resulted in another approach for that damage category: damage is now calculated based on the area of company buildings, instead of on the number of jobs per location. Also the categories, the maximum damages, and damage functions were changed (see chapter 4). The use of BAG data for the location and number of residences instead of Bridgis data enabled the transition to other residence categories: The apartments are now classified according to the floor of the building at which they are located. The residence category 'farms' was abandoned, and farms are now classified as 'single family houses' (see chapter 5).

The damage of businesses, residences, infrastructure and other categories are quantified in monetary terms. The output of SSM2015 also identifies and maps special objects and areas, if flooded. These include vulnerable objects, cultural heritage, IED-installations[5] and vulnerable (nature) areas. The flooded special objects and areas are identified, counted and mapped. The flooding of these objects may be of relevance for flood risk managers and their identification is required for the Water Framework Directive. These special objects are summarized in table 3.2.

Furthermore, we suggest to also assessing the number of affected persons, the mortality rate per grid cell and the number of fatalities. HIS-SSM also assessed these. These impacts are not discussed further in this report.

[4] BAG = Basis Administratie Gebouwen. This is data of the municipalities which is up-to-data and free available. It contains the precise location and footprint of buildings and many attributes of objects, such as the total living space, the function of the building etc. The use of BAG is explained further in chapter 4 and 5.

[5] IED = Idustrial Emission Directive.

Table 3.1 Impact categories for SSM2015 (1 = direct physical damage, 2 = damage due to business interruption)

	Impact categories SSM2015	1	2
Businesses	Meeting facilities (pubs, hotels, churches, etc.)	X	X
	Offices	X	X
	Health services	X	X
	Industries	X	X
	Education facilities	X	X
	Sport facilities	X	X
	Retail and commerce	X	X
Residences	Single family houses	X	X
	Ground floor apartments	X	X
	First floor apartments	X	X
	Higher floor apartments	X	X
Infrastructure	Regional roads	X	
	Motorways	X	
	Other roads	X	
	Railroads – electrified	X	
	Railroads – unelectrified	X	
Other categories	Agriculture	X	
	Green houses	X	
	Recreation intensive	X	
	Recreation extensive	X	
	Urban area	X	
	Airports	X	
	Vehicles	X	
	Pumping stations	X	
	Waste water treatment plants	X	

Table 3.2 Categories of special objects and areas which are identified and mapped if flooded

Special objects and protected areas[6], [7]	
1	Residence
2	Hotel / pension
3	Education
4	Hospital / accomodation
5	Public facility
6	Office / business
7	Other object
8	National cultural heritage
9	IED-installations[8]
10	Waterbodies designated as recreational waters
11	Areas designated for the abstraction of water intended for human consumption
12	Areas designated for the protection of habitats or species

[6] Potentially affected protected areas identified in Annex IV(1)(i), (iii) and (v) of Directive 2000/60/EC (Water Framework Directive)

[7] The vulnerable objects are defined according the regional risk profile (RRP) as buildings with many people or buildings with people without self-sufficiency (the sick, the elderly, the children) (risicokaart.nl).

[8] Installations as referred to in Annex I of Directive 2010/75/EU concerning industrial emissions which might cause accidental pollution in case of flooding

3.3 Data sources

The object and land use data has been updated. Table 3.3 provides an overview of the data sources used for SSM2015. The data used in HIS-SSM is provided in annex A. The data of residences, businesses, infrastructure, landuse, waste water treatments and pumps and number of inhabitants all have been updated in SSM2015. The consequences of the updates for each damage category are discussed per damage category in the chapters 4 to 7.

Table 3.3 Source of data for the various groups of damage categories in SSM2015

	Category group	Source name	Format*	Unit in raster
1	Businesses	BAG 2014	Point	Area of each business type per cel
2	Residences	BAG 2014	Point	Number of each type per cell
3	Roads & railroads	Nationaal wegenbestand (NWB-Wegen) RWS 2015	Line	sum length (m per cell)
4	Railroads	Nationaal wegenbestand – spoorwegen RWS 2011	Line	sum length (m per cell)
5	Landuse categories	Bestand Bodemgebruik CBS 2008	Polygon	sum surface (m2 per cell)
6	Water treatment plants & pumps	WIS RWS 2005	Point	Number per cell
6	Affected persons, fatalities, vehicles	CBS buurten en wijken 2013 & BAG 2014	Polygon	Number per cell with residences
7	Vulnerable objects, installations)	Risicokaart.nl, accessed at nov. 2014	Point	Number per cell
8	Protected areas*	Risicokaart.nl, accessed at nov. 2014	Area	M^2 per cell

*For example (swimming water locations and drinking water source locations)

The land use file of CBS was replaced with a more recent file. For the other categories not only an update, but also a change to another file type was used or the category data was slightly adapted. The category ‘urban area’ consists in SSM2015 of the CBS land use category ‘build-up area (20) and ‘build-up construction area’ (34).

The residential data and business data is obtained from BAG. The BAG (Basisregistratie Adressen en Gebouwen[9]) contains data on all buildings in the Netherlands, it is updated yearly and available without costs. This BAG contains data in more detail and in completely different format as BRIDGIS and Dun & Bradstreet, which were used for HIS-SSM. To accommodate the data update with BAG data, the residence categories, business categories, maximum damage figures and damage functions were all changed.

In unprotected areas no damage is calculated for agriculture, nature and recreational areas. In the more frequently flooded unprotected floodplain parts, these land use types are adapted to floods. Machines, buildings and other vulnerable assets are raised or placed in the protected areas. Furthermore, no business interruption damage is assessed for those areas.

[9] *https://data.overheid.nl/data/dataset/basisregistratie-adressen-en-gebouwen-bag- of http://geodata.nationaalgeoregister.nl/inspireadressen/atom/inspireadressen.xml of http://www.nlextract.nl/file-cabinet*

The roads and railroads file of the “Nationaal wegenbestand RWS” was updated and adapted as will be discussed in chapter 6. Bridges and tunnels were removed from the main roads and railroads were divided in electrified and non-electrified lines to be able to distinguish small company railroads from the main railroad lines.

3.4 Input parameters

Flood impacts depend on various factors, such as the flood severity, the land use and objects present, behaviour of people, timing of the flooding and so on. This section discusses the flood parameters which must be taken into account.

The flood parameters which may influence damage are:
- parameters directly related to the flood pattern: water depth, flow velocity, water level rise rate, flood duration;
- parameters which are not directly related to the flood pattern, but also affect the impact of floods, such as: the presence of waves, season, temperature, presence of storm, water quality, presence of debris, human actions.

We propose to consider the water depth as primary parameter for all damage categories and to add flow velocity and water level rise rates for those categories for which this may be relevant. We suggest neglecting the influence of the other parameters. This means that we propose to use the same parameters as used in HIS-SSM. This proposal is discussed below.

The decision to include a certain flood parameter was based on the following criteria, which are discussed below:
- The correlation between the parameter and the damage;
- The availability of data on the input parameter (is it common practice to determine the flood parameter);
- Correlation with other input parameters;
- Variation in the parameter value at different locations and for different flood events in the Netherlands.

Water depth
In both HIS-SSM and SSM2015 water depth is the only obligatory parameter. Water level rise rate, and flow velocity may also be used. The correlation between water depth and damage has been studied intensively for many damage categories. This water depth parameter is used in all unit loss damage methods (e.g. see HAZUS (FEMA, 2009) and FLEMO (Thieken et al, 2008). The water depth is a standard outcome of all flood inundation models and water depth estimates can also be made by comparing water levels and elevation maps. Water depths vary from place to place and between flood events. These variations lead to different flood damage estimates.

Flow velocity
Flow velocity is used in HIS-SSM, but only in the damage function of residential buildings. If it exceeds 2 m/s single family houses are expected to collapse, the damage function is set to 1 and the maximum damage occurs. For high rise apartment buildings, the threshold for collapse is set at 8 m/s.

In many countries flow velocity is a commonly used parameter in damage assessment (Groot et al., 2000). In the US model HAZUS, for example, the threshold for flow velocity is about 1.7 m/s at 6 m water depth and 2.5 m/s at 3 m water depth (FEMA, 2009). The flow velocity is taken into account when it exceeds that threshold.

High flow velocities could occur during a flooding in the Netherlands. In 1953, for example high flow velocities occurred due to the tidal currents. Also in small streets or due to breaches in obstacles higher flow velocities could occur.

The effect of flow velocity on damage is not known precisely. Thieken *et al*. (2005) studied the effect of flow velocity on flood damage of 1200 German houses. She found barely any difference in damage between places with low, average or high flow velocities. Only places were extreme flow velocities were reported had statistically more damage. Yet this only applied to 2% of the observations. Flow velocity, therefore, seems to have an insignificant impact on the total flood damage for the German cases. These cases, however, generally were houses flooded due to river floods with minor water depths. In coastal floods or in situations with large water depths, conclusions might be different.

High flow velocities are rarely found in model results of flood simulations in the Netherlands, since the Netherlands is flat, and because at the moment generally large cell sizes (50 or 100m) are used and roughness values used are very high for urban areas. This means that in urban areas the simulated flow velocities will generally be less than 0.5 m/s. However, near the breach and also at locations where secondary embankments or other obstacles are overtopped locally higher values may be found.

SSM2015 will often be used to assess damages corresponding with a simulated flood pattern. Since these flood patterns will only rarely contain higher flow velocities, omitting flow velocity would generally not affect the damage estimates. However, at breach locations and other specific locations differences in results may occur. It is likely that in the near future more detailed modelling approaches (e.g. with 3di) may become more common. These could result in better flow velocity estimates. Besides, we might also want to use SSM2015 in future in more sloping areas, such as for modelling of damage due to flooding of the brooks in Limburg. High flow velocities are more likely there.

We propose, therefore, to accommodate the use of the flow velocity as parameter in SSM2015. We must, however, keep in mind that actual flow velocities are not assessed accurately at the moment, because of the scale and approach used in common flood inundation models.

Water level rise rate

In HIS-SSM the water level rise rate is used to assess flood fatalities. Its use is discussed in De Bruijn & Slager (2014). We propose to accommodate the use of this criterion also in SSM2015.

Flood duration

Flood impacts depend on the flood duration. The material damage is not very sensitive to the flood duration, but it may increase with increasing duration. Damage due to business interruption significantly depends on the duration of flooding (and the duration of the recovery of transport and utility services after a flooding). This damage type increases with duration mainly during the first days and weeks. After a few days to weeks substitution effects and replacement effects reduce the effect of business interruption. Of course, the effect of substitution depends on the scale and the system considered (e.g. the effect may still be significant for the businesses flooded, while the effect may have disappeared at the scale of a province or at the scale of the Netherlands' economy). Not for all damage categories substitution is relevant. For specific objects which are difficult to replace, or which are relevant for many people, interruption costs may increase with duration even after weeks. Examples of such items are highways and other critical infrastructure types.

In the Netherlands, flood duration in protected areas along the main water bodies may vary between days (upstream in the riverine area) to months (in the lowest parts of the riverine area, and in coastal and tidal river areas) (Wagenaar, 2012). The flood duration of unprotected areas is generally very short (hours) and duration of flooding of areas along regional water ways is also limited.

Some models capture the impact of flood duration on the material damage. Yet in those cases the time scale is usually measured in hours reaching a maximum at about 1 day (FEMA, 2008). If these models would be applied to the Dutch flood durations, the maximum contribution related to flood duration would be found everywhere. It would then not be a significant parameter to model. The impact could better be considered in the maximum damage figure. However, if SSM2015 would also be used for flooding of unprotected areas with a short flood duration, its damage figures should be adapted to compensate for the short duration of the flooding there.

Commonly used flood inundation models are not useful for the assessment of the flood duration. To model flood duration, the drainage system should be included in more detail in the model schematisation than is usually done and the model runs should be extended to accommodate the drainage of the area. Water will generally flow out first by gravity through the breach, through the drainage system or through additional openings in the embankments. Then the lowest areas may have to be pumped dry if these are located below the level of the drainage system. An indicative flood duration map which was based on flood and area characteristics is shown in figure 3.1.

The flood duration is correlated with the water depth (Wagenaar, 2012). This correlation reduces the need to take into account flood duration.

It is proposed not to use flood duration as a parameter in SSM2015, since flood duration data is commonly not available and because knowledge on the precise impact of flood duration on damage is lacking. However, flood duration is taken into account implicitly in the damage due to business interruption by using the water depth which is correlated to the duration of flooding (and duration of recovery). Because of the short duration of flooding in the unprotected areas, business interruption damage is neglected for those areas (see Slager et al., 2013).

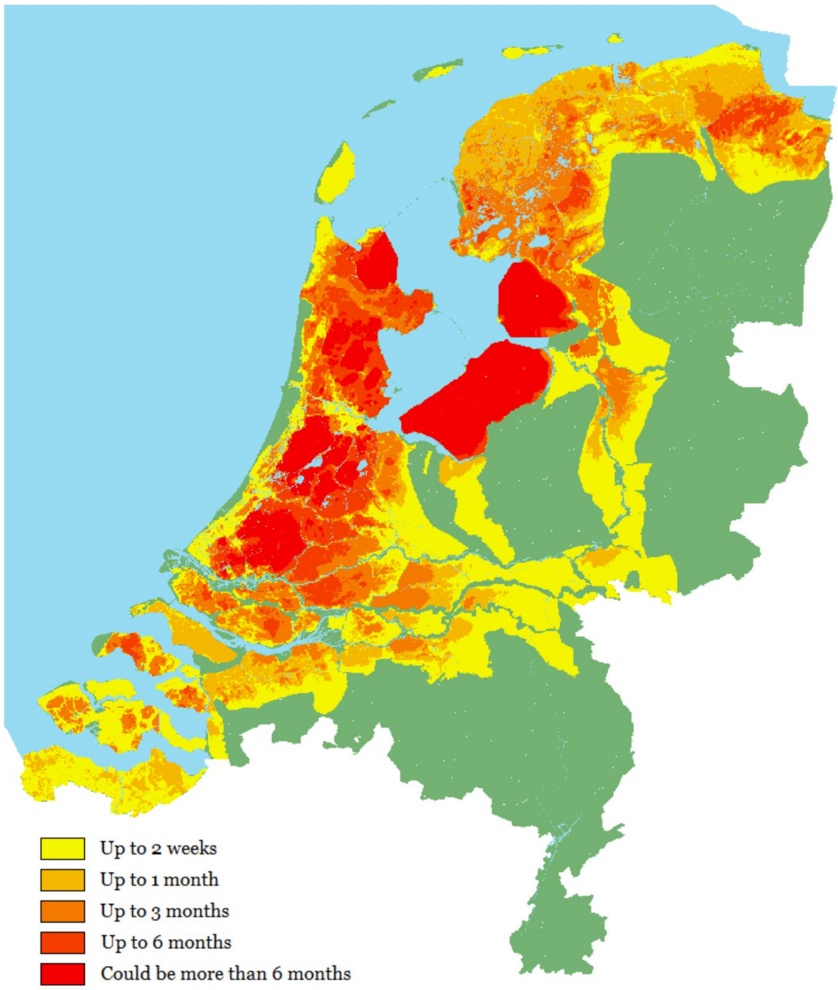


Figure 3.1 Indicative flood duration map for flooding from the main waterways (Source: Wagenaar 2012).

Salinity of the flood water

It was expected that the salinity of the flood water (fresh or salt water) has an impact on flood damage (Duiser, 1982), especially to agricultural damage. Duiser (1982) estimated that damage to agriculture is about 30% higher in case of a salt water flood. However, others found that damage to agriculture due to the 1953 flooding was limited to one to three years and that after this period yields were higher than before the 1953 flooding (due to the fertile sediments deposited by the flooding) (Anonymus, 2002). Since agricultural damage contributes little to the total damage, taking into account salinity would not influence the total flood damage much. For other types of objects, such as buildings, salinity could also make a difference. This difference is, however, never quantified or researched. Taking it into account would, therefore, first require extra research which falls outside the scope of this report. It was therefore decided not to consider the effect of salinity on flood damage in SSM2015 until better knowledge is available.

Other parameters

Next to the parameters which are directly linked to the flooding, also parameters such as the presence of waves, presence of storm, debris, water quality, season, temperature and human actions may affect damage.

Storm, waves and debris in the water may cause collapse of buildings due to lower flow velocities than the mentioned flow velocity thresholds above. If water becomes polluted damages may increase and costs for cleaning may rise. The season will strongly affect agricultural damage and the temperature will affect if it would lower to below zero during a flooding, or if it would rise above 10 degrees and a strong growth of mold would occur. Human actions, such as evacuation of cars and furniture to safe locations, moving machines or equipment to safe locations, protecting houses from entering water and so on, might also affect damage. There is little data on the effect of these parameters on the damage. The Thieken et al. (2005) studied the effect of contamination and of human actions on German flood impacts. They showed that highly contaminated water caused about 80% more flood damage than non-contaminated water. They decided therefore, to include contamination as an input parameter to the German flood damage model FLEMO. It is not clear whether the 80% figure is also valid for the Netherlands.

Thieken et al. (2005) also studied the effect of precautionary measures on flood impacts. They found that flood damage could reduce by 50%, if effective precautionary measures were taken. American studies showed a maximum decrease of about 35% of total damage (Caresell et all, 2004; Scawthorn et al, 2006). These studies lead to the inclusion of precaution as an input parameter to the German flood damage model FLEMO. This information may be used to assess the impacts of improving preparation or other types of emergency measures. Their validity for the Netherlands depends on the data which they were based on. If they were all based on shallow floods of short duration, they may not be valid for deep large scale flooding in the Netherlands which may last for months.

The parameters are not accommodated explicitly in SSM2015 at the moment. There is too little information on the relationship between the parameter and damage and it is not common practice to assess the value for these parameters.

3.5 Definitions and starting points

3.5.1 Definition of maximum damage

As explained in the introduction, flood damage is calculated by multiplying the maximum flood damage per object with a damage factor which depends on the water depth (and other flood parameters). The damage factor gives the percentage of the maximum damage which occurs given a certain water depth (or other set of flood parameters). To get a consistent model in which the damage factor corresponds with the maximum damage value, the precise meaning of ‘maximum flood damage’ must be defined clearly. The maximum damage of an object may be defined in roughly two ways:

1. *As the total value* of the object or business, including the part of the value which is not susceptible to flooding. This value will then include the value of land and location, the value of foundations of buildings and the value of furniture on high floors. The corresponding damage value should then reach at maximum the fraction of the value which may be damaged by flooding.
2. *As the maximum potential damage*. This value is equal to the damage which will be expected when water depths rise very high (or other relevant flood parameters become very large). The corresponding damage function should then reach one.

Models may also be based on definitions which are a mixture of these two.

The difference between the two definitions is illustrated with a hypothetical building which had a recorded damage of 50 in a flood event. The building has a value of 100, but only 75 of this value is susceptible to flooding (25 is attributed to land, location and other non-vulnerable values). If definition 1 is followed, the maximum damage is defined as 100, and the damage factor in the event is 0.5. The product of the damage factor and the maximum value will then be 0.5 * 100 (= 50). If definition 2 is applied, the maximum damage is 75 and the damage factor 0.67. The product of the damage factor and the maximum value will then equal 0.67 *75 = 50.

The definition of this maximum damage differs between damage models and causes differences in the height of damage functions and maximum damage figures. The definition behind the damage functions and figures must be known in order to compare them.

It is not completely clear which definition is used in HIS-SSM for the determination of the maximum damage. In international literature, often the first definition is used and damage functions are applied which do not go up to 1.

For SSM2015 we suggest to use the second definition and vary all damage functions between zero and 1. This means, however, that it must be assessed which part of the value of a business of building may be vulnerable to flooding and that the business and building values must be corrected for the part of the value which is not susceptible to flooding.

3.5.2 Valuation ground

Damage values of capital goods and stock can be estimated based on the actual value of objects lost or on their replacement value. For the assessment of damage to businesses we propose to use (see chapter 4):

- For capital goods: the actual value of those capital goods: The replacement costs would result in an overestimation of the damage due to a flood. Replacement costs will be higher, since in general capital goods will be replaced by better replacements. In HIS-SSM the maximum physical damage to moveables and immoveables of businesses is based upon the replacement value of the capital goods.
- For business interruption: a value derived from the added value of the business sector.

For residences we propose to use the replacement (reconstruction) value, since depreciation is not relevant for residences (see chapter 5). For furnishing we propose to use the actual value.

For agriculture, green houses, recreation and airports the damage values are based on added value. For infrastructure, urban areas, water treatment plants and pumps values are based on repair costs.

All damage figures are based on values excluding tax. (ex. BTW).

3.5.3 Spatial resolution in impact calculations

SSM2015 is able to calculate flood impacts on a resolution of 5, 25 and 100 m cell size. The resolution of the output data is equal to the input flood depth map (and other flood parameter maps) which the user provides.

4 Proposed improvements for damage to businesses

This chapter discusses the method used in HIS-SSM for damage assessment of businesses and suggests improvements for the SSM2015 method. The damage to business is expected to be underestimated in HIS-SSM (see Kind, 2011), in which only about 10 to 15% of the total damage is related to businesses (see chapter 1.4 and 8). The data, maximum damages and the damage functions are improved.

4.1 Overview of the method used in HIS-SSM

HIS-SSM distinguishes three different damage types for the category 'businesses' (see chapter 3):

- **Direct damages to capital goods (Physical damage):** Damage to moveable and unmoveable goods (buildings, furnishing, vehicles, machinery, supplies, etc.) caused by contact with water.
- **Direct damages caused by business interruption:** Damage or costs incurred by business interruption in flooded businesses.
- **Indirect damages:** Damage or costs of businesses outside the flooded area, as a consequence of supply or demand interruption due to flooding elsewhere.

These damage types are calculated for nine standard business categories (see table 4.1). The category definition is based on an aggregated version of the SIC (Standard Industrial Classification). Briene *et al.* (2002) and Sluijs *et al*. (2000) provided for each of the three damage types and for each of the 9 business categories a maximum damage which is based on the average damage per job in a particular business category.

Table 4.1 Overview of the maximum damages per business category and damage type

Sector	Physical damage (k€/job)	Business Interruption (k€/job)	Indirect (k€/job)
Mining	1 820	84	116
Construction	45	26	45
Trade/Hotel, catering industry	20	8	4
Transport/Communication	75	11	6
Banking/Insurance	90	14	7
Government	60	9	2
Industry	279	62	72
Utility companies	620	112	163
Healthcare/Other	20	3	6

The number of jobs per business category for each postal code area (6 PPC) is obtained from the Dun & Bradstreet database. This database was last updated in HIS-SSM in 2005.

HIS-SSM uses two different damage functions for all nine businesses and damage types together (see figure 4.1). One damage function is used for both physical damage and business interruption for the transport and communication category and the other one is used for physical and business interruption for all other business categories. The choice to use one single function both for physical damage and for business interruption is, to our best knowledge, not motivated in literature.

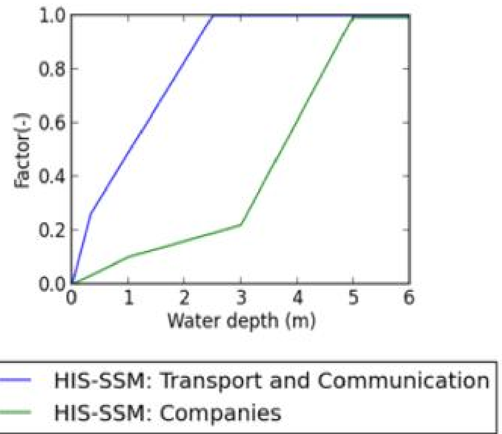


Figure 4.1 The damage functions used to calculate damage to businesses in HIS-SSM.

Both functions are based on a long series of publications dating back to the 1980s (Wagemaker, 2006). The most influential work was Duiser (1982). Duiser formulated a damage function for businesses very similar to the one now used in HIS-SSM for all functions except transport & communication. He combined damage functions from the 1953 floods and from a study of the province of Gelderland (1973). The green function (for all business categories except transport & communication) slowly increases up to a damage factor of 0.24 at 3 meters water depth and then increases linearly to 1 at a depth of 5 meters (Kok et al., 2005).

For water depths smaller than 3 meters, the function for companies (all except transport & communication) is based on a function of the Province of Gelderland, which rises quickly in the first meter to a damage factor of 0.24 and then becomes almost horizontal. This function was based on the assumption that at 3m of water depth maximum damage would occur and that this maximum damage was equal to 0.24 of the *total value* of the business. The function did not increase to 1, since in that model a factor of 1 was linked with the *total value* of the business (including the value of land and other non-vulnerable valuables). However, in HIS-SSM a damage factor of one is linked with the *maximum flood damage* of the business and not with its *total value*. The function thus should go up to 1 (see for this discussion on the meaning of a damage factor of 1 also chapter 3.5).

For water depths larger than 3m the function for business categories other than transport was based on the function for structural damages to houses derived from the 1953 flood data. This function is very steep, because in a few villages, houses were completely destroyed leading to damage factors of 1. The function from Duiser (1982) was adopted and slightly adjusted by several authors, before it was used in HIS-SSM.

Obviously, modern buildings are not comparable with the houses that collapsed in 1953 and in 1945. Most collapsed houses had single layer brick walls which may fail due to flow velocities between 1 and 2 m/s (Vrouwenvelder & Waarts, 1994). Modern buildings often have stronger concrete frameworks that can resist flow velocities from 2 up to 7 m/s. Flow velocities exceeding 2 m/s are very rare in the Netherlands. Therefore, building collapse will occur less frequently (see chapter 3.4). Since building collapse (which is implicitly assumed in these functions to happen due to large water depths) is less likely in the current situation, these functions are not considered applicable to current businesses.

Business interruption in HIS-SSM
In HIS-SSM the business interruption *inside* the flooded area is calculated with a method similar to the calculation method for physical damage (i.e. damage function and maximum damage). This maximum damage due to business interruption is set equal to the added value per unit of time multiplied by the expected interruption duration. The added value was derived directly from economic data, but the interruption duration was based on a rough estimate. The maximum interruption period ranges from 1 year for industry and utility companies down to 2 months for the other companies. The maximum damage only occurs if water depths exceed 5m, if not, the duration is multiplied with a factor and is thus in fact shortened. Consequently, HIS-SSM indirectly assumes that in areas with water depths less than 3m interruption lasts much shorter than 2 months (or shorter than 1 year for industry).

The business interruption *outside* the flooded area is also explicitly calculated. This is done with a fixed multiplier on the business interruption inside the flooded area. This multiplier was based on an input-output model. After application of the multiplier the business interruption outside the flooded area is reduced with 75% to take into account substitution effects outside the flooded area.

4.2 Knowledge derived from other impact models, events or previous research projects

4.2.1 International studies and damage models considered

Since HIS-SSM was released in 2000, new data and knowledge on damage to businesses has become available. This new knowledge and data is now used to update and improve the assessment of flood damage to businesses. This section discusses potential improvements in the assessment of damage due to flooding of businesses by investigating:
- the definition and number of distinguished categories;
- potential maximum damage per category; and
- damage functions of the categories.

The first step of this analysis is a comparison between HIS-SSM and information from the studies and damage models: Gauderis (2012), FLEMO (Kreibich, 2010), HAZUS (FEMA, 2009), MCM (Penning-Rowsell, 2005), Rhine Atlas (ICPR, 2001) and Tebodin (Sluijs, 2000) (see chapter 1.3).

These models and methods differ in the number of business categories which they consider: HIS-SSM distinguishes 9 business categories and contains 2 different damage functions for all 9 functions together. HIS-SSM is more detailed than the Rhine Atlas, about equally detailed as the FLEMO model and less detailed than Tebodin, HAZUS and MCM.

The following sections compare respectively the maximum damage figures and damage functions used in the studies and models mentioned.

4.2.2 Comparison of different rationales regarding the maximum damages

Although maximum damage figures per business category depend on the price level of the country and cannot be compared directly, the method used to assess the maximum damages can be compared. The maximum damage figures can be derived based on:

- **Economic data:** This is the most frequently used method. National economic data is used to derive the value of capital goods and business interruption for each business category on a national level. To obtain the average value of capital goods and business interruption per job, the contribution per business category to the national economy is then divided by the total number of jobs for that the category. The method is used for the assessment of maximum damages in e.g. HIS-SSM, FLEMO and Gauderis (2012).
- **Calculating damage to a hypothetical business:** MCM uses a different method: An average business representative for a damage category is defined and for each aspect and part of the business the expected flood impact is assessed by experts. Based on this assessment a maximum damage is constructed.

The first method seems simple to apply. It is, however, not sufficient to know the average value of a job in a certain business category. The fraction of this value that is vulnerable to floods must also be known. It is difficult to distinguish the capital goods that may be affected by floods from the non-vulnerable ones. The use of a hypothetical business doesn’t have this disadvantage. The problem with the latter method is, however, that it is very time consuming to define a hypothetical business for each category and get expert judgements for all business parts. Furthermore, the definition of the hypothetical business must be done in such a way that this business is representative for the category and that the total damage in the category corresponds with the total damage for that category which would be expected in reality.

This comparison provides no clear reason to change the method (use of economic data) to determine maximum damages used in HIS-SSM.

4.2.3 Comparison of the damage functions used internationally

This section compares damage functions used in HIS-SSM with international damage functions (see section 4.2.1). When comparing damage functions and models, one should keep in mind that most damage functions are based on a single flood event that may not be representative for the average Dutch situation. Also the type of businesses, the distribution over floors and the dependency of utility services may differ between countries and distort comparison.

Damage function for physical damage

Figure 4.2 shows both the function used in HIS-SSM for physical damage for all business types except transport (blue function), as well as an averaged international function for damage to businesses (green function). This average function was obtained from a damage library (Wagenaar, 2013) by averaging the business functions of the FLEMO, HAZUS, Rhine Atlas, Tebodin and MCM models (see chapter 1.3). The functions of each model are provided separately in figure 4.2 as well. To obtain the average functions, the individual functions of the different models were combined in such a way that each model/study was weighted equally. It is observed that below water depths of 3.5 m the blue function (HIS-SSM) gives relatively low damage factors compared to the green function (average of international functions). The steep ascend of the blue function for depths larger than 3 m deviates from the slope of the curves of the international damage models.

The definition of the damage occurring when the damage factor is 1 in HIS-SSM is not explicitly described. Most likely, a damage factor of 1 in HIS-SSM corresponds with the maximum expected damage of businesses due to extreme flood events. The average function of all damage models does not go up to one. There, a factor of one is associated with the value of the business instead of the potential damage of the business. This difference makes comparison more difficult.

The functions used in HIS-SSM are among the least motivated functions. In contrast, MCM and FLEMO[10] are well described. They are derived in different ways, but they are comparable, especially in the first 2 m. From these observations it is recommended to adapt the HIS-SSM functions as will be explained in section 4.3.

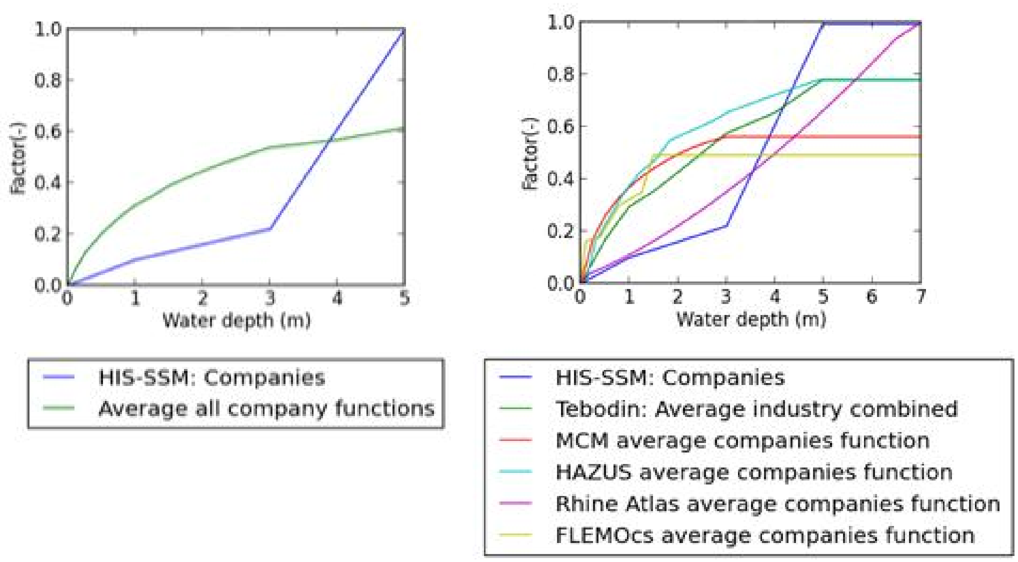


Figure 4.2 Left: The averages of all business functions from HIS-SSM, FLEMO, HAZUS, MCM, Tebodin and the Rhine Atlas compared to the HIS-SSM function. Right: The average of all business damage functions except the HIS-SSM function.

[10] *The FLEMO function reaches it maximum at a water depth of 2m. It was derived from data of the 2002 Elbe flood which barely had any water depth exceeding 2m. The curve-section between 1.5 and 2m is based on the damage records corresponding with water depths exceeding 1.5 m, which explains the sharp increase above 1.5m.*

4.2.4 Assessment of damage related to business interruption

Background and theory of business interruption damage
To assess business interruption damage, an estimate of the duration of business interruption is crucial. Business interruption duration can be defined in different ways:

1. *Interruption duration for the business itself***:** The duration that the business cannot function at its original location.
2. *Interruption duration for the economy***:** The duration that the value the business used to produce is lost to the economy. In this definition the duration is shorter than in the first definition: if non-flooded businesses take over production, interruption of the production is considered overestimated.

The duration in the second definition is on average shorter than the first definition, as many interrupted activities can go on *outside* the flooded area.

The damage due to business interruption can be assessed by:

- Looking at the damage for the flooded company
- Looking at the impacts for the economy and taking into account substitution of damaged facilities by other companies
- Looking at the impacts for the economy and taking into account substitution and also cascading effects to companies which are affected by production losses or interruption of flooded companies.

Negative cascading effects and positive substitution effects
Indirect business interruption (outside the affected area) can occur because companies rely on activities inside the flooded area. A famous example of this damage is the indirect damage due to the flooding of a single hard drive component factory during the Thailand flood of 2011. This flood created a worldwide shortage in this very specific component and subsequently interrupted the hard drive production for many companies. Consequently, the hard drive price rose and caused worldwide economic damage as less computer systems and software were sold. For cost-benefit analyses in the Netherlands we are only interested in damage within the Netherlands.

Another import aspect is substitution: companies or institutes outside the flooded areas may take over the production of interrupted activity of flooded companies or institutes. For example, if Rotterdam would become flooded, empty office buildings in The Hague may be used as replacement for flooded office buildings in Rotterdam to be able to resume activities before the office buildings in Rotterdam are dry and repaired. The same can happen with work that other companies can take over because they are not working on full capacity.

The interruption effects in SSM2015 are determined for the Dutch government on national scale. Substitution of activities by German companies for example, may be considered as a loss for the Dutch economy.

Substitution effects depend on the state of the economy at the moment of the flood. When the economy is operating near full capacity, substitution effects will be weaker than in a recession because fewer alternatives are idle. These factors make it very difficult to model the substitution.

Business interruption duration

When substitution effects are completely neglected (definition 1), an interruption duration of one year may be realistic. In that case the interruption duration becomes equal to the flood duration plus restoration duration and this is often in the order of one year or even longer (FEMA, 2008; Lamond et al, 2014; Wagenaar, 2012). Lamond et al. (2014) shows that even with small water depths and relatively little damage restoring flooded houses in the UK takes a long time. For example in the UK floods of the summer of 2007 the average duration to restore a building was 9 months, despite the relatively small water depths (Lamond et al., 2014). This long duration is explained by the complexity of restoring a flooded building. Water will suck into the building materials and can cause dangerous mold growth, if the drying process is not carried out correctly and completely. This drying process alone can take 2 weeks to 3 months before normal repair work can even start. Furthermore, it needs specialized skills and machinery which are in short supply after a major flood. This shortage caused significant restoration delays after the UK flood of the summer of 2007. In the UK this restoration process is well organized and standardized by insurance companies who have ample experience with it (e.g. detailed guidelines for contractors). In the Netherlands, which rarely experiences floods, these restoration durations can therefore be even longer than in the UK. A maximum interruption duration estimate of one year therefore seems very reasonable.

However, the duration of interruption becomes much shorter if substitution is taken into account. For sectors in which substitution is easy to realize (e.g. offices or other sectors in which value is created by human labour) the substitution effect is probably much larger than negative cascading effects. Also for the education sector where the negative indirect business interruption effects are expected to be very small (multiplier of 1.25) and the substitution possibilities are expected to be good, substitution must be taken into account. Cancelling out the large substitution effects with the small negative damage effects which is sometimes proposed (Gauderis, 2012; De Bruijn et al., 2014) therefore seems to be incorrect. Only for industry and utilities in which most value is created by specialized equipment rather than human labour, substitution seems difficult. Differentiation between sectors is thus needed.

Substitution may be less after large floods than after small floods: When one office is flooded it is easy to find a replacement, but when all offices in a region are flooded this is much more difficult. This explains why the business interruption plus indirect damage was that small during the Elbe floods in 2002. The Elbe floods were in fact more a collection of small floods affecting several regions a little bit, rather than affecting one region severely. For future studies it is therefore recommended to look into the relationship between the size of the affected area and the business interruption duration.

Damage function for business interruption

The business interruption calculated with HIS-SSM is in total on average about 4% of the total damage. Observations of actual flood events show much larger fractions (Gauderis and Kind, 2011; Vilier, 2013). Table 4.2 shows examples of recent international event and model data of damage due to business interruption. The contribution of business interruption damage as percentage of the total damage ranges from 5% in the Elbe floods in 2002 to 125% for the Thailand flood in 2011.

Table 4.2 Business interruption as percentage of the total damage for different events and models.

Event/model	Fraction of the total damage	Reference
Elbe floods 2002	5%	Gauderis and Kind, 2011
UK floods 2007	12%	Chatterton et al, 2010
Hurricane Katrina 2005	30%	Gauderis and Kind, 2011
ARIO (input output model)*	30%	Vilier, 2013
Hurricane Sandy 2012	37%	Vilier, 2013
Japan tsunami 2011	50%	Vilier, 2013
Thailand flood 2011	125%	Vilier, 2013

**This model depends on the size of the affected area, this number is based on a simulated flooding in dikering 15 (Lopiker- en Krimpenerwaard)*

Several recent national studies (WV21, Deltaprogramma Veiligheid) therefore, corrected the total damage for underestimating the business interruption with a correction factor (WV21 correction factor[11]). In these studies the positive and negative effects of business interruption effects *outside* the flooded area were estimated to have in total a negligible effect.

HIS-SSM uses the same damage function for both damage to capital goods and for business interruption, although both damage types are different and have a different sensitivity to water depth and other flood related parameters (see chapter 4.1). No other international model expresses business interruption in a damage function depending on water depth. Based on the HAZUS manual (FEMA, 2009), it is however possible to derive a plausible function which relates business interruption to water depth (see figure 4.3). This is illustrated by Wagenaar (2012) and explained in annex B.

The HAZUS function for business interruption differs significantly from the HIS-SSM function for damage due to business interruption (see figure 4.3). The function derived from HAZUS is based on the assumption that recovery takes a lot of time, even if the damage is not very large. This is caused by fixed delays, such as waiting time due to contractor shortages, getting permits and waiting for the repair of the infrastructure.

[11] This correction factor served to correct many issues in HIS-SSM and not only business interruption.

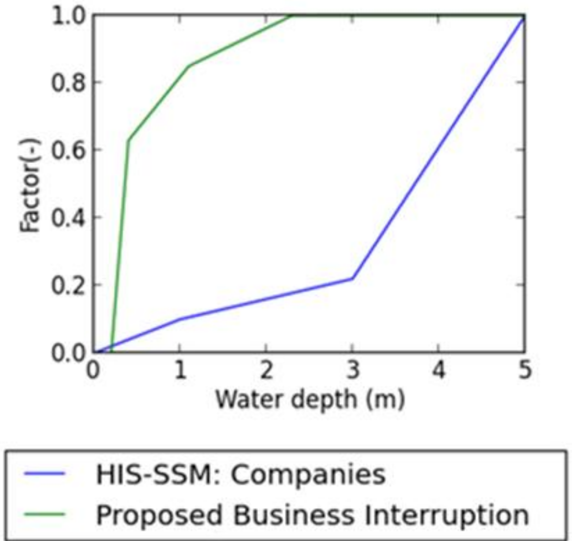


Figure 4.3 Function for business interruption in HIS-SSM and the proposed function for SSM2015 (De Bruijn et al., 2014) which was derived from the HAZUS model for banks by Wagenaar (2012) (green). Other businesses have similar functions in HAZUS.

To improve the calculation of damage due to business interruption several suggestions have been made in the last years. Gauderis, (2009) recommended to extend the assumed interruption duration of 2 months to 1 year for each category based on HAZUS (FEMA, 2008). He also proposed a new damage function for business interruption. De Bruijn et al. (2014) adopted the recommendation of Gauderis (2009) to extend the interruption duration, and his idea to improve the damage function. However, they did not use his function, but instead they took the damage function for business interruption from HAZUS (see figure 4.3). De Bruijn et al. (2014) also followed Gauderis (2009) suggestion to no longer take into account the positive and negative indirect business interruption damage because those are highly uncertain and it's even unclear whether the net indirect damages are positive or negative. These earlier proposed changes result in an increase of the share of damage related to business interruption from about 5% in HIS-SSM to about 30% of the total damage in SSM2015. Section 4.3 proposes the approach for SSM2015.

4.3 Proposed improvements in flood damage assessment to businesses

This section describes the proposed improvement in standard flood damage assessment to businesses. First, the categorization of business sectors is discussed, then maximum damages are described and finally new damage functions are proposed.

4.3.1 Use of subcategories from BAG

To assess damage to business the BAG data of July 2014 is used in SSM2015 and the classification of business damage into categories was adapted to enable use of the BAG data.

BAG is one of the national BASE registrations. All Dutch municipalities have the obligation to build and maintain the BAG data register. The BAG contains the footprint, useable area (m^2), coordinates and function of all buildings. One building could have multiple functions. Table 4.3 shows the business categories which are distinguished in the BAG and the proposed business categories in SSM2015.

Table 4.3 The proposed SSM2015 business categories and the link to BAG user functions (both the original Dutch name and its translation are given).

	SSM2015	BAG
1	Meeting facilities (pubs, hotels, churches, etc.)	Bijeenkomstfunctie (meeting facilities)
		Logisfunctie (accommodation for guests)
2	Offices	Kantoorfunctie (offices)
		Celfunctie (detention home for prisoners)
3	Health services	Gezondheidszorg (health services)
4	Industries	Industrie (industries)
		Overige gebruiksfunctie[12] (others)
5	Education facilities	Onderwijsfunctie (eduction facilities)
6	Sport facilities	Sportfunctie (sport facilities)
7	Retail and Commerce	Winkelfunctie (shops and commerce)

The value of the different business sectors was derived from CBS where the SBI categorisation was used. In order to translate the data of CBS to the categories in the BAG, they were linked as is shown in table 4.4.

[12] *The other use functions with an area larger than 100 m^2 were added to this industry function.*

Table 4.4 Indeling SBI in BAG-categorieën

SSM2015 category	SBI 2008 (number and description)
Industry	• B Mining • 10-39: Industries: (Food, drink and tobacco industry; Textile, clothing and leather industry, Wood industry, Paper industry, Graphics industry, Oil industry, Chemical industry, Pharmaceutical industry, Rubber and plastics industry, Building materials industry, Base metal industry, Metal products industry, Electro-technical industry, Electrical manufacturing industry, Machine-industry, Automotive industry, Other vehicles industry, Furniture industry, Repair and install. of machines and installations, Energy companies, Drinking water companies, Solid waste collection and management. • 45 Automotive retail and repair • 46 Trade and bulk supply • 52 Warehousing, transportation service industry • 58-60: Publishing, Film, radio and television • 95 Repair of consumer goods
Offices	• 41-43: Construction: (General construction, project development companies, civil engineering and construction companies, specialised construction companies) • 49-51: Transportation: land, water and air transportation. • 53: Postal and courier services • 61-66: Communication and finance services: Telecommunicatie, IT- en information services, financial services, insurers, and other financial services. • 69-70: Management advice and holdings • 71 -75: Architects and consultancy companies, Research companies, Advertising and market research, Design and veterinary services • 80-82: Private security agencies, other business services • 84: Public administration and civil service
Retail and commerce	• 47 Retail (not automotive) • 77Rental companies (moveables) • 78Employment agencies, employment offices • 79Travel agencies, tourism agencies • 96 Other services industry
Education facilities	• 85 Education
Health services	• 86 Health care • 87-88 Nursing and health service industry
Meeting facilities	• 90-92 Arts, culture and gambling • 94 Non-profit organisations, special interest groups • I 55-56: Hotel and catering industry
Sport facilities	• 93 Sports and recreation

4.3.2 Improvements in the maximum physical damages

Physical damage
In HIS-SSM the maximum physical damage to capital goods is based upon their replacement value. It is proposed to change to the actual value of capital goods (see section 3.1). The maximum damage value should be equal to the part of the actual value of the capital goods that is vulnerable to flooding. This value includes the value of buildings, machinery and installations, ICT infrastructure, and other tangible assets. Direct damage values should also include damage to stock for those categories for which stock is relevant.

To obtain the maximum damage, subsequently the following steps have been carried out:
1. Assess the economic value of the capital goods (other than ‘stock’).
2. Assess the economic value of stock.

3. Assess the 'susceptibility factor': The part of the economic value which is susceptible to flooding.
4. Multiply the susceptibility factor with the economic value to obtain the maximum damage per capital good type for each business category.
5. Add the different types of capital goods to obtain the total maximum damage to capital goods for each business category.

These are discussed below.

1. Economic value of capital goods other than stock
Data on the actual value of capital goods per business category is obtained from the Statline database of CBS, without any need for further processing. The data is accessible via *Macro-economie / Groeirekeningen / Kapitaalgoederenvoorraad, ("bedrijfsgebouwen/machines en installaties, computers en overige materiële vaste activa").*[13]

2. Stock value
Damage to stock includes damage to stored raw materials, components, semi manufactured products, and finished products. For most business categories, damage to stock is assumed to be minimal, as it may not exist (e.g. services sector, utility companies) or is not vulnerable to flooding (e.g. mining). For industrial sectors, trading sectors and warehousing, however it is likely that significant vulnerable stock exists. Useful sources for the calculation of these damages are Sluijs et al. (2000) and Snuverink et al. (1998).

In HIS-SSM damage to stock was included for the industrial sector only. For other business categories damage to stored products and supplies was not taken into consideration (Briene *et al*, 2002).

It is proposed to include damage to stock for the business categories industrial sectors (10 to 32, trading sectors (46 & 47) and warehousing (52). The calculation of damages to stock for those categories will be based on the assessments of Sluijs et al (2000) and Snuverink et al (1998). Their fractions are adjusted to make them consistent both with values for capital damage. They are translated from replacement values to actual values by multiplying them with a factor of 0.55, which equals the average current value factor of the assets (Gauderis, 2012). In table 4.5 the share of stock (in the total maximum damage) is given for each relevant business category based on the value of buildings and machinery in that sector. The value of stock can thus be obtained by multiplying the total economic value of buildings and machinery with 'contribution factor/(1-contribution factor)'.

[13] *http://statline.cbs.nl/statweb/*

Table 4.5 Contribution of stock to the total damage of industry, trade and warehousing business categories (buildings + machinery+ stock) [14]

Business sector (based on SBI2008)	HIS-SSM	SSM2015
10-12 Food, drink and tobacco industry	0.40	0.55
13-15 Textile, clothing and leather industry	0.38	0.53
16 Wood industry	0.18	0.29
17 Paper industry	0.30	0.43
18 Graphics industry	0.18	0.29
19 Oil industry	0.06	0.10
20 Chemical industry	0.11	0.18
21 Pharmaceutical industry	0.11	0.18
22 Rubber and plastics industry	0.26	0.39
23 Building materials industry	0.16	0.26
24 Base metal industry	0.23	0.35
25 Metal products industry	0.19	0.30
26 Electro technical industry	0.48	0.62
27 Electrical manufacturing industry	0.18	0.29
28 Machine-industry	0.19	0.30
29 Automotive industry	0.31	0.45
30 Other vehicles industry	0.31	0.45
31-32 Furniture industry	0.50	0.64
46 Trade and bulk supply	0.70	0.80
47 Retail (not automotive)	0.70	0.80
52 Warehousing, transportation service industry	0.70	0.80

3. Assessment of the susceptibility factor

Gauderis (2012) provides susceptibility factors which enable to translate the economic value of businesses in the CBS database to maximum flood damage values. They are the fraction of the economic value which may be lost due to a flooding. The susceptibility factor depends both on the type of capital good, as well as the business sector. The susceptibility factors of Gauderis (2012) are based on Sluijs et al. (2000). In general the following assumptions are used for the susceptibility factor: for buildings 80%, machinery: 80%, ICT: 100% and other tangible assets: 80%. Table 4.6 shows the susceptibility factor for those business categories for which these factors deviate from these general assumptions.

[14] *Based on Gauderis (2012)*

Table 4.6 Fraction of the total value of capital goods of businesses that is susceptible to flooding (Gauderis, 2012)

Business sector (based on SBI2008)	Buildings	Machinery	ICT	Other	Stock
10-12 Food, drink and tobacco industry	0.80	0.80	0.80	0.80	1.00
13-15 Textile, clothing and leather industry	0.80	0.80	0.80	0.80	1.00
16 Wood industry	0.80	0.80	0.80	0.80	1.00
17 Paper industry	0.80	0.80	0.80	0.80	1.00
18 Graphics industry	0.80	0.80	0.80	0.80	1.00
19 Oil industry	0.80	0.50	0.50	0.50	0.20
20 Chemical industry	0.80	0.50	0.50	0.50	0.50
21 Pharmaceutical industry	0.80	0.80	0.80	0.80	1.00
22 Rubber and plastics industry	0.80	0.80	0.80	0.80	0.80
23 Building materials industry	0.80	0.50	0.50	0.50	0.90
24 Base metal industry	0.80	0.50	0.50	0.50	0.50
25 Metal products industry	0.80	0.80	0.80	0.80	0.90
26 Electro technical industry	0.80	0.80	0.80	0.80	1.00
27 Electrical manufacturing industry	0.80	1.00	1.00	1.00	1.00
28 Machine-industry	0.80	0.80	0.80	0.80	1.00
29 Automotive industry	0.80	0.80	0.80	0.80	0.80
30 Other vehicles industry	0.80	0.80	0.80	0.80	0.80
31-32 Furniture industry	0.80	0.80	0.80	0.80	1.00
46 Trade and bulk supply	0.80	0.80	1.00	0.80	0.80
47 Retail (not automotive)	0.80	0.80	1.00	0.80	0.80
52 Warehousing, transportation service industry	0.80	0.50	0.50	0.50	0.80
All others*	0.80	0.80	1.00	0.8	-*

* Stock is not considered for the categories which are not mentioned separately in table 4.3.

4. Maximum damage values per capital good type for each business category

For each business category, the maximum damage value per capital good can now be obtained by multiplying the susceptibility factor of table 4.6 with the economic value of each type of capital good obtained from the CBS statline database.

5. Maximum damage values per business category

Finally, the maximum damage values per business category are assessed. To do so, first the part of the value susceptible for flooding of all companies in all CBS categories which are part of one SSM2015 category are added. Next, this total susceptible value of companies in one SSM2015 category is divided by the total area of that business type in the Netherlands (this area is taken from the BAG data). This provides the mean value of one square meter of business in the category. This is repeated for all SSM2015 categories.(see table 4.7).

Table 4.7 The maximum physical damage to businesses (€/m^2)

SSM2015 Category	Maximum damage (€/m^2)
Meeting facilities	168
Health services	1974
Industry	1497
Offices	1283
Education	993
Sports	102
Retail and commerce	1508

4.3.3 Proposal for business interruption assessment in SSM2015

Maximum damage value related to Business interruption
The business interruption damage is assessed by first multiplying the maximum damage value of business interruption with a damage factor which depends on the water depth. The damage is then corrected by taking into account the cascading effect to and the substitution effect of surrounding areas. The method is comparable with HIS-SSM. However, the substitution and multiplier effects are assessed more transparently.

The maximum damage value for business interruption depends on the direct damage: The loss of production of machines which are destroyed by the flood, is considered in a different way compared to the loss of production of machines which are not damaged, but cannot be used because of the flooding. The proposed method follows the recommendations of Gauderis (2012), but adds the consideration of substitution and cascading effects to that method.

Gross and net value-added
The damage of business interruption is assessed by the effect on human consumption. This effect is equal to the loss of production. However, in some cases this should not be based on gross value added but on net value-added.

Since after a flood with extensive damage to capital goods there will be no, or at least less, depreciation, net value-added is a more accurate description of the loss of production costs. In order to assess the costs due to business interruption, therefore, the weighted average of the actual damage fraction multiplied by the net value-added (to account for the reduction in depreciation) plus the inverse damage fraction times the gross value-added (to account for the depreciation of the non-damaged capital goods) is taken as starting point (see equation 4.1).

$$Max\ damage\ business\ interruption = \sum_i \left(f_{2,i}(wd) * NTW_i + \left(1 - f_{2,i}(wd)\right) * BTW_i\right) \qquad \text{[Eq.4.1]}$$

The maximum damage for business interruption thus depends on the damage factor for the damage to capital goods.

This formula does not apply to the mining industry, as in this sector the actual value-added depends on the supply of mining products. The mining products are assumed not to be affected in case of flooding, but remain stable in the subsoil. As a consequence, for this category the fraction of the gross value added is subtracted from the fraction of the net value-added.

Duration of business interruption
In HIS-SSM the maximum period of business interruption is assumed to be 2 months for most categories and 1 year for industry and utilities. Literature on recent flood events (e.g. New Orleans, Germany) suggests that 2 months may be too short for some categories. Wagenaar (2012) showed that expected flood durations in the Netherlands alone often already exceeds this period, even without restoration. It is, therefore, suggested to change this period to 1 year of business interruption for all business categories.

Cascading effects and substitution
It is proposed to explicitly estimate the positive (substitution) and negative business interruption effects per sector. This leads to equation 4.2 for the business interruption. The term '$(1 - SF_i) * M_i$ ' was added to the formula used by Gauderis (2009) and De Bruijn et al. (2014) to take into account substitution and cascading effects.

$$D_{BI} = \sum_i \left(f_{2,i}(wd) * NTW_i + \left(1 - f_{2,i}(wd)\right) * BTW_i \right) * f_1(wd) * ID * \boldsymbol{(1 - SF_i) * M_i} \qquad \text{[Eq. 4.2]}$$

Where,

- D_{BI} = Total damage due to business interruption of all damage categories [M€]
- $f_{2,i}(wd)$ = Damage factor based on the damage function of the direct physical damage, for damage category i. [-]
- NTW_i= Net added value for damage category i [M€/y]
- BTW_i= Gross added value for damage category i [M€/y]
- $f_1(wd)$= Damage factor based on the damage function for the business interruption [-]
- ID= Maximum interruption duration of the damaged object, (set to 1 year for all categories) [y]
- SF_i = Substitution factor for damage category i [-] (see table 4.6)
- M_i= Multiplier for indirect damages for damage category i [-] (see table 4.8)

To take into account cascading effects we propose to use the multipliers of NEI (2002) (see table 4.8 and 4.9). These were also used in HIS-SSM.

Table 4.8 Multipliers to take into account cascading effects as estimated for HIS-SSM (NEI, 2002)

HIS-SSM category	Multiplier [-]
Mining	1.72
Utilities	1.69
Industry (average)	1.88
Construction	1.57
Trade and hospitality	1.46
Banking and insurance	1.50
Transport and communication	1.57
Government and education	1.25
Healthcare and other	1.54

Table 4.9 Multipliers to take into account cascading effects for SSM2015 for the BAG categories

BAG category	Multiplier [-]	Dutch name
Meeting facilities	1.5	Bijeenkomst
Health services	1.5	Gezondheid
Industry	1.9	Industrie
Offices	1.5	Kantoor
Education	1.25	Onderwijs
Sport	1.5	Sport
Retail and commerce	1.45	Winkel

Substitution factor
The substitution effect is added with a substitution factor similar to the recapture factor that is used in studies like FEMA (2008) and Park et al. (2010). These studies use a slightly different factor with a narrower definition: they focused on the output of the company itself rather than the economy as a whole. The magnitude of the substitution factor is difficult to estimate and existing estimates have been criticized (Seligson, 2010).

For SSM2015 new estimates have been made, as the definition is expanded (see table 4.10). Sectors which depend more on labour can easier find substitutes than sectors that derive their value with machinery, because human capital can easily be moved or replaced outside the flooded area while it is much more difficult to replace machinery.

No literature was available for reference. Therefore, the substitution factor was estimated in such a way that the interruption duration for the economy including multiplier effects is equal to 6 months for all categories except for industry and education (as mentioned in Gauderis, 2009). This leads to interruption duration for the economy of about 4 months when substitution effects are considered.

For industry and education an exception is made. Industry depends very much on machinery and substitution in the Netherlands is expected to be much more difficult to accomplish. As a consequence, the maximum interruption duration (including substitution and a multiplier effect) is estimated to be 15 months. Without the large multiplier for industry this is 8 months, twice the size of the other categories. For education, a lower estimate is used because it is expected that education is relatively easy to substitute for. These estimates however remain very rough and need to be improved in future research.

Table 4.10 Estimated substitution factors per business type, interruption duration with and without multiplier effects

BAG category	Interruption of functioning of flooded company [month]	Substitution factor [-]	Interruption duration including substitution effects [month]	Interruption duration including substitution & multiplier effects [month]
Meeting facilities	12	0.66	4	6
Health services	12	0.66	4	6
Industry	12	0.33	8	15
Offices	12	0.66	4	6
Education	12	0.80	2	3
Sport	12	0.66	4	6
Retail and commerce	12	0.66	4	6

The substitution factor estimates should not be confused with the HIS-SSM assumption that positive substitution effect compensates for 75% of the multiplier effect. This SSM2015 substitution factor affects the entire business interruption estimate rather than only the multiplier part.

SSM2015 substitution factors are derived for the Netherlands. When looking at a different economic scale, different estimates are necessary. If, for example, the damage for a city would be assessed then substitution effects realized in other cities should be neglected.

4.3.4 Overview of the proposed maximum damage figures per category

The resulting proposed maximum damage values per business category are provided in table 4.11 which can be used in equation 4.2. Table 4.12 provides the resulting maximum damages which are obtained after applying the substitution factor and multipliers as provided in table 4.9 and 4.10.

Table 4.11 Maximum damage per category per m² (based on BAG 2014, CBS 2011)

SSM2015	Maximum direct damage (€/m²)	Gross value added (€/m²)	Net value added (€/m²)
Meeting facilities	168	285	258
Health services	1974	2206	2069
Industry	1565	734	636
Offices	1283	2171	1847
Education	993	733	649
Sports	102	107	90
Retail and commerce	1508	677	560

Table 4.12 Maximum damage per category per m² (based on BAG 2014, CBS 2011)

SSM2015	Maximum direct damage (€/m²)	Gross value added (€/m²)	Net value added (€/m²)
Meeting facilities	168	145	132
Health services	1974	1125	1055
Industry	1565	808	700
Offices	1283	1107	942
Education	993	183	162
Sports	102	54	46
Retail and commerce	1508	334	276

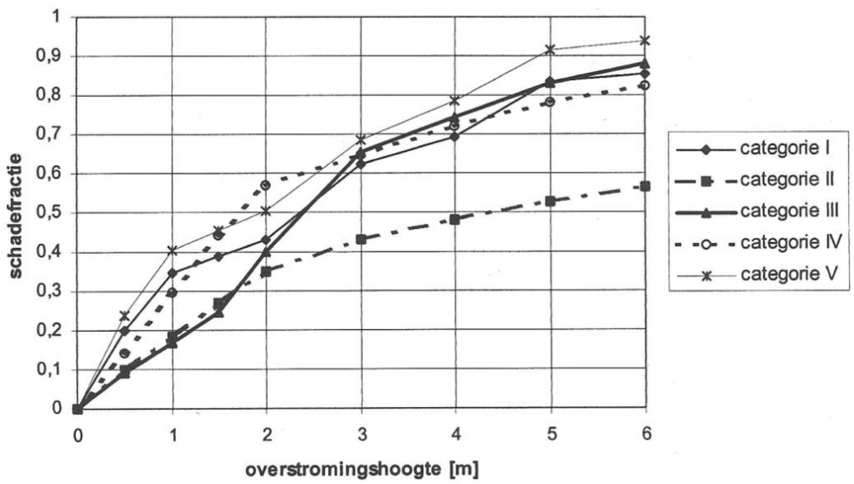
4.3.5 Improvement of damage functions

To propose new damage functions for businesses, three types of businesses with significantly different characteristics are distinguished:

- **Industry:** Businesses that relatively have a lot of machines and installations and that typically have a medium height.
- **Stores:** Businesses that are mostly on the ground floor of buildings with relatively a lot of inventory.
- **Offices:** Businesses that have relatively little inventory and that typically are situated in higher buildings with multiple floors.

Industry damage functions
A good alternative for the HIS-SSM function for industry is the set of Tebodin functions. These functions are well documented, made in a systematic way, focused on the Dutch situation and have the same level of detail as the available geographical information (LISA). This extra detail is useful in the case of industry as there is probably significant variation between different industries.

The Tebodin functions (Sluijs, 2000) consist of a set of 54 different functions. There are 18 different industry types categorized based on the SBI codes and each industry type has separate functions for the building structure, furnishing and inventory. Some of the aggregated Tebodin functions are shown in figure 4.4.



Category I:	*Industries not part of one of the other categories*
Category II:	*Oil- and chemical industry, metal industry (raw products, construction materials etc.)*
Category III:	*Food processing industry*
Category IV:	*Fine chemistry*
Category V:	*Officemachines and computerrelated industry*

Figure 4.4 Examples of aggregated Tebodin functions (Sluijs et al. 2000).

Figure 4.5 shows the average function of the Tebodin data set and the industry functions of the HAZUS and FLEMO models. The average of the Tebodin damage functions is remarkably similar to the average of the HAZUS and FLEMO models and to the average of all business damage functions. The Tebodin functions are thus in line with international damage functions for industry and seem to be more realistic than the HIS-SSM businesses functions. It is, therefore, proposed to use the average Tebodin function for industry.

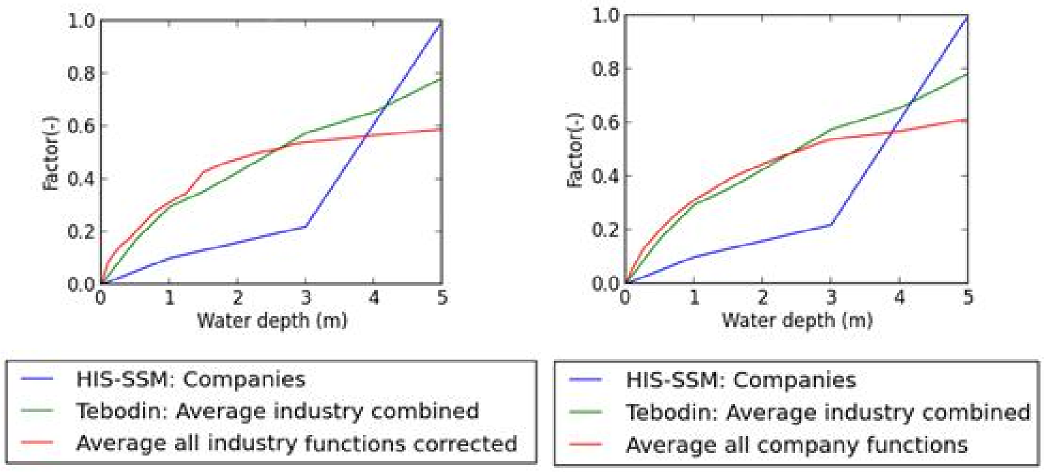


Figure 4.5 Left: The average of all Tebodin functions compared to the equally weighted averages of the FLEMO and HAZUS industry damage functions. Right: The Tebodin damage functions compared to all business damage functions as discussed in 4.2. The functions are not yet scaled to one in this figure.

Store damage function

The stores function will be based on a hypothetical business building with only one floor and relatively a lot of vulnerable inventory. The function will be based on the average business function of all businesses similar to the one used for “other industries”. This average function is adjusted for the specific characteristics of the hypothetical store.

The adjustments to the function take into account that this type of business is typically located on the ground floor of buildings. From Sluijs et al (2000) and Gauderis (2012) it can be concluded that approximately 80% of the value of the building and inventory may be vulnerable to flooding. The function is adapted to make it reach a maximum damage factor of 1 at a water depth of 3m.

Office damage function

The office damage function will be based on a hypothetical office, which is located in a building with several floors where the actual building holds the majority of the value of the capital goods.

The function will be based on the average function for businesses from the international models (see paragraph 4.2). Maximum damage will only be reached from 8m water depth onwards, as it is assumed that some of the value will be located on higher floors in the building and will only be damaged due to higher flood depths. The first 5 meters of the function is identical to the average function of all business functions.

For flooding depths between 5 to 8 meters the gradient of the function will continue from the one between 4 and 5 meters. This results in a damage factor of 0.8 at 8m water depth. This in turn corresponds to the maximum damage from Sluijs et al (2000) and Gauderis (2011). In SSM2015 the function is scaled in order to make it go to 1, because the non-vulnerable value of the stores is already deducted from the maximum damage value with which this damage fraction is calculated in the damage model.

The resulting damage function is based on the assumption that a significant part of the damage is caused at lower flooding depths with a second significant increase around 3 m of water depth. The slow rise in the end corresponds with the probability of the building being a multi-floor building. Figure 4.6 shows the proposed damage function.

Functions per category

Figure 4.6 shows the proposed damage functions for SSM2015 and the HIS-SSM function. Industry-specific functions are described in appendix C. Table 4.13 relates the business categories and damage functions.

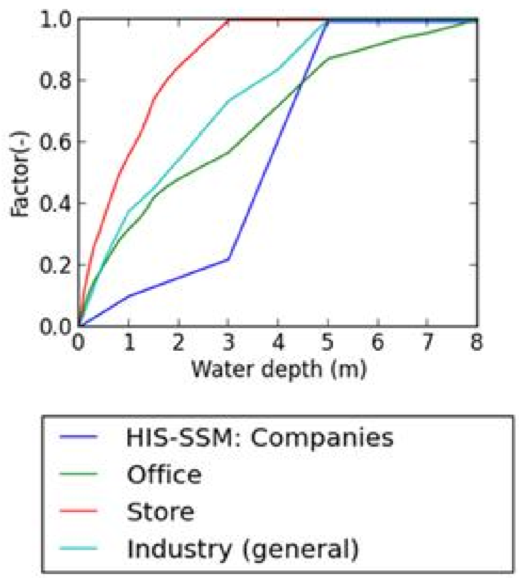


Figure 4.6 Proposed business functions for SSM2015 (note the long x-axis that makes the functions look steeper).

Table 4.13 Overview of the damage functions used for each damage category.

Category	Function
Meeting facilities	Store
Health services	Office
Industry	Industry
Offices	Office
Education	Office
Sport	Industry
Retail and commerce	Shop

Damage function for business interruption

The detailed description of the business interruption calculation as found in FEMA (2009) seems more convincing than the function used in HIS-SSM. Business interruption is difficult to relate directly to water depth.

Factors like the recovery capacity, flood duration and substitution possibilities for business activities seem at least as important as the water depth. As a matter of fact, business interruption really depends on the length and severity of the interruption of utilities and infrastructure. These aspects are difficult to model.

In reality, business interruption may be severe, almost regardless of the damage extent to a specific building. As a consequence, it can be expected that even low water depths may cause long interruption of businesses. The function derived from HAZUS by Wagenaar (2012) exactly describes this process and therefore seems more applicable than the HIS-SSM function. The proposed function starts at 0.25 m, as it is assumed that below this threshold business interruption will be negligible.

Due to lack of data on this issue and on possible differentiation between categories, a general function for business interruption is proposed. Figure 4.7 shows the HIS-SSM functions and the proposed functions for SSM2015.

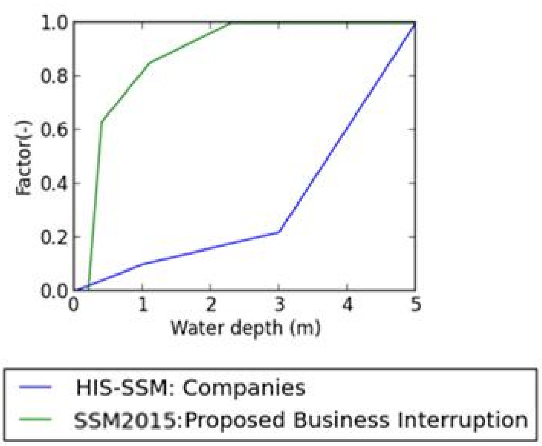


Figure 4.7 Proposed function for business interruption

The damage for business interruption is calculated by multiplying the damage factor obtained from the SSM2015 function in figure 4.7 and the maximum damage for business interruption obtained from equation 4.1 in section 4.3.2.

4.4 Test of the improvements on dikering area 22 (Dordrecht)

In this section the effects of the proposed changes are illustrated by testing them on a water depth map dikering area 22 (see chapter 1.4). Table 4.14 provides the combined effect of the proposed changes. The physical damage increases by a factor of about 4. This is the combined effect of the new maximum damages, the use of the BAG database and the new damage functions.

Table 4.14 Damage (M€) to businesses calculated with HIS-SSM and SSM2015.

Calculation	Physical damage (M€)	Business interruption (M€)	Total damage (M€)
HIS-SSM – 2000 (no changes)	384	92	476
HIS-SSM -2011 (with inflation correction) (*1.22)	468	122	590
SSM2015-2011	1109	906	2015

Table 4.15 shows the total damage of Dordrecht (including all damage types, not only damage to businesses) and the part of the damage caused by damage to businesses. About 32% of all damage is damage to businesses. Damage due to business interruption is about 14% of the total damage in Dordrecht (taking into account the HIS-SSM method for all categories except for businesses) and about 45% of all business damage is damage related to business interruption. These observations correspond with reports on the Carlisle flood in the UK in 2005 (Jongman et al, 2012), where 30% of the direct damage is attributed to business damage.

Table 4.15 The effect of the changes to the business damage to total damage.

Impact type	HIS-SSM (2000)		HIS-SSM with for businesses the changes as proposed for SSM2015	
	Damage (M€)	Fraction total (%)	Damage (M€)	Fraction of total damage (%)
Physical damage to businesses	384	8	1109	17
Other physical damage	4341	90	4341	68
Total physical damage	4725	98	5450	32
Business interruption	93	1.9	907	14
Total	4818	100	6356	100

Table 4.15 shows that business interruption for the dike ring area is about 2% of the total damage calculated with HIS-SSM. This increases to 14% in the proposed method. This huge increase was expected. The WV21 project (Kind, 2011) already added 14% to the total damage of HIS-SSM to adjust for the low estimate for business interruption in HIS-SSM.

4.5 Discussion and recommendations for further research

Damage due to business interruption

The proposed changes to the calculation of damage to businesses have a major impact on the calculation of total damages. In this respect damage to businesses can be seen as a special weakness within HIS-SSM that this proposal is trying to address. However, the duration of business interruption, which has been changed from 2 months to at maximum one year, is uncertain. It is recommended to study whether this duration should be differentiated between sectors and how substitution effects influence this business interruption damage duration. It could also be considered to relate the duration of business interruption to the fraction of the total economy that is affected, or the fraction of a specific business category that is affected by the event.

Damage functions

In general damage functions seem to be the most uncertain aspect of the damage calculation (de Moel et al., 2012). The method used to create the damage functions has been described and can be repeated, but it is still not systematic, and depends partly on theory and partly on findings from actual flood events.

Therefore, the uncertainty of damage functions and their impact on the results of flood damage models should be further researched. The following activities are recommended in order to increase the reliability of damage functions:

- Consider a more systematic method to create damage functions. It could be tried to base damage functions on a method similar to that of MCM (Penning-Rowsell) in which a hypothetical building is broken down in parts which are all valued.
- Study in more detail the factors that determine what percentage of the value of the capital goods can actually be damaged. The calculation is sensitive for this parameter and it is right now only based on expert judgment in Sluijs et al (2000).
- From the proposed functions especially the function for office buildings could get more attention. This could ideally be done with new geographical data about average heights of buildings in different categories.

5 Proposed improvements for damage to residences

5.1 Overview of the method used in HIS-SSM

Damage to residences in HIS-SSM is roughly 60 to 75% of the total damage. Five types of residences are distinguished in HIS-SSM, these are:

- Low-rise buildings (maisonette, residential space above shops).
- Middle-range apartment buildings less than 4 floors.
- High-rise apartment buildings more than 4 floors).
- Farms (farm houses).
- Single-family houses (bungalow, cottage, semi-detached, terraced house, town house, villa, trailers, unknown).

In HIS-SSM about two third of the total damage to residences is caused by damage to single family houses and one third is caused by the other residence categories (see chapter 1.4). For these categories only the direct material damage is calculated.

The data on the location and type of residences is obtained from the geographical database Bridgis which contains data of the year 2000. HIS-SSM uses per 6 digit postal code area, the total number of residences and the most dominant residence category from that database.

Each residence category corresponds with a different maximum damage figure, which is composed by the potential damage to the building structure and the potential damage to furnishing. The damage to the building structure is based on the reconstruction value, which is considered equal to the average market price of residences minus 21 % to compensate for the value of the land, which is not susceptible to flooding. The furnishing part is based on a fixed furnishing value of 70k€ per object (Briene et al, 2000). This value of the furnishing was assessed through a calculation tool (www.ineas.nl)[15] and was based on a household consisting of two adults, two children in an average house, with an average income. The maximum damages per residence type in HIS-SSM are presented in table 5.1.

Table 5.1 Maximum damage values per housing type in HIS-SSM, price level 2000. (NEI, 2002)

Residence category	Market value (€)	Value of land, (21% of the market value) (€)	Reconstruction value (€)	Maximum damage HIS-SSM (€)
Low-rise building	127.000	25.000	102.000	172.000
Middle-range building	127.000	25.000	102.000	172.000
High-rise buildings	102.000	25.000	102.000	172.000
Farms	427.000	95.000	332.000	402.000
Single-family house	219.000	48.000	171.000	241.000

Damage functions

There is one damage function used for both ‘single family houses’ and farm houses. The other three categories have each their own damage function (see figure 5.1).

[15] *Currently this tool is no longer available from this web-site.*

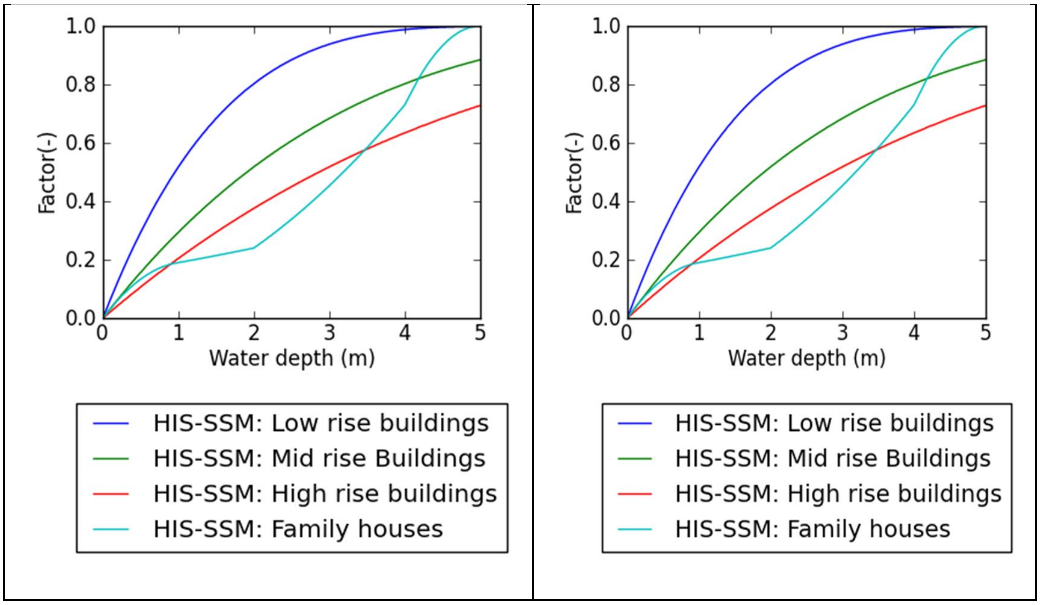


Figure 5.1 Left: The 4 functions used for residences in HIS-SSM. Right: The derivation of the function used for single family houses from a function for the structure of residences and the furnishing of residences (housing combined is the function used for single family houses)

It is difficult to trace back the exact origin of the damage functions in HIS-SSM (Wagemaker, 2006). Duiser (1982) was the first to provide similar functions. He also gave an elaborate motivation for its assumptions and his work is therefore most likely the source of the HIS-SSM functions.

The damage function for single family houses is constructed from the damage function for furniture and one for the building structure. The function for the building structure of single family houses is derived from 1953 data. In the first 2 meter this data was combined with data from absolute damage functions from Penning and Rowsell (Duiser, 1982). At a depth of 5m the HIS-SSM function reaches one. The function for furnishing is for the first 2 meters of water depth based on Penning-Rowsell (2005). For larger water depths the function approaches 1 based on the observation of 1953 that houses often collapse when the water depth exceeds 2.5m (Duiser, 1982). This collapse has been observed for several villages in 1953 but not for all villages affected by depths larger than 2 m. It is however, possible that house behaviour in the storm surge of 1953 is not representative for the expected behaviour of houses in future floods. Differences may occur, because:

- Conditions may be different: 1953 was a storm surge. Potential future floodings may be storm surges, but also river floods. Waves, flow velocities, flood duration and so on may differ significantly from 1953.
- ‘Average family houses of 2015’ will differ from the flood affected houses in Zeeland in 1953: on average the quality is much better. Houses are now build of concrete and not of single brick stones and will be more resistant to floods.

To assess flood damage to residences which are no single family houses or farms, HIS-SSM uses one function per building instead of one function per residence. The functions for low, mid en high rise buildings assume 2, 4 or 6 floor buildings. The functions are briefly described in Kok *et al* (2005).

It is assumed that inhabitants of higher floors will be affected by shallow floods as well, because they have possessions in storage boxes on the ground floor and they suffer from damage to elevators, central installations and so on. Table 5.2 shows the relationship between the damage factor and the percentage of the building that is actually flooded for a high rise building (a building with 6 floors). This table indicates that large damage fractions are used even if only a small part of the total number of floors is flooded. This does not seem right. This table and the figure 5.1 both give the impression that the damage functions for high rise buildings are too steep.

Table 5.2 Percentage of the building actually flooded compared to percentage of the damage which is calculated with the functions in HIS-SSM for a high rise building of 6 floors.

Water depth (m)	Percentage of building volume underwater	Percentage of the total damage according to HIS-SSM
0	0	0
1	7	20
2	13	38
3	20	52
4	26	63
5	33	73

5.2 Knowledge from other impact models, events or previous research projects

It is difficult to compare maximum flood damages internationally because of difference in welfare, prices of residences and differences in reconstruction costs. Damage functions, however, can more easily be compared. This section compares the damage functions for single family houses as used in HAZUS (FEMA, 2009), MCM (Penning-Rowsell, 2005) FLEMO (Kreibich, 2010) IHE (Billah, 2007) Rhine Atlas (ICPR, 2001) (See chapter 1.3). Figure 5.2 shows the average damage functions of these damage models and studies.

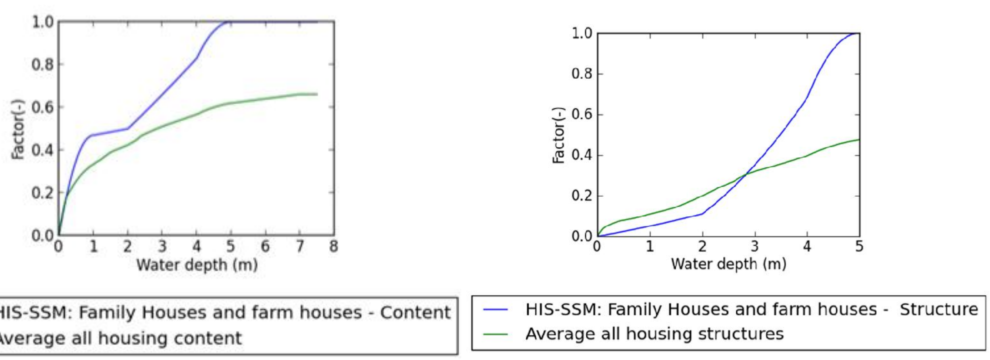


Figure 5.2 Single family houses damage function compared to the weighted average of other studies. Left the furnishing and right the structure.

The differences between the HIS-SSM curve and the average of the other curves are partly caused by a difference in the meaning of a damage factor of 1: in some models a damage factor of 1 refers to the total loss of the house value including land value (which is never reached) and in others it refers to maximum flood damage (see section 3.5). Figure 5.2 shows that the HIS-SSM functions have the same shape as the international functions for at least the range between 0 and 2 m water depth. After those first 2 meters the HIS-SSM function shows a steep rise which is not found in the international functions. This steep rise in the HIS-SSM functions at a depth of 2 to 5 m is related to the expectation that houses collapse due to high water depths (Duiser, 1982). The international functions seem to suggest that total reconstruction is uncommon even at large water depths. Further research should therefore be done to better understand what physically happens to a building during and after a flood.

The difference between HIS-SSM and the international curve and the weak motivation of the HIS-SSM curve indicate that the validity of the HIS-SSM single family houses functions is arguable. However, right now there seems to be not enough scientific evidence to either change or justify the HIS-SSM functions. One should be very careful when using the curve for analyses in which the curve shape is crucial, e.g. to assess the effect of measures such as flood-proofing or raising houses, constructing mounds, building or removing compartment dikes and so on. The large difference in damage factor between HIS-SSM and other international functions in the water depth range between 2 and 5m, and the large difference in damage factor between a water depth of 2 and 4m may seem to make such measures more effective than they are.

More research should therefore be done before possible changes can be proposed.

5.3 Proposal for improvements

This section discusses the method and possible improvements in the damage calculation for residences by studying subsequently the following:

- Geographical data;
- Maximum damages per category;
- Damage functions of the various categories.

5.3.1 Geographical data and category definitions

We propose to update the data in HIS-SSM from Bridgis with the up-to-date data in the BAG database.

The geographical data in HIS-SSM is outdated and updating the data with new data from Bridgis is very expensive. The geographical database BAG (Basisregistratie Adressen en Gebouwen) from the Kadaster is free, open to the public, very accurate and well maintained. The Dutch law “Wettelijke regeling basis registratie adressen en gebouwen” states that all public organisations that need this type of information are supposed to use this database and report possible errors. This makes the database very reliable and widely accepted.

The change from Bridgis to BAG would not only up-date the number of residences in the area to the current state, but this change also enables important improvements in accuracy. In HIS-SSM the number of residences is provided per six digit postal code and linked to the dominant category for that postal code area. The BAG data would enable:

- The use of exact coordinates of the residences;
- The use of the exact object category (instead of the most frequent);
- Better differentiation in the height of buildings.

The simplification of using postal codes instead of the real coordinates means that residences may be schematized at maximum a few hundred meters away from their actual position. This is often an insignificant error because the spatial variation in water depth is often small. However, when the resolution of the damage calculation is changed from the current 100x100m to 25x25m the exact coordinates may become more relevant. This is especially the case in areas where people intentionally live on the higher and thus safer places, such as the unprotected areas or valleys such as Limburg.

The simplification of using the most frequent category instead of the actual categories can also cause errors, since the difference in damage between the categories is large.

HIS-SSM differentiates in height in the damage functions. This differentiation only makes a distinction between 1, 2, 4 and 6 or more floors. The exact height of residences can be crucial information in a damage model as residences in high rise buildings often suffer much less damage than ground floor apartments.

The BAG data gives the exact coordinates and separates the buildings and the addresses, which is useful to distinguish houses from apartments. Furthermore, it gives the footprint area of each building, and the living area for each address. This information can be used to estimate the height (number of floors) of each building. The living area can be used to make a distinction between small and large residences. BAG, therefore, seems to overcome most of the shortcomings of the Bridgis database. However, the BAG data does not distinguish farms from single family houses.

It is proposed to distinguish in SSM2015 the following residence categories:

- Single family houses: All buildings with only one address in them. This includes all normal houses, farms and villas.
- Ground floor apartments: These are apartments located on the ground floor of an apartment building.
- First floor apartments: Apartments on the first floor of an apartment building or apartments above stores, restaurants or other functions.
- Higher apartments: Apartments higher than the first floor of an apartment building. In the building of the higher apartments there may be ground floor and first floor apartments, but there may also be for example stores, restaurants, offices, or schools.

These four residence categories can be distinguished based on the number of floors in a building. This number of floors in a building is estimated by dividing the total living area as registered in BAG by the building footprint. Furthermore, it is assumed that in buildings with multiple functions, the residential function is on the highest floors. Figure 5.3 shows the differences between HIS-SSM and SSM2015 in a schematic way.

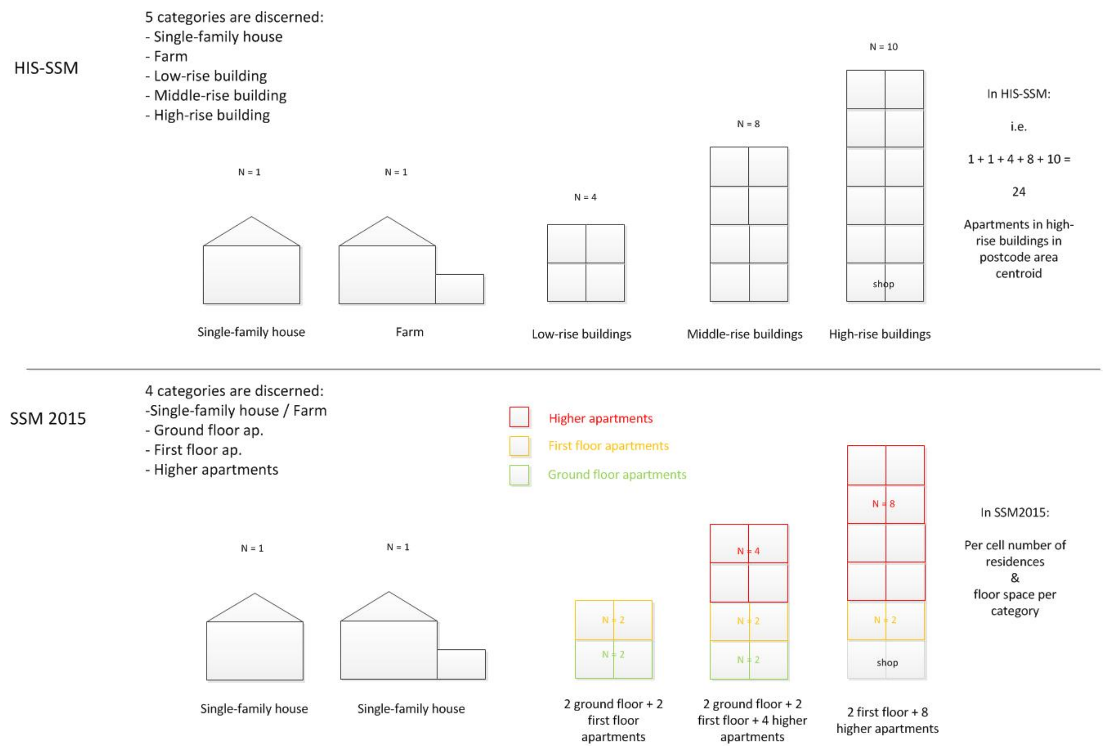


Figure 5.3 Overview of the changes in the definition of the housing categories

5.3.2 Proposal for improvements of the direct maximum damage

We propose to change from an average maximum damage per housing category to maximum damages based on the reconstruction costs per m^2 living space. This proposal is discussed in this section.

In HIS-SSM the reconstruction costs are assumed to be 79% of the total value of residences. As is illustrated by table 5.3 the cost of reconstruction for a residence, is however, much less than 79 %. We propose to use the data on average construction costs for residences instead of assuming that these are certain percentage of the average value of residences of a certain category.

Table 5.3 Average construction costs and market value per residence

Year	Construction Costs (k€)	Market Value (k€)	CC as % of MV
2005	117	223	52%
2006	118	236	50%
2007	130	248	52%
2008	134	255	53%
2009	131	238	55%
2010	127	240	53%
2011**	127	240	53%
2012**	123	227	54%

In SSM2015 the physical damage to the structure of houses is assessed by multiplying the surface of the living space per house derived from the BAG data with the construction costs per m^2. To enable this calculation the construction costs per m^2 were derived from the CBS and BAG data. The StatLine database at the CBS website (www.cbs.nl) provides the construction costs per m^3 residence. The database presents construction costs segregated to region and per year both for owner-occupied residences and for residences in the rental sector. As there are no significant differences in building costs between regions and in building costs for the rental and own-occupied sectors, we propose not to differentiate between regions or between these two sectors. The average construction costs are € 260/m^3 (2011 price level), the costs per square meter are not provided. Since we will combine the maximum damage derived from Statline with the areas obtained from BAG we followed the following procedure to obtain values per square meter:

- We assessed the average living space of all houses build in 2009, 2010, 2011 and 2012 and also the mean of all houses build in the period from 2009 to 2012.
- We determined the average construction costs of residences build in those years (taking into account differences in costs and numbers of rental houses and houses occupied by the owner).
- Next, we averaged the costs per m^2 by dividing the average construction costs by the average areas derived from the BAG data and we corrected the outcomes for inflation to make them comparable to the number obtained for the year 2011.
- The average construction costs for a residence build in the period 2009-2012 are 1017 €/m^2 en vary between 900 and 1100 €/m^2 (see table 5.4). We therefore propose to use the value of 1000 €/m^2 for the construction costs in the damage assessment.

Table 5.4 Overview on the construction costs in different years and calculation of construction costs per m^2

BAG DATA			CBS						Combination BAG en CBS		
Construction Year	#	Average living space (m^2)	# Rental	# Owned	Sum	Construc-tion costs rental (k€)	Construc-tion costs owned (k€)	Average construct-ion costs (k€)	Construc-tion costs per m^2	Inflation	Corrected construct-ion costs (€/ m^2)
2012	11	115	15484	21886	37370	94	144	123	1076		1076
2011	992	128	17681	38123	55804	100	140	127	996	2.3	1019
2010	15267	121	19397	41631	61028	100	139	127	1048	1.3	1086
2009	32800	131	25951	46695	72646	97	146	128	982	1.2	1029
2008	43869	134	23741	63457	87198	99	147	134	999	2.5	1073
2007	48016	134	23743	64175	87918	99	141	130	966	1.6	1055
2006	49351	135	23917	72530	96447	86	129	118	878	1.1	969
2005	15267	121	18637	64636	83273	85	126	117	967	1.7	1085
2004	43165	136	17300	58880	76180	80	127	116	856	1.2	973
2003	42410	139	15848	56605	72453	90	126	118	853	2.1	989
2002	45892	136	13159	54024	67183	78	120	112	825	3.4	990
2001	51275	135	11108	51218	62326	74	112	105	780	4.5	978
2000	51799	132	14311	64252	78563	60	99	92	696	2.6	895
Sum	505748	132							Average		**1017**

The maximum damage figures for residences are based on the full construction costs, although probably some parts may not be vulnerable to flooding (e.g. the foundation). This may lead to a small overestimation. However, the maximum damage does not include additional costs next to reconstruction costs, such as costs for demolition and cleaning of the area before reconstruction may start. It is expected that the maximum damages proposed here will give a good indication of the potential flood damages due to extreme floods with large depths and flow velocities.

Maximum damages to furnishing
In HIS-SSM the maximum damages to furnishing is set at € 70.000 (price level 2000). This was considered the average value of furnishing for an average household, with an average income, living in an average house. Tools of insurance companies show that this amount still corresponds to the current value of the furnishing for a household with similar characteristics. We therefore propose to keep the maximum damages for furnishing at the same amount of € 70.000 (price level 2011).

5.3.3 Maximum damage due to interruption of housing services

Residences are capital goods that provide a service or added value to their owner. A house provides its owner living space, shelter, privacy, etc. Currently, there are no damages included within HIS-SSM for loss of residence services caused either by inaccessibility of the residence or by severe damage to the residence. Following the Rebelgroup consultancy (2009a, 2009b) we propose to include loss of housing services in the damage calculations in SSM2015.

The production value of a house is the rent that is paid by its inhabitants (or fictive rent in case of an owner-occupied house). The gross added value of a house is the rent (real or fictive) reduced by costs for goods and services required for maintenance of the house. As expenditures for maintenance are small compared to other expenses, the gross added value from housing services is supposed to be equal to the production value i.e. the rent (real or fictive).

The gross added value of housing services consists out of two components:
- Depreciation of the actual building (the grounds on which the construction stands do not depreciate).
- Real interest on the invested capital (total value of the building and the grounds it is built on).

Damage from loss of housing services is, similar to loss of production from businesses, equal to:

Added value from housing services (per unit of time)
X
Duration of the interruption of the housing services (in the same unit of time)

Within the BAG the current value of each and every house is recorded as the WOZ. This amount is updated annually and, therefore, representative for the actual value of the house and its grounds. Rebelgroup Consultancy (2009b) shows that the value of housing services is 4.5 % of the value of the house and grounds, which is equal to the value added within the sector “rental of real estate”. We propose to adopt this recommendation for use within the calculation for damage from interruption residence services in the SSM2015. For the value of the house we propose to use the WOZ, which is updated annually.

Unfortunately, the WOZ values for residences in the BAG were not available in 2014 when the method was developed. Therefore, we propose to use the average value of residences from the CBS database until the actual WOZ value for each house is available. The average value of residences in The Netherlands for the year 2011 was € 237.000 (CBS data).

The duration of interruption is estimated to be at maximum one year. The actual interruption depends on the flood duration and the duration of restoration. Both are mildly correlated with the water depth (Duiser, 1982; Wagenaar, 2012). Therefore, a damage function depending on the water depth is used to estimate the fraction of the maximum duration that will occur (see next section).

5.3.4 Proposal for improvements in the damage functions

It is proposed to maintain the HIS-SSM damage function for single family houses. This function is adequately motivated and is comparable with international functions for at least the range of water depths from 0 to 2.5 m. The quality of the function is more uncertain for larger water depths. However, more research is needed before a better function can be proposed.

The proposal to separate apartments per floor instead of per building requires new damage functions. We propose to use the HIS-SSM function for low rise buildings for all apartments. This function reaches 1 at 2.5m, which corresponds with the height of the ceiling of the ground floor. For apartments on the first floor, this damage function is shifted 2.5m (the height of the first floor). For apartments on the second flood or higher, a function is used which rises stepwise to 1. Since water depths are rarely higher than 5m this function will not influence damage much.

For the interruption of residence services the same function is chosen as for business interruption (see chapter 4). Figure 5.4 shows the proposed damage functions.

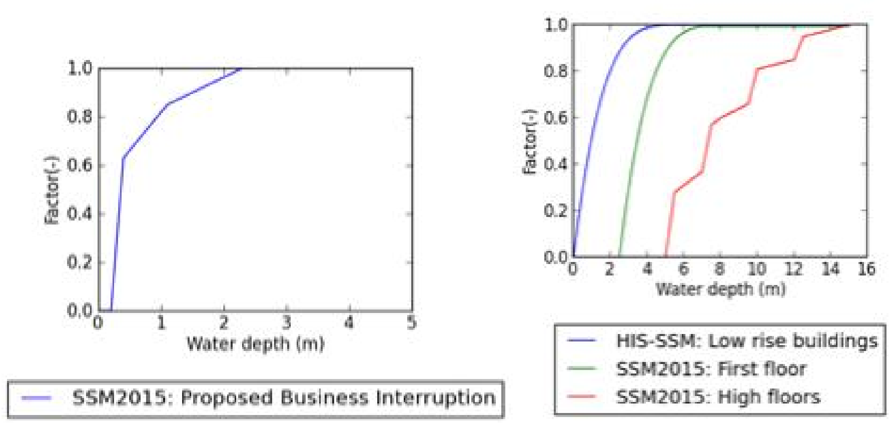


Figure 5.4 Proposed functions for apartments and for housing services interruption

5.3.5 Overview of proposed improvements

The following improvements are proposed:

- *Use BAG for the geographical data instead of Bridgis*. This enables the use of the exact coordinates of the residences, the exact number of residences per category and easy updating of the number of residences.
- *Differentiate apartments based on the floor at which they are located instead* of the height of the entire building. This introduces the information of how many apartments stay dry and how many will become flooded. A consequence of this change is that new damage functions are needed for apartments. These functions were proposed in the previous section.
- *Introduce interruption of housing services* as an extra damage category.
- *Implement new maximum damage figures* based on the floor area per house and on reconstruction costs.

5.4 Test of the improvements on the dikering 22 – Island of Dordrecht

In this paragraph the effect of the proposed changes are illustrated by testing the new data, maximum damage figures and damage functions on dike ring 22 (Island of Dordrecht) using the WV21 water depth map. The purpose of the test is to see the individual impacts of the following changes:

- New geographical data (without height differentiation in buildings).
- New maximum damages & Interruption of housing services.
- New damage functions and taking into account the height of apartments.

5.4.1 New geographical data (without height differentiation)

In Bridgis, as used in HIS-SSM, about 42,000 residential buildings are located in the dike ring ‘Dordrecht’, represented through 1897 locations (6-digit postcode-centroids) (see figure 5.5). Most of the residential buildings are situated in the northern urban part of the study area.

In SSM2015 about 44,000 residences are located in Dordrecht. They are located in the same areas as the residences shown in figure 5.5.

The use of BAG instead of Bridgis is tested without taking into account the improvements regarding the height of apartments. The BAG data has a better resolution, it enables the use of number of residences per category instead of only the dominant residence category, and in the BAG the actual number of residences is considered, while in HIS-SSM the number of residences in 2000 was provided.

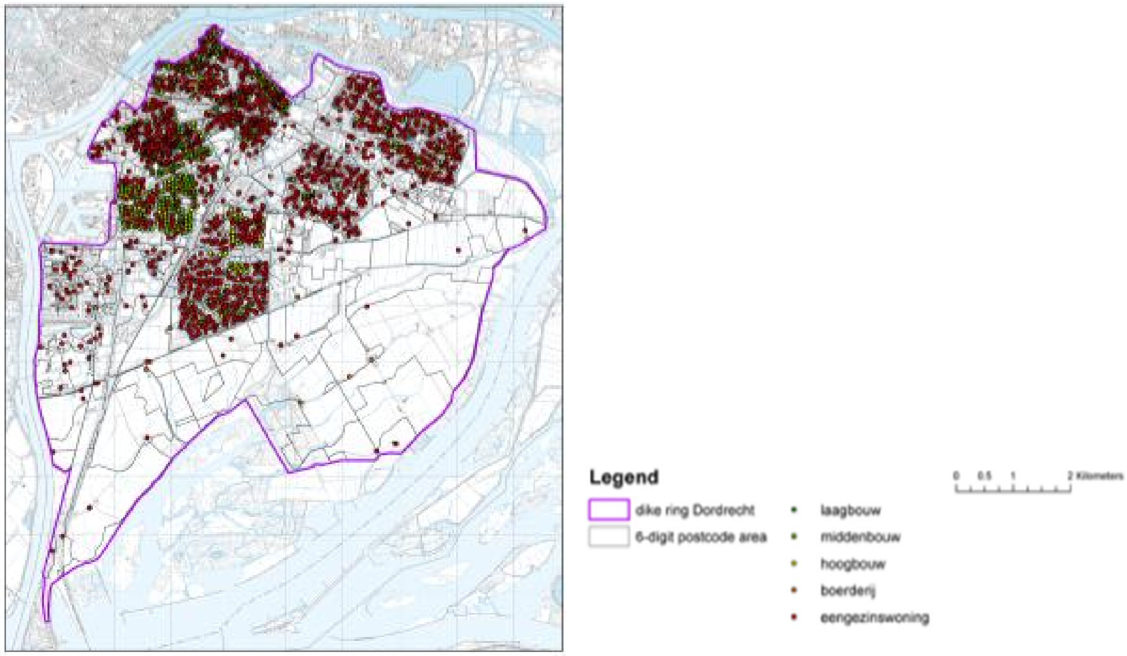


Figure 5.5 Spatial distribution of residences in HIS-SSM in dike ring 22: Dordrecht

Table 5.5 The effect of the changed data on number of type of houses on residence damage (M€) calculated by HIS-SSM and by applying BAG (price level 2000)[16]

	Damage HIS-SSM	Number affected	Damage (BAG)	Number affected
Single family houses - Furnishing	1 186	29712	1 058	26462
Single family houses - Structure	1 095	29712	987	26462
Apartments - Furnishing	487	12443	639	17242
Apartments - Structure	710	12443	932	17242
Interruption housing services	€ 0	-	0	-
Total	3 479	42155	3 617	43704
Change	-	-	4.0%	3.6%

The use of new data results in a damage increase of about 4% (see table 5.5). It should be noted that the number of apartments increased significantly, while the number of single family houses decreased. The explanation for this change is that HIS-SSM assigns the dominant residence type per postal code to all residences in that postal code area, while SSM2015 assigns the correct type of residence to each residence. Furthermore, the Bridgis data is based on the year 2000 and BAG uses the number of residences in 2011.

[16] *In this test the BAG2012 was used, while currently the BAG version of 2014 has been implemented. For the message of the comparison this has no effect.*

5.4.2 New maximum damages and addition of the category ‘interruption of residence services’

The impact of the new maximum damages is isolated and tested on dike ring 22. The HIS-SSM method is carried out for the price level of 2000 (where it was developed for). The new maximum damages result in a decrease of the damage to residences of about 26% (table 5.6). This decrease is caused by the implementation of the new lower maximum damages for the building structure in SSM2015. In HIS-SSM the value of ground/location is underestimated and the maximum damage, calculated as the total value of the residence minus the ground value is therefore overestimated. In SSM2015 this was corrected (see section 5.3).

Table 5.6 Damage to residences (M€) calculated by HIS-SSM and by applying new maximum damage value

	Price level 2000	Price level 2011	
	HIS-SSM 2000	HIS-SSM (*1.22)	New max. damages
Single family houses - Furnishing	1 186	1 447	1186
Single family houses - Structure	1 095	1 336	768
Apartments - Furnishing	487	594	487
Apartments - Structure	710	866	696
Interruption housing services	€0	0	0
Total	3 479	4 244	3137
Change	-	-	-26%

Table 5.7 shows the impact of the introduction of the category ‘interruption of housing services’.

Table 5.7 Damage to residences (M€) calculated by HIS-SSM and with HIS-SSM but with housing interruption damage included

	HIS-SSM 2000	HIS-SSM 2011 (*1.22)	Including interruption (2011)
Single family houses - Furnishing	1 186	1 447	1 447
Single family houses - Structure	1 095	1 336	1 336
Apartments - Furnishing	487	594	594
Apartments - Structure	710	866	866
Interruption housing services	0	0	546
Total	3 479	4 244	4 790
Change	-	-	13%

5.4.3 New damage functions and the separation per floor

The impact of differentiating apartments based on the floor at which they are located, was also tested on dike ring 22. The new damage functions for the higher floors are part of this test. However, the differentiation in heights can only be made when BAG data is used instead of Bridgis data. The effect of this change is therefore assessed by applying both the old method and functions and the proposed method and functions on the BAG data and comparing the results (see table 5.8). The effect of the consideration of the floor level of apartments on the damage to residences is large (about -30%).

Table 5.8 Damage to residences (M€) calculated by HIS-SSM, by HIS-SSM method but with BAG data and by differentiation in floor for multi-floor buildings (maximum damages of the HIS-SSM method) (price level 2000) [17]

	Bridgis data HIS-SSM method	BAG data – HIS-SSM method	BAG data- Proposed method
Single family houses – Furnishing	1 186	1 058	1 058
Single family houses – Structure	1 095	987	987
Apartments - Furnishing	487	639	247
Apartments - Structure	710	932	360
Interruption housing services	0	0	0
Total	3 479	3 617	2 652
Change	-	4.0%	-26.7%

5.4.4 Total impact changes

Table 5.9 shows the combined impact of all changes, by providing damages calculated with HIS-SSM and damages calculated with proposed SSM2015 method. (HIS-SSM data was indexed to a price level of 2011). The improvements result in a reduction of about 33% of the residence damage in dike ring ‘Dordrecht’. This reduction is caused by the new damage functions for apartments, the reduction in the number of single family houses and the reduction of the maximum damage figures for residences.

Table 5.9 Damage to residences (M€) calculated by HIS-SSM and by SSM2015 for reference year 2011

	HIS-SSM 2000	HIS-SSM 2011 (*1.22)	Damage SSM2015
Single family houses - Furnishing	1 186	1 447	1062
Single family houses - Structure	1 095	1 336	664
Apartments - Furnishing	487	594	335
Apartments - Structure	710	866	358
Interruption housing services	0	0	444
Total	3 479	4 244	2862
Change			-33%

5.5 Summary and recommendations

The proposed changes for damage calculations for residences have a large impact on the total damage for residences and also on the total damage of areas. The three changes that have the most significant impact are the proposed changes in maximum structural damages, inclusion of interruption of housing services and the height differentiation of apartments in multi-floor buildings.

We have identified a number of issues that would benefit from further research:

- The damage function for single family houses in the range of 3 to 5 meters flooding depth is uncertain. The HIS-SSM functions diverge from the international average based on the argument that residences will collapse at such water depths. This assumption could be further researched for modern residences to validate or modify the existing function.

[17] *In this test the BAG2012 was used, while currently the BAG version of 2014 has been implemented. For the message of the comparison this has no effect.*

- The housing services interruption is based on an estimate of the interruption costs as a percentage of the residence value per year. This percentage is uncertain and should be analysed further.
- The interruption duration will be larger for large floods and smaller for small floods. This could be further researched and added to the model.
- The maximum damage estimate for furnishing is still uncertain. It is based on insurance estimates from 2000 copied from Briene et al. (2000) and corresponds with estimates of insurance companies. The total damage is very sensitive to this estimate (especially for low water depths). It is suggested to study this figure and the uncertainty around it.

6 Proposed improvements for damages to Infrastructure

6.1 Overview method used in HIS-SSM

HIS-SSM calculates the damage to roads, railways and airports. In this chapter the method used for roads and railways will be discussed and recommendations will be made for improvement. Direct damage to roads and railways makes up approximately 3 to 5% of the total damage in HIS-SSM.

Currently, the following categories of roads and railways are used in HIS-SSM:
- Regional roads;
- Highways;
- Other roads;
- Railways.

For all these categories the direct damage is assessed. For highways and railways also the indirect damage is calculated and for railways the business interruption is assessed as well. Tunnels, bridges and other objects that can be part of the infrastructure are included in the maximum damage to the roads and railways. The maximum damage figures used are summarized in table 6.1.

Table 6.1 Maximum damages in HIS-SSM (price level 2000).

Category	Direct damage (€/m)	Business Interruption (€/m)	Indirect damage (€/m)
Regional roads	980	-	-
Highways	1450	-	650
Other roads	270	-	-
Railways	25150	86	151

The maximum damages for roads were copied from CROW (2001) and are based on estimated construction costs. The maximum damage figures for railways are also equal to reconstruction costs. They were based on reports of the National Railway company NS (NS jaarverslag, 2001).

For both railways and roads one damage function is used (see figure 6.1). There is no motivation for this function available in the literature (Wagemaker, 2005).

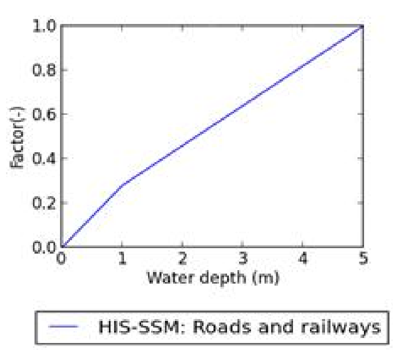


Figure 6.1 Damage function used for roads and railways in HIS-SSM.

The geographical data comes from NWB. This database shows the roads as single lines with some attributes. No distinction is made between single or double track railways or between the number of highway lanes.

6.2 Knowledge from other impact models, flood events or previous research projects

In most (international) damage models, infrastructure gets relatively little attention. References on infrastructure data have been found in Germany, Denmark and Australia. The following similarities can be found in the literature:

- Structures related to roads and railways like bridges and tunnels are often treated separately.
- Distinction is made between reparation and full restoration of infrastructure elements depending on the severity of the event.
- Flow velocity has been identified as a major input parameter for infrastructure (Kreibich *et al.,* 2009), but is, however, usually not fully considered in damage functions.
- Infrastructure damage functions are developed for macro-scale damage assessments and thus only applicable for longer infrastructure sections including their variations such as crossings, culverts, access roads etc. The applicability of these assessment approaches in micro-scale studies might be limited to some extent.

Elbe floods 2002 / 2013

The Elbe 2002 event caused substantial damages on infrastructure in Germany. Damage to infrastructure and related reconstruction costs of that event are documented comprehensively (e.g. Müller, 2010).

Damage assessment in the COMRISK project (2004):

The COMRISK subproject 7 focussed on a flood risk assessment for the Danish Wadden Sea performed under guidance of the Danish Coastal Authority. Within this project a case study has been carried out in Ribe (Jutland, Southern Denmark). Detailed assumptions on reparation and reconstruction costs for different road types are available from this study (Comrisk, 2007).

Australian assessment guidance (2004):

Based on the insights from previous flood events reaching back to the 1970's, guidance on the assessment of (potential) flood damages is provided by several national authorities (e.g. DNRM, 2002). Unfortunately, damage functions from the recent 2011 Queensland floods are not yet available in literature.

6.2.1 Maximum damages

This section focuses on the maximum damage values identified from the literature.

Maximum damages for roads:

NRE (2000) offers a detailed assessment of road damages and comprehensively discusses aspects which should be considered in the assessment of damages on roads. They distinguish between three aspects:

1. initial costs for road repair;
2. costs due to accelerated deterioration of flooded roads; and
3. costs for bridge repair and increased maintenance.

Based on the 1993 flood event in Australia and recorded damages, NRE (2000) calculates the costs for the abovementioned three aspects. They found that the deterioration aspect accounts for about 50% of the initial repair costs and the bridge repair of approximately one-third, respectively (cf. NRE, 2000, Appendix 4). As a result, NRE (2000) recommends the damage values shown in table 6.2**.**

Table 6.2 Unit damages for roads and bridges (per meter of road inundated), from DNRM 2002

	Initial road repair (€/m)	Accelerated deterioration of roads (€/m)	Initial bridge repair and subsequent increased maintenance (€/m)	Total cost per meter road inundated (€/m)
Major sealed roads	23	12	8	43
Minor sealed roads	7	4	3	14
Unsealed roads	3	2	1	6

A more diverse assessment is provided by Austroads (2004), where it is distinguished between routine work, periodic work (both base costs and incremental costs) and road reparation (both rehabilitation and reconstruction) costs (Table 6.3). The numbers may serve as a basis for the verification of maximum damages.

Table 6.3 Australian Unit Costs for Road Infrastructure Provision (in 2002 €), from Austroads (2004)

Agency activity	Fixed Cost (€)		Incremental costs (€)	
	€	Unit	€	Unit
Routine works				
Ravelling/Crack patching	12.4	m^2		
Pothole patching	20.8	m^2		
Edge patching	20.8	m^2		
Area crack sealing	4.2	m^2		
Linear crack sealing	2.1	m		
Periodic works				
Rejuvenation	0.8	m^2		
Rut regulation	208	m^3		
Reseal	1.1	m^2	1.8	m^2 * 10mm
Mil and replace	0.7	m^2	1.5	m^2 * 10mm
Thin A/C overlay	1.1	m^2	1.3	m^2 * 10mm
Rehabilitation work				
Asphalt overlay	1.1	m^2	1.1	m^2 * 10mm
Granular overlay	0.5	m^2	0.3	m^2 * 10mm
Reconstruction work				
Reconstruction	181	m^2		

In the COMRISK project (Comrisk, 2007), the assessment of damages on road infrastructure has been carried out for different types of roads and ways as shown in table 6.4.

Table 6.4 Infrastructure costs for different road types (in 2007 €) from COMRISK (2007)

Road	Price € /m
Path	147
Secondary road	134
Road 3-6 m	495
Road over 6 m	870
Expressway	870

In addition, Reese *et al.* (2003) give estimates for the cleaning of debris on streets due to flooding (in 2001 values):

- cleaning of sealed surfaces approx. 6.00 Euro per m^2
- cleaning of unsealed surfaces approx. 3.60 Euro per m^2

Another way at looking at the damage is to look at the construction costs of a new road and to use a motivated fraction of that as the maximum damage. The Expert Catalog Kostenkentalen (ECK) estimates the cost of a new highway at 5200 (excl. VAT) €/m. It is, however, not clear whether this cost figure includes the land acquisition costs. Furthermore, not everything that needs to be done during construction has to be done during restoration. A breakdown of the actual costs for an example highway construction project shows much higher costs.

Table 6.5 Breakdown of the construction costs for the 2004 project to expand the A5 by 9 km (Nijland et. al. 2010).

	Construction costs (Nijland et. al. 2010)			Estimated damage fraction (-)	Estimated potential damage (€/m)
	Cost incl. VAT (M€)	Cost excl. VAT (M€)	Cost (€/m)		
Project management	1	1	93	0	0
Cables and pipes	19	16	1774	0-0.25	444
Geometry, installations, signals and lightening	130	109	12138	0.1-0.2	2148
Constructions	103	87	9617	0.02-0.05	480
Procedures, environment and facilities	44	37	4108	0	0
Communication	1	1	93	0	0
Direct execution costs	50	42	4669	0.05-0.15	610
Total	348	292	32493	0.05-0.11	1685 - 3680

Two columns were added to table 6.5 to estimate what aspects of the road are vulnerable to flooding. It was assumed that about 5-10% of the construction costs have to be used for repair since little will happen to the actual road construction. This comes down to a damage of 1685 - 3680 €/m.

Table 6.6 gives an overview of the different maximum damages for highways found in the methods discussed. The comparison shows that the differences between the sources are large.

Table 6.6 Overview of estimates maximum damage roads

Source	Country	Price level	Based on	Damage (€/m)
Natural Resources and Environment	Australia	2000	Flood damage estimate	45
Austroads	Australia	2002	Construction cost	4544
COMRISK	Denmark	2007	Flood damage (maximum)	144*
Estimate based on ECK	Netherlands	2012	Construction cost	520 - 2600**
Estimate based on A5 construction cost	Netherlands	2004	Construction cost	1685 - 3680
HIS-SSM	Netherlands	2000	Maintenance costs	1450

**Only the cleaning costs, damage is only taken into account near dike breaches.*

*** Based on the assumption that the potential damage is 5-10% of the construction costs*

The comparison shows a large difference between estimates based on construction costs and other damage estimates (see table 6.6). An explanation for this is that in the recorded flood events, roads were not damaged severely. The value in HIS-SSM is lower than those based on construction costs and higher than those derived from recorded damages during floods in Denmark and Australia.

The low Australian estimate in table 6.6 is striking. This is probably due to the relatively simple roads in Australia. In the Netherlands roads are generally accompanied by expensive infrastructure such as lightning, signals and noise screens, which are less common in Australia. During the A5 construction in the Netherlands a significant share of the costs went to such accompanying infrastructure. This accompanying infrastructure may be more vulnerable to floods than the basic elements (asphalt and road itself). Most of the damage in the Netherlands to roads is therefore expected to be like that infrastructure.

A major contribution on road damages seems to come from loads on roads after a flooding. Due to the saturation with water, major damage to roads is caused when trucks are using roads as soon as the water is gone from the streets. The damage mechanism has been researched by NRE (2000), leading to the conclusion that “excessive moisture in road pavements leads to deterioration in the durability of roads, and causes effects similar to a large increase in heavy vehicle traffic.” Therefore, a trade-off between the opening of a road for trucks after the flooding and the indirect losses due to traffic interruption has to be made by responsible authorities.

Maximum damages for tunnels

In literature, no references have been found on damages of tunnels as a consequence of flooding. Also no specific regulation in current design standards focussing on the design of tunnels with respect to flooding was found. Nevertheless, the flooding of a tunnel is considered during the design in order to avoid structural damages as a consequence of increased bending moments, which are caused due to an increase of vertical soil pressure as a result of reduced outside horizontal (ground) water pressure (SKRIBT, 2012).

It is assumed that non-structural damages occur if a tunnel is flooded, mainly due to the contact of installations such as lights, ventilation, or communication with water. Therefore, tunnel entrances are often protected by an increased terrain level (so called “Kanteldijk” in Dutch). However, the flood protection for extreme events cannot be guaranteed per se. Further research on maximum damages of this (critical) infrastructure is needed to quantify expected damages.

Maximum damages for bridges
Two different types of bridges have to be distinguished for damage analysis, i.e. bridges over small channels or small rivers and bridges over large rivers. Small bridges are often part of the local water system and are, therefore, often not above the flood water level. They are thus flood-prone. For large bridges it is assumed that they generally cross the flooding source. In the design of those bridges a freeboard is used. Though the freeboard varies between different countries (VIF, 2012), the stability of a bridge is ensured for the design flood event. Large bridges are, therefore, probably safe during a flooding.

NRE (2000) estimated about one third of the reconstruction costs of roads to be particularly required for bridges.

Maximum damage for railways
Beside the available values in HIS-SSM, very limited information can be found in the literature on maximum damages for railway systems. However, from the 2002 Elbe floods, a total damage of 1.025 billion Euros on the rail infrastructure is reported, including the following categories (Müller, 2010):
- approx. 400 km of railway tracks;
- approx. 130 km of railway embankments;
- approx. 94 railway bridges;
- approx. 200 train stations and stops;
- approx. 240 junctions;
- approx. 25 railway control centres;
- 12 train vehicles and 4 high speed trains.

If we would assume that the high speed trains and the train vehicles had a value of around 125 million euro, we can assess the damage to the railways as 1.025 billion minus 125 million equals about 900 million euro. This is equal to 2250 €/m. Note that this is not a maximum damage, but the damage corresponding with the water depth which occurred in the Elbe flooding. The maximum potential damage may be twice as high, or even higher.

Another way to look at the maximum damage is to look at construction costs. The average construction costs for railways in the Netherlands are 40.000 €/m (Teulings et al, 2004). Since only about 5 – 50% of these construction costs are expected to be needed to recover from the flood damage, the potential damage to railroads lies between 2000 and 20.000 €/m.

There seems to be a large difference between the maximum damage calculated based on the construction costs (like HIS-SSM) and the maximum damage based on the real flood data from the Elbe flood in 2002. A possible explanation could be that many of the railways flooded in Germany were in relatively less populated areas and were possibly not equipped with electrification and automatic train control systems.

6.2.2 Interruption damage

Several studies have estimated the impact of interrupted roads due to flooding. Rolfe et al. (2011) assesses the actual damage to a road interrupted during the Queensland flood of 2011 in Australia using two different methods. The first was to look at the impact at the Gross Regional Product for the days of the interruption. The second method looked at the traffic flows and used the costs of delays.

Bakker *et al.* (2006) used a traffic flow model to assess the damage during a flood also using the costs of delays. Table 6.7 shows the results in a comparable way (all translated into euro per day for one highway).

Table 6.7 Interruption costs of a flooded highway per day.

Study	Damage M€/day	Source
Cost of delays for one highway during the Queensland flood of 2011, Australia	3.78	Rolfe *et al*, 2011
Estimated impact on the economy of one highway flood of 2011, Queensland, Australia	1.36	Rolfe *et al,* 2011
Cost of delays traffic, scenario one highway in the Netherlands	2.73	Bakker *et al,* 2006

The different studies and methods all give results in the same order of magnitude. The actual costs however depend on the road network structure (are there other roads available) and on the region (is the road used frequently also by people outside the flooded area). When multiple roads are flooded the damage may increase exponentially because alternatives are diminishing. Furthermore, especially Bakker et al. (2006) stressed that the damage per day will be much higher in the first months than in later months as the interruption will change behaviour. The study by Rolfe *et al.* (2011) couldn't really consider those effects because the interruption in the actual case only lasted 18 days.

HIS-SSM expresses the interruption costs per meter (table 6.1). The evaluation, however, cannot be done per meter, but should be done per segment connecting major points. This is because no matter how large the flooded part of a segment is, when it is flooded somewhere the whole segment is interrupted. These segments can, however, still be defined in different ways.

6.2.3 Damage functions

Damage functions for roads:
According to Kreibich *et al.* (2009), flow velocity is seen as the most important parameter for the assessment of damages on roads. In addition to water depth, NRE (2000) lists the following aspects, which influence the level of damage for road infrastructure:

- velocity of the flow;
- period of inundation;
- condition of the road;
- classification of road;
- the direction of flowing water relative to the pavement; and
- the presence of structures and bridges.

The assessment of road damages is fairly complex if all aspects are taken into account. However, due to limitations in the availability of data and the absence of reliable local flow velocities, simplified assumptions are required on the damage function. The neglected input parameters are taken into account implicitly in the maximum damage or the damage function. This is acceptable in the Netherlands, since differences between roads in the same road category are small. Flow velocities are generally low, road conditions are generally good and the duration of flooding is mostly long.

The function in HIS-SSM is not motivated and its basis is unknown (Wagemaker, 2005). The shape of the function is not according to expectations. A more obvious shape would be that most of the damage occurs in the first meters water depth as the potential damage consists mostly of lightening, signals, installations and cleaning up. These are all expected to be relatively adding more to the damage in their first meters than at higher depths.

Damage functions for railways
Little is known about the vulnerability of railways. Railway damage is also expected to depend on flow velocity. Furthermore, the damage also mostly consists out of installations and facilities that are probably damaged in the first meters of water depth.

Damage function for interruption costs
A damage function for interruption costs could be constructed using the water depth as indicator of the flood duration. This could be done based on a study of the relationship between water depth and flood duration as for example carried out in Duiser (1982) or Wagenaar, (2012).

6.2.4 Geographical data for damage assessment

Availability of data
The spatial data on infrastructure in HIS-SSM is based on the “DID bestand wegen / spoorwegen”. However, the information available from TOP10 are characterised by more detailed and more comprehensive spatial information. Different assessment approaches have been developed to convert the data from TOP10 in order to update the DID datasets (cf. Burzel, 2013).

For the road system, the additional information “fysiek voorkomen” has been considered from the TOP10 dataset in order to distinguish between the following types of roads:
- roads in tunnels;
- roads on bridges; and
- unclassified roads.

The availability of this data makes it possible to include separate damage functions for bridges and tunnels or, if applicable, exclude tunnels and bridges from the damage analysis. The latter case is especially relevant if the tunnel/bridge is situated under/over water permanently. Therefore, the location of water has been taken from TOP10 and an additional attribute “overwater” is appended to the new GIS dataset.

In addition to the amendments mentioned above, the type of railway (person, goods, mixed) and its configuration with or without electricity has been added as attributes to the new GIS dataset for the railway system. It is now possible to distinguish between main and side lines, as all main lines in the Netherlands are electrified, and to include particular damage functions for bridges/tunnels or to exclude them from the damage analysis, if permanent situated under/over water.

6.2.5 Overlap with other categories in HIS-SSM

A more careful examination of what can damage to roads shows that most damage is expected to be towards objects around the road (e.g. lightening) rather than towards the actual construction.

There is also a damage category called urban areas in HIS-SSM which is defined as street furniture, paved surfaces, pipes and cables. These categories therefore seem to partly overlap with the infrastructure category “Other roads” in HIS-SSM. This could be solved by removing the roads which are located in urban areas.

6.3 Proposal for improvements

6.3.1 Proposal for improvements in the definition of categories

To assess flood damage to roads it is proposed to keep the same categories definitions as used in HIS-SSM, but to exclude ‘other roads’ which are located in urban areas from the category ‘other roads’. As explained in the previous section, damage to these other roads is already included in the damage category ‘urban area’. It is proposed to take the long bridges and tunnels out of the highway and main road data as these are expected to be safe for flooding. On the long term bridges and tunnels in smaller roads might also be identified and threated separately.

It is recommended to distinguish between major and minor railways. This separation can be done based on whether the railway is electrified. This distinguishes the major public railways and transport lines from the small company railways or the minor provincial railways. About 75% of all railways in the Netherlands are electrified (see figure 6.2 for an example of the railroad classification for the western part of the Netherlands).

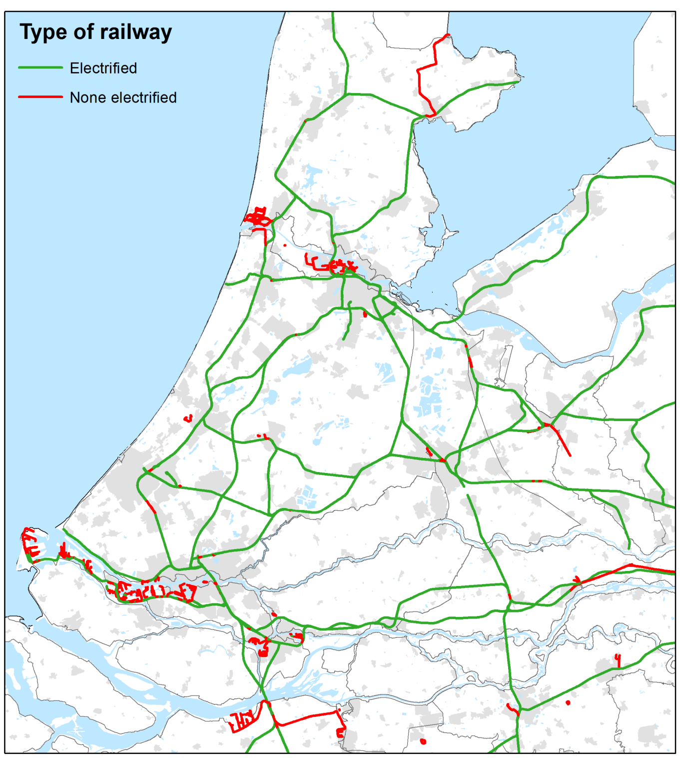


Figure 6.2 The major (electrified) and minor (non-electrified) railways in the west of the Netherlands.

6.3.2 Proposal for improvements in the maximum damage

Roads (direct):
Significant differences in estimates for the maximum damage to roads have been found in the literature. The maximum damage in HIS-SSM lies within the range of values found. It is, therefore, proposed not to change the maximum damage for highways, regional roads and other roads but only to correct the values for inflation. It has to be noted that this maximum damage figure then reflects the assumption that roads will barely be damaged by floods, as this damage figure is only a small fraction of the construction costs (see estimates table 6.4). The HIS-SSM damage figure then mainly reflects costs made for cleaning and for repairing objects attached to the road (lightening, signals, installations, noise screen, etc.).

Roads (Business interruption and indirect):
The interruption damage of roads in HIS-SSM seems orders of magnitudes too small based on other studies and data. There are several ways of improving this. Yet, all of them need a fundamental different method than the current calculation of damage per meter. More research, therefore, needs to be done before a new method can be implemented. For now it is proposed to take out the interruption damage until a better method is developed. It is proposed to calculate the meters of roads and railroads damaged and mention the road numbers and railway sections in the output of the damage model, but not to translate this into business interruption costs. This identification of damaged roads and railroads may serve as input for an analysis of indirect damage.

Railways (direct):
The current estimate based on construction costs is probably far too high based on the large difference between damages recorded in the Elbe floods of 2002 and typical construction costs. It is proposed to change the maximum damage to twice the damage that occurred in the Elbe floods of 2002 (assuming that the damage was then 50% of the maximum damage, since water depths were only somewhere between 0 and 3 meter) and to correct that number for inflation. Further research on damages to railway infrastructure is recommended.

The maximum damage for non electrified railways is estimated to be about 25% of the electrified railways, because electrified railways are expected to be a double track while non-electrified railways are a single railway track. Furthermore, it is expected that the damage to the electric installations is approximately half of the potential damage to a railway track. Also these estimates are highly uncertain.

Railways (Business interruption and indirect):
It is proposed to take the interruption of railways out of HIS-SSM until a better method is available. The railroad sections affected by floods will be identified and reported in the SSM2015 output. Table 6.8 provides the proposal.

Table 6.8 Proposed maximum damage values (price level 2011)

Category	Direct damage (€/m)	Interruption (€/m)
Regional roads	1200	-
Highways	1770	-
Other roads	327	-
Railways - Electrified	5400	-
Railways – Non-electrified	1350	-

6.3.3 Proposal for improvements in the damage functions

It is proposed to replace the HIS-SSM function with a function with a more logical shape. This new damage function was constructed based on the systematic expert judgment approach as used in MCM (Penning-Roswell et al, 2005) using the data of the A5 construction costs of 2004. Figure 6.3 shows the resulting function. The function starts relatively slow as roads are not vulnerable for low water depths (<25cm), then it rises rapidly when the electric infrastructure is hit and then it becomes less steep since additional water is not expected to affect the damage significantly. This function is also applied for railways.

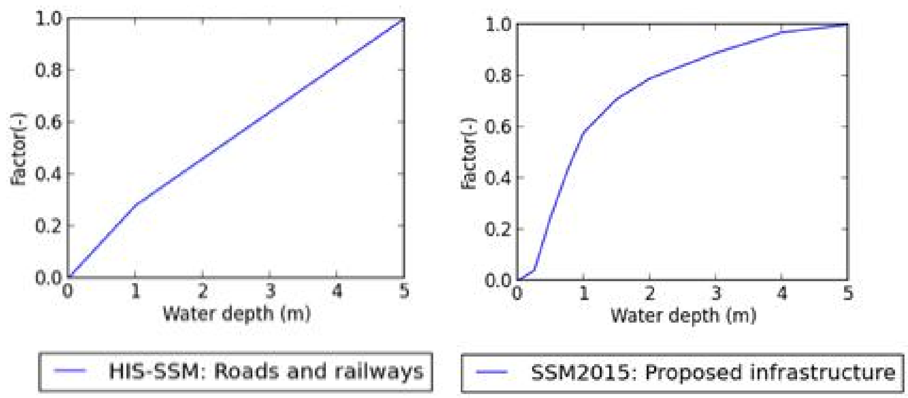


Figure 6.3 Left: HIS-SSM function for all infrastructure, Right: Proposed function for all infrastructure

It is assumed that the water depth map used as input reflects the water depth at the railroad well. If the raised structure on which many railroads are located, is not captured in the water depth map, this function may lead to an overestimation of the damage. It should then be shifted to take the raised structure into account.

6.4 Test improvements on dikering 22 – Island of Dordrecht

In this paragraph the effect of the proposed changes are illustrated by testing the new data category definitions, maximum damages and damage function on dikering 22 (Island of Dordrecht) using the WV21 water depth map (see figure 1.1). The purpose of the test is to see the individual impacts of the following changes:

- Category definitions;
  - Removing overlap urban areas/other roads
  - Separating major and minor railways
- New maximum damages;
- New damage function.

In HIS-SSM, the local road network accounts for 450 km of length and is highly concentrated in the northern urban area. Several railroad connections also pass through the area. In SSM2015 the total road network considered is smaller, since a part of the road network (the small ‘other roads’ in urban areas) was also considered in the category ‘urban area’ and has been removed from the road network.

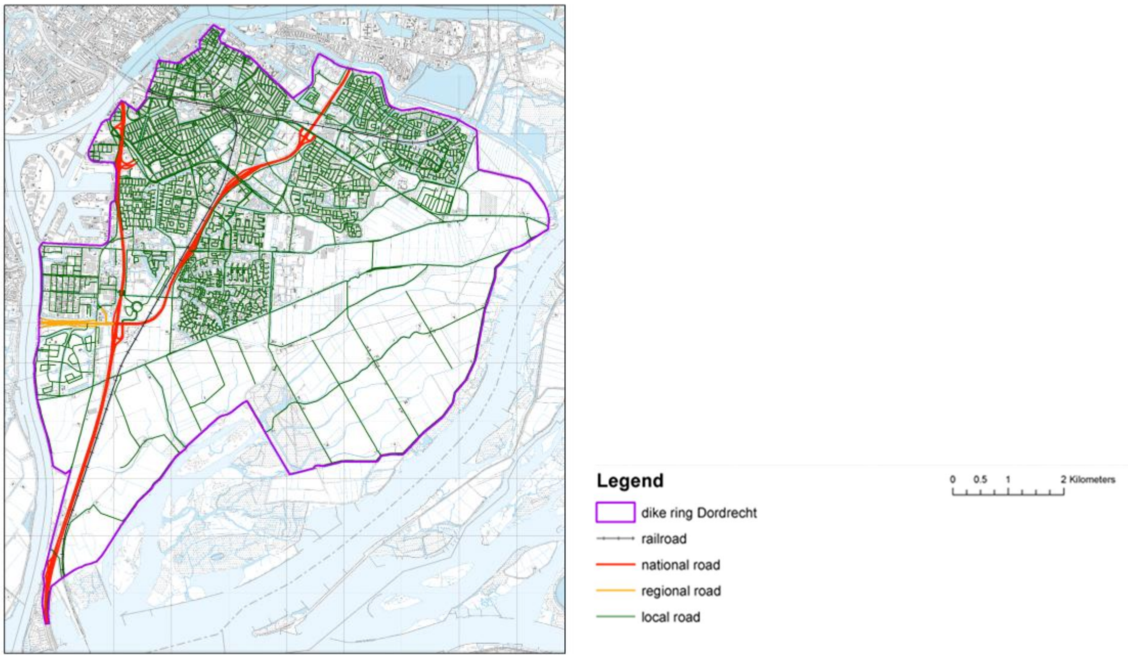


Figure 6.4 Spatial distribution of roads and railroads in dike ring 22: Island of Dordrecht

6.4.1 Category definitions

Three changes were tested in the category definitions:
- removal of the overlap between urban areas/other roads,
- other spatial resolution data
- and separating major from minor railways based on whether the railway is electrified.

The maximum damage for electrified railways has been set equal to the HIS-SSM maximum railway damage and the maximum damage to non-electrified railways to 25% of that figure. The results provided in table 6.9 and 6.10 show that he damage to roads decreases significantly when the proposed method is implemented. The main reason for this reduction is the decrease of the number of road kilometres in the category ‘other roads’. The roads in urban areas are now only taken into account in the land use category ‘urban area’. They are not part of the infrastructure damage anymore (see chapter 7). All railways in the test area are electrified.

Table 6.9 Damage to infrastructure (M€) calculated with HIS-SSM and by using new category definitions (price level 2000, HIS-SSM data)

	Damage (HIS-SSM 2000)	Damage (New categories)	Change (%)
Highways	9.4	7.4	-21 %
Regional roads	0.7	0.5	-29 %
Other roads	47.4	19.8	-58 %
Railways	85.3	82.8	-3 %
- Electrified	85.3	82.8	
- Nonelectrified	-	-	
Total	142.9	110.5	-23 %

*Table 6.10 Total (affected) length (km) for each damage category calculated with HIS-SSM and with the new data and definitions**

	HIS-SSM		New data & definitions	
	Total length	Affected length	Total length	Affected length
Highways	43	22	43	22
Regional roads	7	2	7	2
Other roads	450	365	269	165
Railways	15	9	16	
- Electrified	15	9	16	9

6.4.2 New maximum damages

The impact of the new maximum damages is isolated and tested on dike ring 22. The reduction of the maximum damage of railroads results in much lower flood damages (see table 6.11).

Table 6.11 Damage to infrastructure (M€) calculated with HIS-SSM and by using new maximum damages

	HIS-SSM 2000	HIS-SSM 2011	New maximum damages	Change (%)
Highways	9.4	12	12	0
Regional roads	0.7	0.9	0.9	0
Other roads	47	59	59	0
Railways	85	106	18	-82
- Electrified	85	106	18	
- Not electrified	-	-	-	
Total	143	177	89	-50

6.4.3 New damage functions

The impact of the new damage function for infrastructure is tested isolated from the other changes. Table 6.12 shows the results. The implementation of the new steeper damage function results in increased flood damage. The damage in the category ‘other roads’ is reduced because other roads in urban areas’ were removed from this category. Without this new definition the damage of that category would increase with about 65%.

Table 6.12 Damage to infrastructure (M€) calculated with HIS-SSM and by using new damage functions (price level 2000)

	HIS-SSM 2000	New damage functions	Change (%)
Highways	9.4	13	37
Regional roads	0.7	0.8	14
Other roads	47	78	65
Railways	85	144	69
Total	143	189	32

6.4.4 Impact of all changes

Table 6.13 shows the combined impact of all changes for the test area. The proposed changes result in a large decrease in damage to infrastructure. The removal of urban roads and the reduction of the maximum damage for railways contribute most to this decrease in infrastructure damage.

Table 6.13 Damage to infrastructure (M€) calculated with HIS-SSM and SSM2015

	HIS-SSM 2000	HIS-SSM (2011)	SSM2015 (2011)	Change (%)
National roads	9.4	12	20	71
Regional roads	0.7	0.9	1	45
Other roads	47	58	36	-37
Railways	85	104	32	-69
Total	143	174	90	-48

6.5 Recommendations for further research

The analysis in this report served as a first scan of possibilities for improvements of the way the infrastructure is represented in HIS-SSM. Several further improvements are recommended:

- The interruption costs should be studied further. The studies mentioned in 6.2.2 can be used for this improvement.
- The potential damage should be studied further to reduce the uncertainty in this figure. The potential damage to infrastructure and the damage functions are still very uncertain. Only a few studies are done on this topic and the results from these studies give very different answers.

7 Proposed improvements for damage to other categories

7.1 Overview method used in HIS-SSM

In addition to residences, businesses and infrastructure, HIS-SSM calculates damage for the following 'other' categories:

- **Agriculture:** Damage to crops, cattle, agricultural machines and/or agricultural buildings.
- **Horticulture:** Damage to horticulture buildings including the crops and installations.
- **Recreation intensive:** Damage to holiday houses, attraction parks, zoos, etc.
- **Recreation extensive:** Damage to nature and city parks.
- **Urban area:** Damage to street furniture (incl. lightening), paved area, cables and pipes.
- **Airports:** Damage to the entire terrain belonging to an airport.
- **Vehicles:** Damage to private cars (excluding company vehicles).
- **Pumping stations:** Damage to pumping stations with different sizes as part of the water system.
- **Wastewater treatment plants:** Damage to plants that treat municipal wastewater.

These 'other' categories contribute 10 to 20% of the total damage in a typical run and often include a large area (e.g. 13% of the test area). In general, flooding of urban area and vehicles (cars) constitutes the major share of damage of these categories, although locally other categories can be important.

Table 7.1 shows the source of the geographical data of the different categories, the unit used for calculation and a maximum damage value per unit. The number of vehicles is based on 0.42 times the number of inhabitants, defined per postcode unit.

Table 7.1 Source of geographical data, unit and maximum damage per unit.

Category	Source geographical data	Unit	Maximum damage (€, price level 2000)
Agriculture	CBS Bestand Bodemgebruik 2000	m^2	1.50
Horticulture	CBS Bestand Bodemgebruik 2000	m^2	40.10
Recreation intensive	CBS Bestand Bodemgebruik 2000	m^2	10.89
Recreation extensive	CBS Bestand Bodemgebruik 2000	m^2	8.85
Urban areas	CBS Bestand Bodemgebruik 2000	m^2	48.90
Airports	CBS Bestand Bodemgebruik 2000	m^2	120
Vehicles	Geo-Marktprofiel BV	Number/ ppc	6 510
Pumping stations	WIS 2005	Number	747 200
Waste water treatment	WIS 2005	Number	10 853 000

**Waterstaatkundig Informatie Systeem*

Several damage functions are used for these categories (see figure 7.1). Most of the functions are steep till 0.5 m, and flatten when the depths become larger. In contrast, the function for vehicles differs, as it starts from 0.5 m, ascending linearly to a damage factor of 0.8 at 5 m.

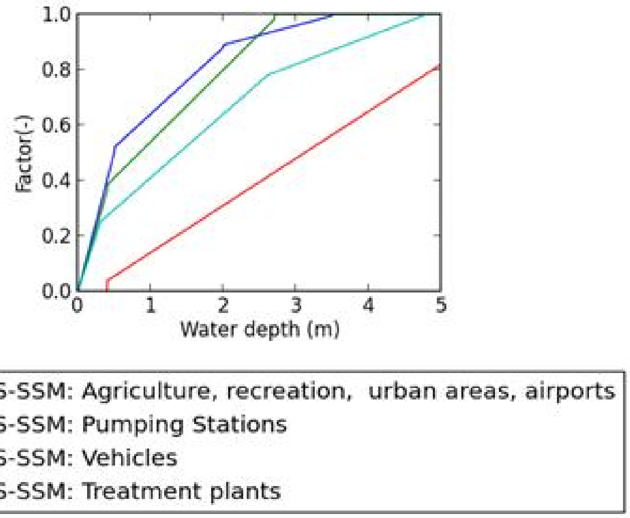


Figure 7.1 Damage functions used for the categories mentioned in table 7.1.

7.2 Knowledge from other impact models, events or previous research projects

7.2.1 Geographical data

Since the first release, updates of existing and new geographical data sources have become available. These can be utilized for an improvement of HIS-SSM.

The ‘bestand bodemgebruik of 2000’ is updated to a new version of 2008. This new file is applicable for use without changes to the HIS-SSM method.

Some methods concerning damage calculation to agriculture and horticulture, differentiate in damage to several crop types or damage due to flooding from salt or fresh water sources. The agricultural categories can be differentiated in several more categories based on crop types available in the detailed LGN6 dataset (Landelijk Grondgebruik Nederland). Furthermore, in the HIS-SSM method, damage to agricultural buildings (e.g. for cattle or machine storage) is not spatially differentiated, although geographical information about the exact location of agricultural buildings is available from the BAG. As a consequence, HIS-SSM is probably underestimating intensive agriculture damage and overestimating extensive agricultural damage.

The geographical data for vehicles is based on a population map assuming 0.42 car per inhabitant. The population map in HIS-SSM is based on inhabitants per postcode area. However, it is proposed to use in SSM2015 new geographical data from CBS with average household size per neighbourhood. A population map is made by multiplying the residences with the average household size and a vehicle map by multiplying the inhabitant map with 0.42.

7.2.2 Maximum damages

Little new data or studies have become available about maximum damages for the categories in the group “other categories”. An inflation correction is necessary for the maximum damages with the price level 2000.

For agriculture and horticulture a recommendation is made in Morselt et al. (2006) to change the method for determining damage to agriculture to a complete different way. It was recommended to calculate direct damage to crops based on the added value of a harvest or the added value from cattle. The added value is available per sector in the CBS statline database. This recommendation has not been followed yet in this report.

7.2.3 Damage functions

Also, little new data or studies have become available about damage functions for the categories in the group “other categories”. Most categories will be unchanged. Only the categories ‘vehicles’ and ‘urban area’ will be discussed here.

Vehicles (Cars)
An exception is the damage function for vehicles. The damage function for vehicles in HIS-SSM differs from international functions. For example, at a water depth of 4 m, a vehicles is supposed to be damaged for 65%. The HAZUS model offers an alternative function that may be more realistic. The two damage functions are shown in figure 7.2.

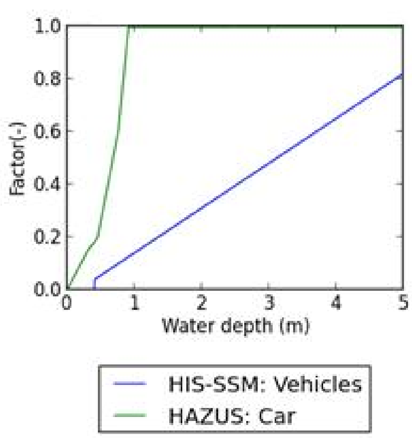


Figure 7.2   Damage function for vehicles in HIS-SSM compared with HAZUS

Evacuation of vehicles (cars) is not included in the SSM2015. However, it is likely that many people who evacuate, leave the area by car.

7.3 Proposal for improvements

7.3.1 Proposal for improvements in the definition of categories

It is proposed to update the geographical land use data “CBS Bodembestand 2000” with the newer 2008 version. In addition, vehicles are updated based on the new population map.

In chapter 6 it was explained that damage to urban area and damage to roads may be caused by similar aspects. In both cases, damages to lighting, poles, and so on may be the main contributing factors. Therefore, it is proposed here to change the urban area function into the infrastructure damage function. The damage functions are already very similar, but according to the new function, paved areas are less vulnerable to low water depths (below 40 cm) than with the old function.

7.3.2 Proposal for improvements in the maximum damage per category

It is proposed to use an inflation correction on all the maximum damages in the other categories group. Table 7.2 shows the new maximum damages.

Table 7.2 Source of geographical data, unit and maximum damage per unit.

Category	Maximum damage (€, price level 2000)	Unit	Maximum damage (€, price level 2011)
Agriculture	1.50	m^2	1.83
Horticulture	40.10	m^2	49
Recreation intensive	10.89	m^2	13.29
Recreation extensive	8.85	m^2	10.79
Urban areas	48.90	m^2	59.65
Airports	120	m^2	146
Vehicles	6 510	Number*	7 942
Pumping stations	747 200	Number	911 600
Waste water treatment	10 853 000	Number	13 240 000

* In contrast to HIS-SSM, damage to vehicles is now calculated for each address location

7.3.3 Proposal for improvements in the damage functions

It is proposed to use the damage function for cars from HAZUS (see figure 7.2). The damage function of urban area is set equal to the one for infrastructure (see figure 7.3).

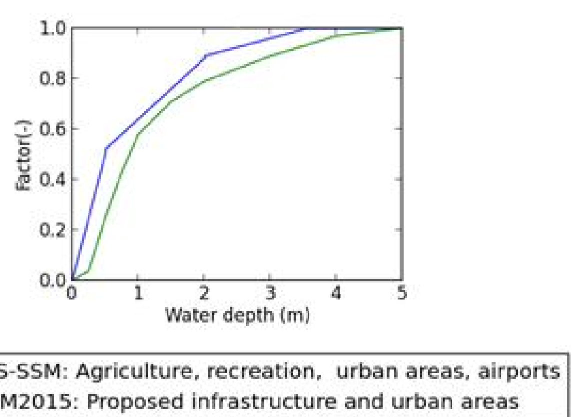


Figure 7.3 Damage function of urban area in 2015 compared to the original HIS-SSM function

7.4 Test improvements on dikering 22 – Island of Dordrecht

In this paragraph the effect of the proposed changes are illustrated by testing the new data, maximum damages and damage function on dikering 22 (Island of Dordrecht) using the WV21 water depth map (see 1.2). The purpose of the test is to investigate the individual impacts of the following changes:

- Geographical data update;
- New damage functions;
- Total impact.

Almost half of the study area is used for agriculture and one fourth is urban area (see figure 7.4). The rest is extensive recreation, intensive recreation and green houses.

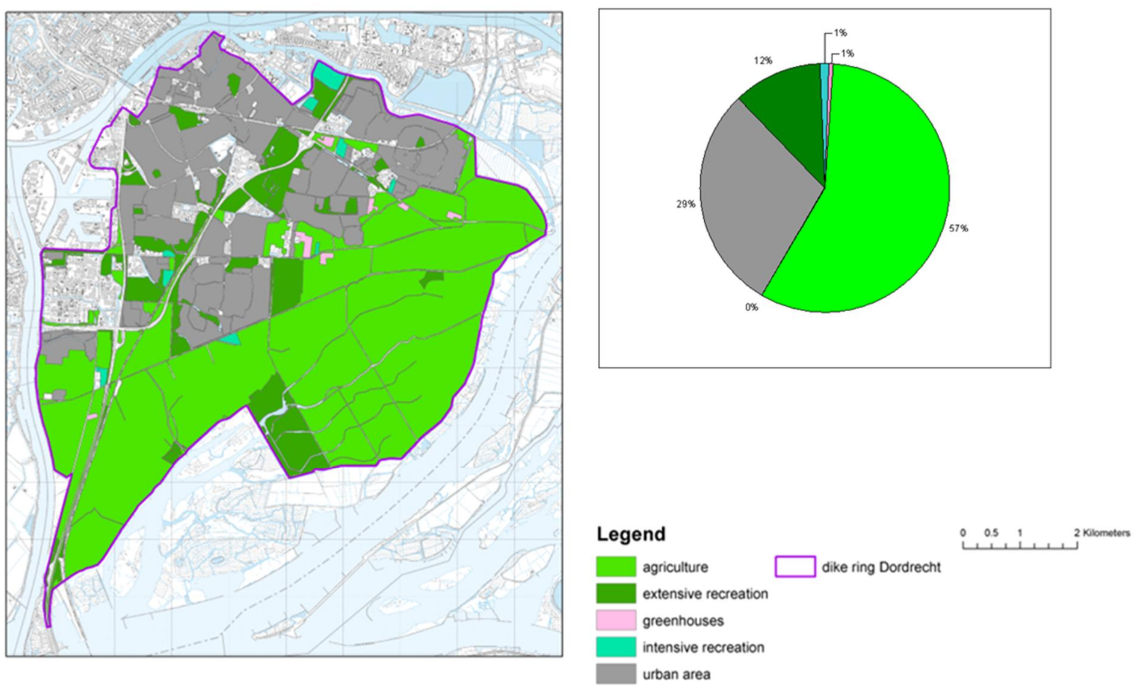


Figure 7.4 Spatial distribution of various land uses in dike ring 22: Island of Dordrecht

7.4.1 Geographical data update

The land use data is updated with new landuse map and the geographical data for the cars has been updated. Table 7.3 shows the result of these changes.

Table 7.3 Damage (M€) to other categories calculated by HIS-SSM and by using new data (price level 2000)

Category	HIS-SSM	Units	New geographical data	Units
Agriculture	21.6	21.6 km^2	19.5	20 km^2
Horticulture	8.2	0.2 km^2	6.2	0.2 km^2
Recreation intensive	3.4	0.4 km^2	3.0	0.4 km^2
Recreation extensive	25.8	4 km^2	25.6	4 km^2
Urban areas	471	10.9 km^2	480	11.1 km^2
Airports	0	0 km^2	0	0 km^2
Total land uses	530	-	534	-
% change	-	-	1 %	-
Vehicles	97.2	40122	97.5	40473
Pumping stations	7.9	13	7.9	13
Waste water treatment	0	0	0	0

Due to the data update the damage slightly increases, although some categories decrease, but differences are negligible.

7.4.2 New damage functions

Secondly, the effect of newly proposed damage function updates is tested with the old geographical data. The inflation correction in the maximum damages is not implemented in this test.

Table 7.4 Damage (M€) to other categories calculated by HIS-SSM and by using improved damage functions (price level 2000)

Category	HIS-SSM	New damage functions
Urban areas	471	434
Vehicles	97	254
Total	568	687
% Change	-	21 %

Table 7.4 shows that the effect of the new damage function for vehicles on the resulting damage is most severe, as damage almost increases with a factor 2.5.

7.4.3 Total impact of all changes together

The land use data update, the maximum damage inflation correction and new damage function are all implemented in a final test. The results of this are shown in table 7.5.The differences with HIS-SSM are small. ?%). Damage to vehicles is roughly tripled when moving from HIS-SSM to the proposed method For SSM2015. This is mainly caused by the changed damage function.

Table 7.5 Damage (M€) to other categories calculated by HIS-SSM and by SSM2015 for price level 2011

	HIS-SSM (2000)	HIS-SSM (2011)	SSM2015 (2011)
Agriculture	22	26	24
Horticulture	8.2	10	8.2
Recreation intensive	3.4	4.1	4.0
Recreation extensive	26	32	33
Urban areas	470	573	549
Airports	0	0	0
Vehicles	97	119	311
Pumping stations	7.9	9.7	9.7
Waste water treatment	0	0	0
Total	634	774	939
Difference			18%

7.5 Recommendations for further research

There are several further research opportunities in the other categories group.

- There are several ways to significantly improve the method for *agriculture damage*. A distinction can be made between intensive and extensive agriculture. Intensive agriculture would be mostly machines, buildings, cattle and installation and would require a very different damage function from crops. Extensive agriculture which would be mostly grass land for cattle and crops, could be improved by making a distinction between a fresh and a salt water flood. Furthermore, possibly a distinction could be made between different crops and potentially the season in which the flood occurs. Furthermore, the recommendations of Morselt et al (2006) about the new maximum damages for agriculture damage could be followed.
- The maximum damage to vehicles could be updated based on the price developments in the last 10 years. Different government policies and societal changes could have impacted the average value of a car in the Netherlands and the number of cars per inhabitant. Evacuation of cars is not included, this could be reconsidered.
- The damage figures for *recreation* should be studied further. The category ‘intensive recreation’ is very broadly defined and might overlap some of the business categories (e.g. restaurants/hotels). Furthermore, within the category itself there are also some possible improvement, e.g. by making distinctions between some of the broad categories (e.g. holiday homes and camping terrain).The damage to extensive recreation seems high, especially compared to the figure of intensive recreation.
- The category ‘*urban area’* remains a vaguely defined category with a significant effect on the total damage. Damage data from urban floods and international experience could possibly help improving the damage assessment of this category. Yet, whether this data is available or useful is unknown.

The above research opportunities are all either uncertain or expected to only have a minor influence on the total damage of a large flood. For local policy, for example in multi-layer safety decisions, these changes may, however, be significant.

8 Overall effects & Discussion

8.1 Effects of all proposed improvements together

8.1.1 On the island of Dordrecht

The effects of the proposed method SSM2015 have been tested by applying it on Dordrecht and on the water depth map for the Netherlands. The effect of each individual improvement on the resulting damage has been discussed in the chapters 4 to 7. The combined effect of all improvements is discussed in this section. For more details on the proposed changes for businesses, infrastructure, residences and other categories we refer to chapter 4 to 7.

To be able to compare the results of HIS-SSM and SSM2015 they were harmonized with respect to price level and economic growth by multiplying the HIS-SSM results of reference year 2000 with a factor 1.4 (1.22 for inflation and 1.18 for economic growth).

Table 8.1 shows that the total damage assessed by SSM2015 is lower and the distribution over the different categories is different from those assessed by HIS-SSM. In the HIS-SSM results the majority of the damage is related to damage to residences, while the damage results derived with SSM2015 are dominated by damage to businesses. The damage to residences has decreased significantly due to the application of the new method, while the damage to businesses has increased a lot. The changes in the other damage categories are also significant, but these have less influence on the total damage. Damage to infrastructures has decreased with about 50%, damage to land use types (urban area mainly) has slightly decreased and damage to other categories has increased.

*Table 8.1 Damage for Dordrecht (water depth map based on flood simulations (see chapter 1.4) calculated with HIS-SSM and SSM2015 both for a price level of 2011. The results of HIS-SSM for price level of 2000 have been corrected with a factor of 1.4 to take into account both inflation and economic growth**

		Physical damage	Business interruption+indirect	Total
Businesses	HIS-SSM	536	148	684
	SSM2015	1109	906	2015
Residences	HIS-SSM	4976	0	4976
	SSM2015	2418	444	2862
Infrastructure	HIS-SSM	200	1	201
	SSM2015	90	0	90
Land uses	HIS-SSM	741	8	749
	SSM2015	619	0	619
Other	HIS-SSM	147	0	147
	SSM2015	320	0	320
Total	HIS-SSM	6600	157	6757
	SSM2015	4557	1350	5907

*If one would be interested in the effect of the new data, only inflation should be taken into account and a correction factor of 1.22 would have to be used. This was done in chapter 4-7.

8.1.2 Effect of changes on the damage calculation for the Netherlands as a whole

The proposed method is also applied to a national water depth map (see figure 8.1). This map is based on the combined water depth maps of many possible simulated flood events related to breaches in the primary defences at design conditions (The WV21 flood simulations). For each hectare the maximum water depth found in any of those events is taken. To be able to compare the results of HIS-SSM and SSM2015 they were harmonized with respect to price level and economic growth by multiplying the HIS-SSM results of reference year 2000 with a factor 1.4 (1.22 for inflation and 1.18 for economic growth). Table 8.3 provides the result.

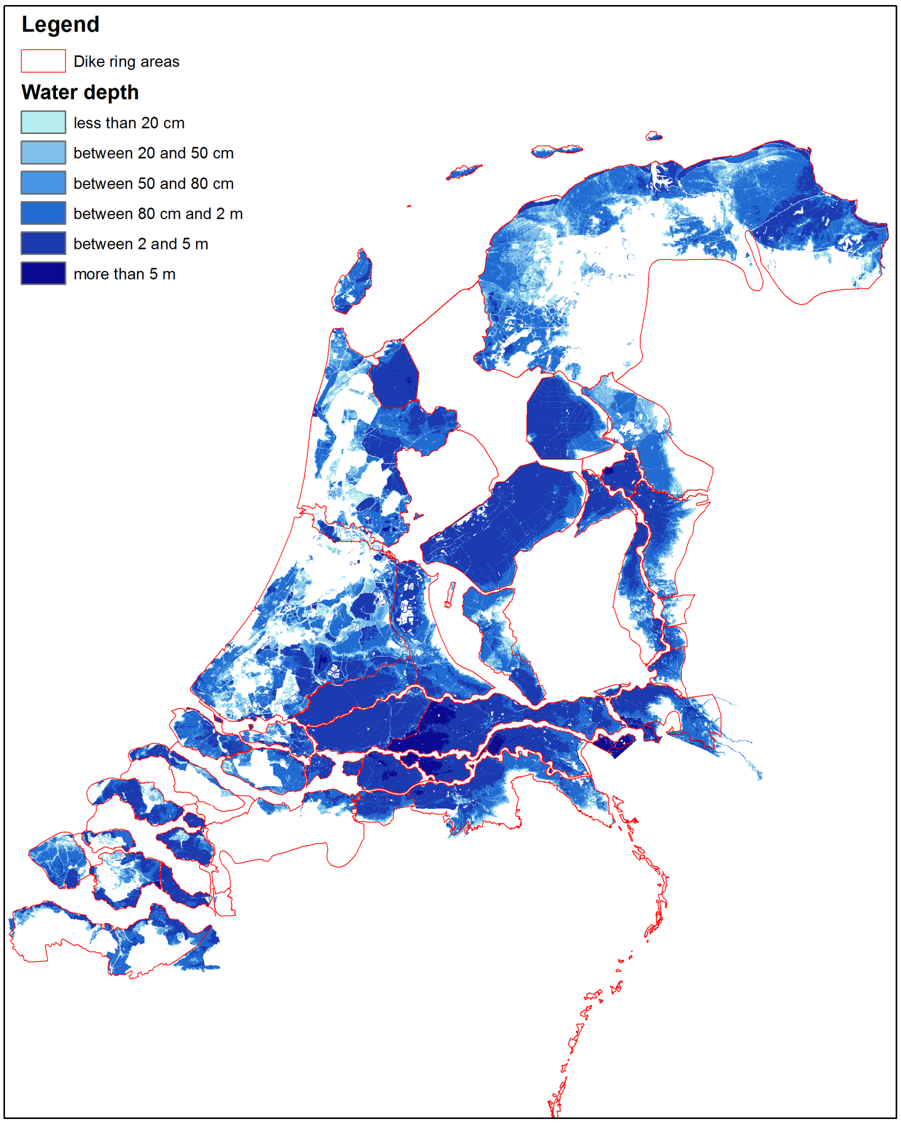


Figure 8.1 National maximum water depth map corresponding with floods caused by breaches in the primary defences at design conditions

Table 8.2 Resulting total damages for national flood maps using HIS-SSM (in Million €), corrected to year 2011 (with a factor of 1.4 for economic growth and inflation, see annex C) and with SSM2015

Category	Type of damage	HIS-SSM		SSM2015		
		Damage (M€)	% of total damage	Damage (M€)	% of total damage	Dif (%)
Businesses	Physical	44915	12	111793	25	149
	Business interruption	9639	3	88522	20	688
	Indirect	1594	0.4			
	Subtotal	56149	**15**	200315	**45**	257
Residences	Physical	220596	59	136940	31	-38
	Indirect	-	-	20891	5	-
	Subtotal	220596	**59**	157831	**36**	-28
Infrastructure	Physical	17753	5	14605	3	-18
	Business interruption	51	0	-	-	-
	Subtotal	17804	**5**	14605	**3**	-18
Land uses	Physical	67122	18	53360	12	-21
	Business interruption	134	0	-	-	-
	Indirect	4287	1	-	-	-
	Subtotal	71542	**19**	53360	**12**	-25
Other	Physical	8090	2	17110	4	111
Sum of all categories	Physical	358476	96	333808	75	-7
	Business interruption	9824	3	109413	25	597
	Indirect	5881	2			
	Total	374182	100	443222	100	18

Results

Table 8.3 provide the resulting damages for the water depth map shown in figure 8.1.

- Total damage for the realistic national water depth map calculated with SSM2015 is about 20% higher than the damage assessed with HIS-SSM;
- The distribution of the damage over the categories changes significantly. The damage to residences reduces with about 30%, while the damage to businesses increases with about a factor 3. Especially the damage due to business interruption increases enormously. The new distribution corresponds better with recent flood events.
- The physical damage to residences and infrastructure decreases significantly; this is mainly attributed to better localization of residences and the decrease in maximal damage of railroads. Furthermore, urban roads were taken out of the infrastructure damage, since those were also taken into account in the category ‘urban area’.

The contribution of the categories businesses and land use types to the total damage depends on the water depth. In HIS-SSM the contribution of business damage to the total damage is large when water depths are high. In SSM2015, the contribution of damage to businesses and land use types to the total damage is larger for low water depths, and smaller at very extreme water depths.

8.2 Completeness

What is included
The proposed changes result in a SSM2015 model which takes into account direct material damage and damage due to business interruption both inside and outside the flooded area. These damage types are assessed quantitatively: both the number of units (m^2/houses/cars) are counted and the damage in euros is assessed.

The module also assesses the impacts to people in a non-monetary form. It quantifies:
- The number of affected persons defined as people living in the flooded area.
- The mortality: the probability to die due to the flooding for someone present at the moment of the flooding. The mortality functions were not changed, although amongst others De Bruijn & Slager (2013) and Kolen et al. (2014) recommended to improve them and made suggestions on directions for improvement.
- The number of fatalities: This number is obtained by multiplying the number of inhabitants by the mortality rate.

It is proposed to also identify special objects and protected area in the output. This identification may be used to assess indirect or environmental damage outside the SSM2015 model. For this purpose chemical installations and protected areas as available at the 'risicokaart.nl' list made for the EU Flood Directive are identified and mapped by SSM2015.

What is excluded
SSM2015 does not assess in monetary terms:
- Damage to flood defences;
- The damage outside the flooded area due to damage to critical infrastructure;
- Societal disruption, stress, emotional damage, potential costs due to image loss, damage to monuments, damage to ecosystems;
- Costs for evacuation;
- Costs for cleaning and demolition of damaged objects after the flooding;
- Damage related to wounded people.

8.3 Applicability of the proposed method

Large scale floods in protected areas
The method is developed to assess damages due to large scale floods in protected areas in the Netherlands. Due to the improvements proposed, now the method is not only able to produce average figures for large areas, but also realistic flood damage maps with a 25 to 100m cell size.

Unprotected flood plains
For flooding in non-protected floodplains the proposed method cannot be used directly. However, with some small adaptations the method could be used for those areas as well, as was tested and explained in Slager et al. (2013). Adaptations need to be made because floods in the unprotected floodplains differ and since the land use and objects in those areas differ. The most important difference in flood type are:
- In the tidal river area, floods last only a few hours to days (in the upper river area, they may last longer, up to weeks).
- The floods usually occur due to overtopping. They are easier to predict and occur more gradually.

Since floods last shorter, business interruption will be less relevant and damage will be less.

The most important difference in objects and land use types are:

- Nature areas usually flood very frequently (up to twice a day) and are adapted to or even dependent on these floods. They are thus not vulnerable to flooding.
- Recreation and agriculture are usually adapted to the flood probability: no valuable buildings, machines, and objects are placed in low-lying areas. Agriculture is usually extensive only.
- Urban areas should not include construction areas, since these may be areas where they construct ‘new nature’ or ‘restore nature’ which have much lower maximum damage values. Construction sites should be excluded from the dataset.
- Houses are often raised, or have a raised ground floor and in some areas people have experience with local flood emergency measures and can effectively protect their property themselves. In the protected areas, such experience is lacking and often potential water depths are much higher, which hampers efficient local flood emergency measures.
- Height differences are relatively large: there are local defences, raised areas, mounds, natural higher areas and so on. Objects are generally based on the higher parts in the floodplains. Using average water depths over a hectare (100m grid cells) or 625m^2 (25m cells) may result in an overestimation of the damage, especially if objects are not flooded at all in reality, but appear to be flooded if the average water depth is used.

These differences can be taken into account by:

- Using a different maximum damage for agriculture, nature and recreation in the unprotected areas;
- Neglecting damage due to business interruption (this must be refined in areas with important industries in flood-prone areas);
- Making accurate flood depth maps on a 5m scale, and assessing damage on a 5m scale. To avoid privacy issues and a false sense of accuracy results may be presented on a 25m scale.

These suggestions were successfully tested by Slager et al. (2013). We propose to include those changes in the SSM2015 tool itself, by assigning a separate land use class to ‘agriculture in unprotected areas’, ‘recreation in unprotected areas’ and so on with appropriate damage functions and maximum damage values. SSM2015 would then accurately calculate damage both for protected and for unprotected areas.

Floods from regional waterways

Regional floods due to breaches in flood defences along rivers or canals may be similar to large-scale floods. If flood depths and durations are comparable to large-scale floods, the SSM2015 could be used. If, however, duration would generally be much shorter, or the flood would be very local and damage could not be assessed on a 25m scale, then adaptations of the SSM2015 would be necessary. In the past, HIS-SSM was applied to assess damages due to breaches in defences along regional waterways. (STOWA advised to use HIS-SSM). It is recommended to discuss whether SSM2015 must be applicable to this kind of floods, and if so, what is done best to make it applicable. At the moment the experimental tool with SSM2015 may be used for this kind of floods. The user can then select SSM2015 functions, functions for the unprotected areas, functions from the damage function library or adapt existing functions.

Floods due to intensive rainfall or drainage problems

Intensive rainfall or drainage problems may cause the presence of water in the streets, in agricultural fields or in low-lying parts of roads, tunnels and so on. SSM2015 is not useful to assess damage related to these problems. These problems are very local, last ‘only’ several hours and water depths are generally less than 30 cm. They require a different approach. The ‘waterschadeschatter’ of Nelen & Schuurmans may be used to assess damages corresponding with drainage problems.

Floods outside the Netherlands

The tool contains data for the Netherlands. The experimental tool made to test the improvements for 2015 can very easily be used for damage assessments outside the Netherlands. The user should provide a flood scenario, data on what is present (land use map, or object data) and he/she may choose functions from the damage function library or use his own damage functions. The tool will then assess damage to the defined categories and produce tables and damage maps.

Future damages

To assess future damages, two approaches can be followed:

1. One could try to get information on how the future could look like and produce future land use map or even future object data. Corresponding damages could then be assessed in the same way as for areas outside the Netherlands. One could use, for example the land use map resulting from the Landuse scanner and the damage functions of the damagescanner which fit to those land use maps (Klijn et al., 2012).This can be done with the experimental version of SSM2015.
2. Since the future is uncertain, it is also possible to add a factor for economic growth and population growth to the outputs of SSM2015 as calculated for the current situation. This approach was followed in the WV21 project (Kind, 2011).

8.4 Uncertainties in the outcomes

8.4.1 Theory of uncertainties

Uncertainty types in SSM2015

The results of SSM2015 are considered to be the best available results for large scale flood damage modelling available in the Netherlands. However, users must be aware that they are uncertain. Uncertainty in the damage, given a certain flood event[18], arises from both:

1. *Variability* in damage between different objects *within* one category (aleatory uncertainty);
2. Uncertainty in the category damage values and damage functions *of one category* (are they right for the average object within the category, or are they too high or too low) (epistemic uncertainty).

Due to the variability in objects within one category, damages of some objects will be overestimated, while damage of others may be underestimated. The categories are not homogeneous: Residences, for example may be of good quality or occasionally, they may consist of single brick walls. Stores may have one or multiple floors, and restaurants may be beach houses on poles, fastfood restaurants or very luxury restaurants. These differences within one category are not taken into account in the damage assessment. If the maximum damage value and damage function would be perfectly known and a flooding would affect many objects, then the calculated damage would be accurate. Over- and underestimations due to variability within a category are then compensated by each other. For small scale floods in which only a few objects are affected, errors due to this type of variability will be most relevant.

The uncertainty within the maximum damage figure and damage function of a category may result in an overestimation or underestimation of the damage of all objects within that category. This error will not become smaller when more objects are flooded. *Epistemic uncertainty* contributes most to this uncertainty. Epistemic uncertainty is the lack of understanding of a system and can in theory be reduced by further study or by collecting more or better data (Wagenaar et al., 2016). The epistemic uncertainty as stated above is not reduced when many objects are flooded. Therefore, it is the dominant uncertainty type for large flood events.

Contributions to uncertainty in SSM2015 outcomes are:

1. *Uncertainty in spatial data which is used as input: such as uncertainty on* where exactly objects are located and on what level (or floor).
2. *Uncertainty in the maximum damage e.g.* due to
   - Uncertainty on the part of the total value which *is susceptible to flooding***:** This uncertainty is relevant for the damage to businesses, residences, agriculture and recreation.
   - *Uncertainty on the duration of recovery and the success of substitution*: This uncertainty is mainly relevant for damage to businesses. The duration of business interruption influences the total damage significantly and is difficult to assess. It depends amongst others on the size and characteristics of the affected area, the economic situation (is it easy to find alternative temporary space for continuation of

[18] The flood event characteristics: water depth, flow velocity, water level rise rate may also be uncertain. This section discusses, however, uncertainties in the damage corresponding with the provided flood information.

offices, schools, etc.), the damage to utility services and transport infrastructure and the repair time of those utility and transport infrastructure.

3 Uncertainty in the damage functions due to:
- *Contribution of implicitly incorporated hazard factors*: Although water depth is explicitly incorporated in the analysis, some other relevant hazard related factors are not (see chapter 3). These factors will differ from location to location and per flood event. They may cause damage differences and thus uncertainties in the damage estimates. Examples are the moment of the flooding (autumn/winter/spring), duration of the flooding, the presence of storm (and waves), temperature (freezing during the flooding will for example increase damage), water quality, etc.
- *Shortage of data:* This is relevant to all damage categories. The damage functions are based on limited sets of data and expert judgements and are thus uncertain.

These contributions will be discussed subsequently below.

Uncertainty in spatial data

The application of spatial information and GIS can be seen as a major improvement in flood damage modelling. The use of spatial information for flood related damage assessments became popular after the first GIS datasets on land-use and buildings were available in the early 1990's such as TOP10-NL within the frame of the BRT (Basisregistratie Topografie in the Netherlands). However, they contribute to uncertainty in the damage outcome for three reasons. Firstly, information provided in most GIS data sets dates back up to two years, as there is a time-consuming workflow from the collection of the data to the release of a new dataset. For example, the TOP10 dataset contains at present[19] for more than half of the Netherlands data of at least two years old, about 25% are from the previous year and another 25% have been updated in 2014. It is reasonable to assume that the age of the BAG dataset, for example, is in the same order of magnitude.

Secondly, all spatial data is afflicted with digitisation errors, mistakes in assigning the correct attributes and so forth. Numbers on the accuracy of individual maps are difficult to find. TOP10 published a quality map[20] (BRT Kwaliteitskaart: TOP10NL), where they state about 69% of all 715 map sheets in the Netherlands to be more than 95% correct, while the remaining 31% of the map sheets do not meet this accuracy criteria. As in the Netherlands information from the BAG are provided and managed by local authorities, it can be assumed that the classification of features is not fully consistent over the whole country. For example, it has been found that features often have meaningless attributes (such as -9999), if the information was presumably not known.

Thirdly, the elevation of objects and residences is not always directly available in spatial data. In SSM2015 the number of floors is derived from the BAG which introduces some uncertainty and assumptions are made on the distribution of value over the different floors in buildings.

This first limitation (timeliness) might be less relevant in the future, as several databases for geographical data are already provided online or at least planned to be published online in

---

[19] *Status: October 2014, for reference see: http://www.kadaster.nl/web/artikel/productartikel/TOP10NL.htm#Documenten*

[20] *Check http://www.kadaster.nl/web/file?uuid=ebda61f0-10d9-42bf-b9c7-7a5e3a8ba16b&owner=23cbe925-35ce-4a72-ac8c-a33a0c19ae1e&contentid=12722 for the original source*

the near future. Accessing this information via web feature services (WFS) will enable the use of the latest datasets for damage modelling. The WFS service of the BAG database, which can be accessed online via the National Georegister was announced to be updated on a daily basis since April 2014[21]. Using datasets such as the BAG via WFS in the future will therefore ensure that the latest dataset is used for damage analysis. However, as this error can be evaluated to be small compared to the accuracy of spatial data, using an offline dataset is favoured, as the pre-processing of the data (e.g. replace incorrect attributes) has to be done only once.

The second limitation (accuracy) is however more relevant and the error can be only reduced by pre-processing and verification procedures, e.g. identifying incorrect attributes of features. Within this context, an aspect to be mentioned is the mismatch between spatial information and their location in reality. Furthermore, the function of buildings could be unclear, which could also result in inaccuracies. In some cases, it is unclear if a canteen in a sports building should be classified as horeca, or as a sports building. Hence, the classification of buildings can be named as an additional source of uncertainty.

Uncertainty in maximum damage

The uncertainty in the maximum damage figure can be divided into two parts: The uncertainty in the value of the object and in the part of that value that is susceptible to flood damage. In SSM2015 the maximum damage value of residences and businesses is derived from economic data (CBS) which provides a total value per sector of all physical assets in the economy. To obtain a maximum damage figure per unit, this total value can be divided by the number of units within that sector. Next, the part of this total value which is susceptible to flooding must be identified. The strength of this method is that the mean object value will be accurate. However, uncertainty is still present in the part of the object that is susceptible to flood damage.

For businesses the uncertainty in damage related to business interruption is very relevant. Interruption damages are often assessed using economic models such as General Equilibrium Models (GEM), Input-Output (IO) models or the recently developed Adaptive Regional Input Output (ARIO) models. It is aimed at modelling the behaviour of economic systems in case of perturbations such as the impact of natural events on the economy. Such models assume that demand and supply are in balance. In case of a flood event, both demand and supply change for particular sectors, where the lost added value to the economy is seen as the business interruption. The use of these models for assessing damages due to business interruption is being discussed. It may be concluded from literature that the extent of business interruption is very uncertain, case specific and depends on the state of the economy and thus changes in time.

Uncertainty in damage functions

Flood damage data is rarely collected in a systematic way (Thieken et al., 2005), and not always available for research. When it is available it is often limited to a single or a few events. These events are often not representative for other types of floods or other countries or areas. Cultural or geographical differences can cause the use of different building or interior materials between regions and affected by events, making one dataset not applicable to other areas. Another problem is that data is often limited to certain ranges of a flood parameter. For example, data may be only available for low water depths or the flood that

[21] See https://www.pdok.nl/nl/actueel/nieuws/artikel/29apr14-bag-services-vanaf-nu-dagelijks-ververst

was the source of the data may have coincided with a storm. In such cases the data cannot be used for events with larger water depths or no storm.

In general, transferring data from one event to another is error-prone. This makes it very difficult to apply knowledge derived from one event to another. Even when the data is applied to the same area as the data was taken from, problems may arise. Different flood events in the same area may lead to very different damages due to different human responses. For example, the same area in the Netherlands flooded in 1993 and 1995 with approximately the same water levels. The second time the damage to housing content was about 80% less (Wind et al., 1999). Also the damages due to Rhine floods of 1995 were less than half of the damages that occurred in 1993, as a result of precaution measures taken by households (Bubeck et al., 2012). This shows the sensitivity of flood damage to other factors than water depth. These other factors (in this case flood experience) are often neglected in the recordings. This example shows that a dataset based on a small number of events does not capture all possible variable values.

Damage data can also be combined with expert knowledge. A common problem in constructing damage functions is that it is difficult to include the large number of parameters that may influence the flood damage. The parameters that are not used are implicitly considered. Each flood damage model based on a limited number of parameters is therefore making assumptions on the effect of the non-explicitly considered parameters. Those non-considered parameters have been very significant in a subset of flood events. For example, in the 2002 Elbe floods contamination was critical (Thieken and Muller, 2005), in the Meuse floods flood experience was critical (Wind et al., 1999) and in the 1945 floods in the Wieringermeerpolder in the Netherlands the waves in the flood water were critical (Duiser, 1982). This last example is complicated by a study of Roos (2003) who showed that the findings of the 1945 Wieringermeerpolder flood are not valid for modern buildings. So also the construction year/type of a building can in some cases be a critical parameter. Other possibly significant parameters are, for example: Building style, flow velocity, flood duration, warning time and preparation.

Parameters that are not used can have a correlation with parameters that are used. For example, the water depth is correlated with the flood duration for floods in the Netherlands (Duiser, 1982; Wagenaar, 2012). Because of this correlation, the uncertainty caused by not knowing the flood duration is limited in the Netherlands. This relationship between two parameters may, however, be completely different for other types of floods (e.g. flash floods). A generally applicable flood damage model therefore still needs all parameters.

Quantifying uncertainty

Although the most important factors contributing to uncertainty can easily be identified, it is very difficult to put a quantitative indication of the uncertainty and the accuracy of damage outcomes. Wagenaar et al. (2016) compared internationally used damage functions and did a probabilistic flood damage analysis to obtain estimates of the effect of uncertainties in damage functions on damage estimates. De Moel *et al* (2012) and Merz *et al*. (2004), Egovoa *et al.* (2008), Gauderis et al. (2013) also studied uncertainties and their effect on flood damage estimates by forward uncertainty propagation models (mostly with Monte Carlo simulations). Their results have been used in this section.

Relative importance of damage uncertainties
Uncertainty in flood damage estimation is long believed to be insignificant compared to other uncertainties in the risk based approach (i.e. flood probabilities and flood patterns). This seemed to be confirmed by Egorova et al. (2007), who made an uncertainty estimate for the direct damages in HIS-SSM using a Monte Carlo analysis. They showed that the uncertainty in damage was only in the order of +/- 20%. This view of a limited uncertainty started to change when flood damage models from different countries were compared. De Moel and Aerts (2011) found large differences between damage functions from different countries. Jongman et al. (2012) applied 7 different flood damage models to two real events in a large European wide cooperation of researchers on this topic. They found very large differences between the models and the recorded damages (differences in the order of a factor 2-10). Chatterton et al. (2014) repeated this experiment and found the same type of differences in a comparison of two UK models (both not included in the other study). De Moel et al. (2014) took these new insights into account in a general uncertainty analysis for the risk based approach. The conclusion was that the uncertainty in flood damage estimation is in the same order of magnitude as the uncertainty in other elements of the risk based approach (i.e. flood probabilities and flood patterns).

All studies mentioned above only looked at the uncertainty in the damage functions and maximum damages for the direct physical damage calculation. However, the uncertainty in other damage types may even be larger. Damages related to business interruption for example, are difficult to estimate and very case specific and therefore the outcome of a general method to assess this type of damage will provide uncertain outcomes.

Uncertainty estimates are important in the communication of model results. Uncertainty estimates can be guidelines on how to use a model and can be used for sensitivity analyses. USACE (1992) and Peterman and Anderson (1999) both showed that communicating uncertainty estimates leads to different decisions. For SSM2015 the uncertainty estimates are intended to be used as indications of the accuracy of the outcome or for sensitivity analyses.

8.4.2 Proposal for SSM2015

It is recommended to do an uncertainty analysis for the outcomes of 2015 and to add a method, indication of accuracy, or concrete suggestions to assess this accuracy in the SSM2015 tool.

The aim of the uncertainty quantification for SSM2015 is to make a rough estimate of the uncertainty with minimal calculation time requirements. A method was developed which first analyses uncertainty in the physical damage, then uncertainty in the damage due to business interruption and finally, uncertainty in the total damage including both damage types.

8.4.3 Proposal for quantification of the uncertainty in the physical damage

The quantification of the uncertainty in physical damage is done using a simple formula which was derived from the results of an analysis of all VNK2 flood scenarios with an advanced uncertainty propagation model (Wagenaar et al., 2016).

The results of the advanced model show that the uncertainty in the damage depends on 3 parameters: median water depth in the flooded area, the variation in the water depth in the area and the total damage in the area. Regression analysis was used to find a relationship between the uncertainty in the physical damage and these three parameters:

The formula is:

$$CV = MAX\,(0.25, 4.26 - 0.2{D_{Ph}}^{0.11} - 3.17{wd_{md}}^{0.036} - 0.09wd_{Std}) \quad \text{[Eq. 8.1]}$$

$$CV = \frac{\sigma}{D_{dph}}$$

- CV = Coefficient of variation [-], indicator for the uncertainty in the physical damage (equal to the Standard Deviation of the damage divided by the average damage).
- D_{ph} = Physical damage [M€]
- wd_{md} = Median water depth in the flooded area [m]
- wd_{Std} = Standard Deviatian of the water depth in the flooded area [m]
- σ = Standard deviation of the damage [M€]

The fit of this formula to the data is good (R^2= 0.71).

SSM2015 uses this formula to calculate the CV and then uses this CV to translate the uncertainty to a lognormal distribution to calculate the 95% range in which the damage outcome is expected to be. Examples of the outcomes are provided in table 8.4 below.

Table 8.3 Impression of the different uncertainty band widths for different flood extents

	Small flooding	Average flooding	Large flooding
Median water depth (m)	0.15	1.3	3
CV	1.10	0.53	0.3
Damage (M EUR)	1	3000	18 000
Low estimate (M EUR)	0.2	996	11 000
High estimate (M EUR)	2.9	7040	29 000
Difference low - average	-80%	-66%	-40%
Difference high- average	+190%	+135%	+60%
High estimate / low estimate	14.5	7.1	2.6

An overview of the method to derive the simple formula is provided in figure 8.2.

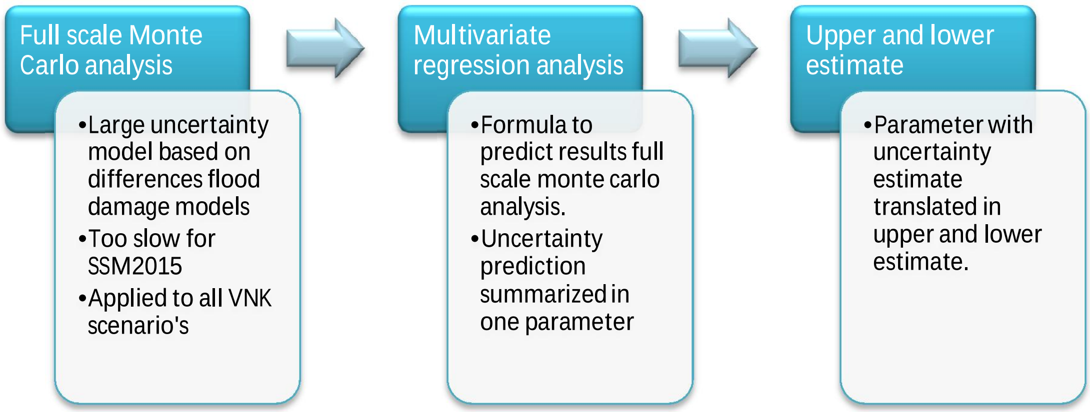


Figure 8.2 Overview of uncertainty estimation procedure developed for SSM2015

Summary of the advanced method
The equation 8.1 was derived from the results of the advanced model of Wagenaar et al. (2016) which quantifies the uncertainty in the outcomes of a flood damage model for residences and businesses, the two most important damage categories. To do so Wagenaar et al. (2016) used a damage function library with 273 functions from 6 damage models (see figure 8.3) and carried out a Monte Carlo analysis. The damage models are all developed for situations which are comparable with Dutch situations. They are not developed for damage assessment of flash floods or for developing countries, but cover Dutch, American, German and English models for river and coastal floods.

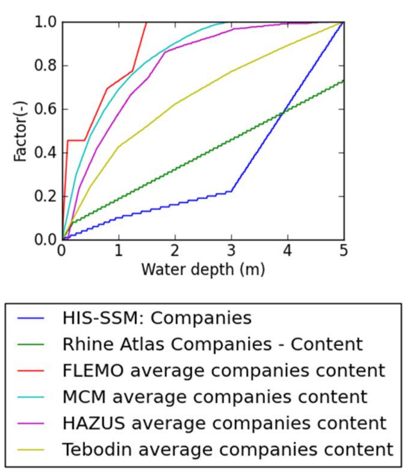


Figure 8.3 The 6 model damage functions applied in the Monte Carlo analysis for content in the companies category.

The Monte Carlo Analysis enabled them to include both epistemic and aleatory uncertainties in the uncertainty analysis. Figure 8.4 provides a schematic overview of the advanced method. They carried out the following steps:

1. They sample one of the 6 damage modules in the library
2. They sample for each group of objects in the area a damage fraction and maximum damage given the uncertainty around the damage function in the model.

They repeat the first two steps 1000 times to obtain 1000 damage outcomes for the same water depth grid. The 1000 outcomes together provide an indication of the uncertainty in the damage outcome. It was confirmed that the uncertainty outcome converged to a value for 1000 samples and thus that this number was sufficient for a good uncertainty indication. A detailed description of the method is found in the paper Wagenaar et al. (2016) which is included in annex D of this report

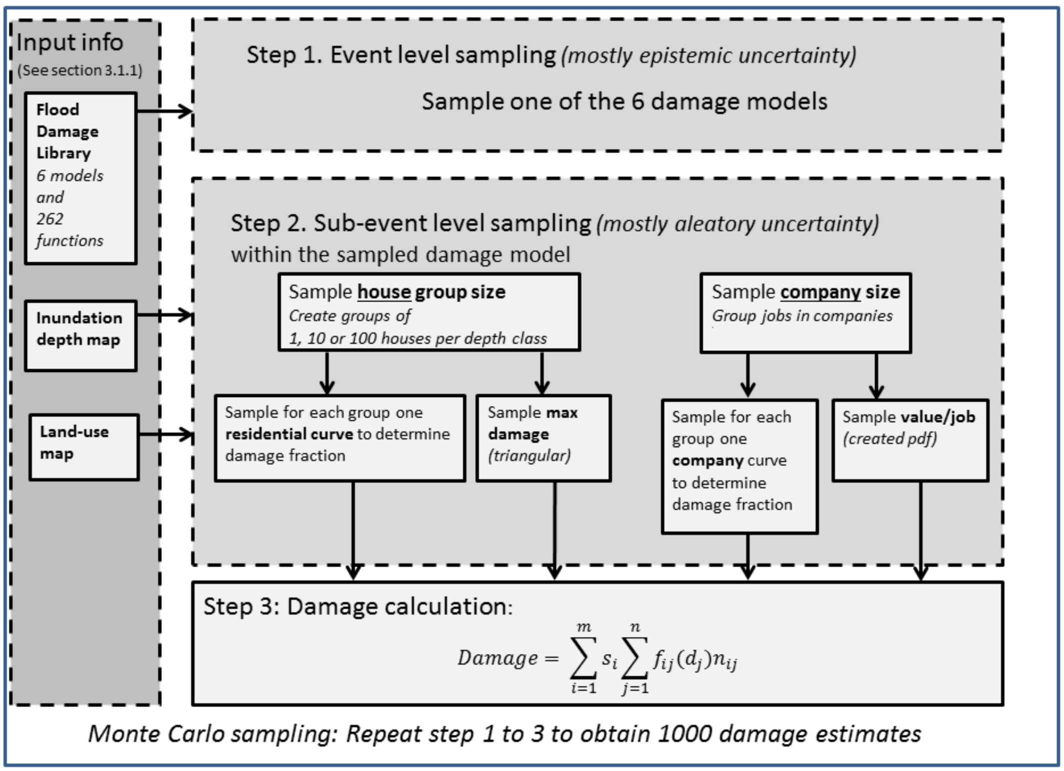


Figure 8.4 Overview of the advanced method to assess uncertainties in damage models (Wagenaar et al., 2016)

Derivation of Equation 8.1 from the results of the advanced model
This Monte Carlo analysis model is too slow to give instant feedback. Therefore, equation 8.1 was derived by regression analysis which calculates uncertainty expressed by one single number: the coefficient of variation (CV). This CV is defined as the standard deviation of the damage divided by the mean of the damage (and thus has no unit). To obtain the CV the following three steps were carried out:

Step 1: The full Monte Carlo analysis was applied to all VNK scenarios
The full Monte Carlo analysis was applied to all the available VNK scenarios. For each scenario the CV, mean water depth, median water depth, standard deviation water depth, total damage and the size of the area flooded was recorded.

Step 2: Derive equation 8.1.
A multivariate regression algorithm was applied to find a formula to estimate the CV given the recorded parameters. This resulted in equation 8.1. This formula has a fit (R^2) with the CV calculations of the VNK scenarios of 0.71.

This prediction formula is least accurate for scenarios with relatively large damages. These are rare among the VNK scenarios and therefore they had too little weight in the regression algorithm. To solve this we looked at the results of the full Monte Carlo analysis. Since in that analysis no CVs below 0.25 were found, we put the minimum CV value for which the formula is valid at 0.25. If the formula results in CV values below 0.25 the CV is set at 0.25. To avoid the same problem with very small damages some very small VNK scenario's received extra weight in the regression analysis. In the future this regression analysis may need to be repeated including scenario's from floods of local waterways to make a slight improvement to the formula.

Step 3: Translate the CV value into an indicative uncertainty band
The CV parameter which indicates the uncertainty needs to be converted into a lower and upper estimate. This is done by assuming a lognormal probability distribution: a normal distribution that cannot take on negative values. With the CV and the mean damage (the deterministic result) it is possible to draw this lognormal distribution. For small uncertainties the distribution will look like a normal distribution, for uncertainties so large that the damage could go negative the normal distribution will deform and skew positively. Based on a 95% confidence interval within this assumed distribution an upper and lower bandwidth value will be estimated. Note that the 95% confidence interval estimate is based on several assumptions and is therefore a rough estimate only.

The lognormal distribution was chosen because it is the standard distribution that resembles the outcomes of the full Monte Carlo analysis best. However, the multiple peaks in the frequency distribution found by applying the advanced method are not represented well by this distribution. Figure 8.5 shows a uniform distribution and some lognormal distributions.

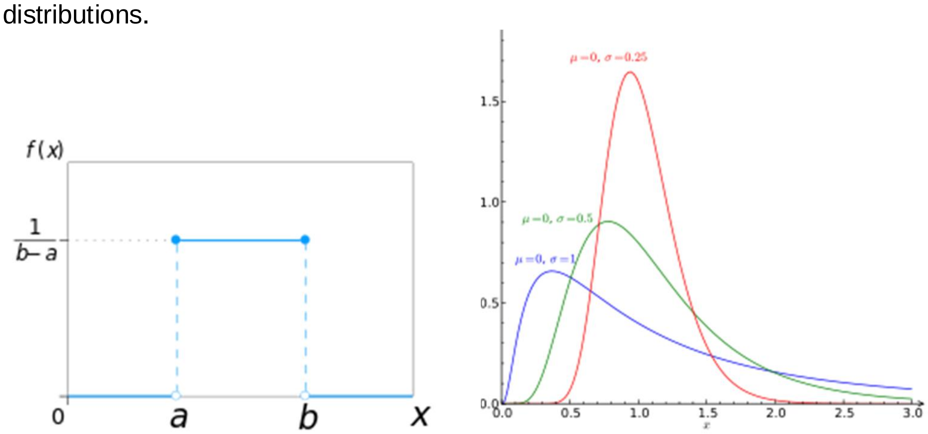


Figure 8.5 Left a picture of a uniform distribution and right a picture of 3 lognormal distributions with different amounts of uncertainty but the same mean (blue most uncertain, red least).

8.4.4 Proposal for quantification of uncertainty in business interruption

The quantification of the uncertainty in business interruption damage for a particular flood event is relatively difficult, as the individual flood characteristics as well as the scale of the flooding have a significant impact on the business interruption effects. A full assessment would require an economic model such as an input-output model. As long as such a model is not implemented in SSM2015, the uncertainty should be indicated by the range of ratios between direct and business interruption damages observed in previous flood events.

To assess the uncertainty in the business interruption damage a distribution function was used which indicates the business interruption damage as percentage of the physical damage (see figure 8.6). This distribution is a lognormal distribution with as average the percentage business interruption that came from the deterministic calculation and as standard deviation 15%. The standard deviation and shape of the distribution are based on expert judgement and international observations on flood damage related to business interruption (see chapter 4). A sensitivity analyses has shown that the uncertainty in the total damage calculation is not very sensitive to either the choice of standard deviation or the choice of distribution.

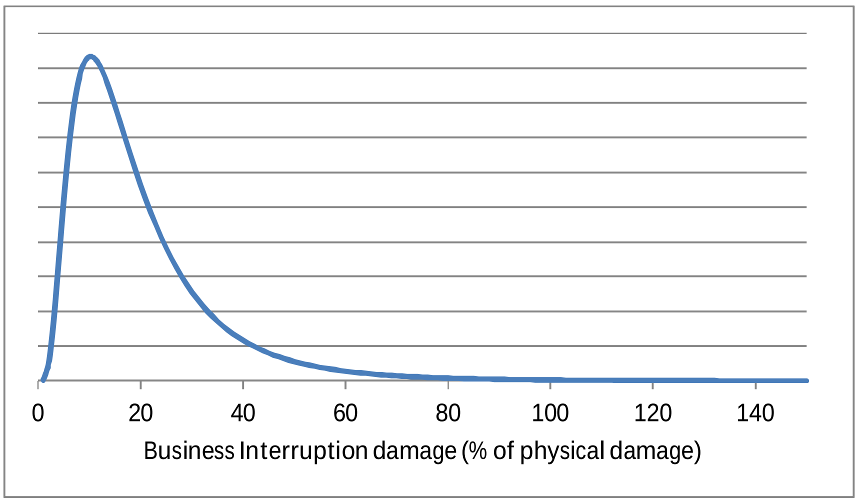


Figure 8.6 Distribution of the business interruption damage.

8.4.5 Combining uncertainties in physical damage and damage due to business interruption

The uncertainty from direct physical damage and business interruption damage cannot be simply added, since they may compensate eachother. Therefore a quick Monte Carlo analysis will be done to add those uncertainties. In this Monte Carlo analysis the total damage will be calculated 4000 times for different direct physical and business interruption damage samples. The business interruption damage in this analysis is sampled as a fraction of the direct physical damage. In that way a high direct damage will always have a relatively high absolute business interruption damage and vice versa. This operation can be done within 0.1 – 1s, including the direct damage calculation. It will therefore not slow down the total runtime of SSM2015.

SSM2015 would then produce 9 resulting values. This is: A low, expected and high value for the direct damage, the business interruption damage and the total value. A result could then look like shown in table 5. Note that the low and high estimate for the total damage is smaller than the sum of the low direct and business interruption estimate.

Table 8.4 Example of possible results of the uncertainty analysis

In (M€)	Low	Expected	High
Direct damage	72	250	635
Business interruption damage	4	125	433
Total damage	96	375	976

8.4.6 Conclusions and recommendations

Even though SSM2015 is based on the latest insights and data, a lot of uncertainty remains. Here, a method is proposed to quantify this uncertainty for the direct damage and the business interruption. The uncertainty in the physical damage is estimated based on the outcomes of an advanced uncertainty propagation model (Wagenaar et al.,2016). The uncertainty in the business interruption damage is quantified based on the bandwidth of international observations combined with expert judgement. The uncertainty due to the direct damage and the business interruption are combined into one uncertainty estimate (the CV) which is translated into a low and a high damage estimate which help users of the damage model SSM2015 to get a sense of the accuracy of the provided outcome. The resulting bandwidth should be regarded a 95% confidence interval which may be used for sensitivity analyse.

The current uncertainty estimates should be seen as rough estimates or as high and low ends of the most likely range of possible outcomes. They are intended to be used to get a feeling of the accuracy of the outcome and for sensitivity analyses of decisions in which the damage outcomes are going to be used. Examples of such decisions are: decisions on the economic optimum protection level of areas, cost-benefit analyses of measures and prioritization issues of different areas or projects. For such decisions only the right order of magnitude of the uncertainty is necessary and for that the method proposed is useful.

The following recommendations are made for future research:

- For the future it is recommended to represent the uncertainty visually in a graph, instead of in numbers
- The BAG update as proposed in Slager en van der Doef (2014) could have consequences for the uncertainty of the direct damage. Especially for very small flood events this could potentially reduce the uncertainty. It is therefore recommended to change the uncertainty model as made in Wagenaar et al. (2016) to implement the BAG based on square meters building area instead of an approach based on the number of jobs.
- Future improvements uncertainty estimation: Monitor how the uncertainty analysis is applied and what the demand is for precision. Also the scientific literature should be followed as better methods may become available to estimate the uncertainty in flood damage estimation.

9 Summary & Recommendations

9.1 Summarizing conclusions

We proposed the following improvements:

- Update the data for residences, businesses, infrastructure, and land use with the data as summarized in chapter 3;
- Improve the values for maximum damages and the damage functions as proposed in chapter 4 to 7. The most important changes proposed are those for damage assessment of residences, businesses and infrastructure;
- Offer users the possibility to carry out calculations on a 25m scale and a 100m scale (instead of only at a 100m scale). For the unprotected flood plains one can also calculate on a 5 m scale.

Improvements per category

We suggest the following improvements per category:

- Damage to businesses (see chapter 4):
  - It is advised to update the data. We advised to use BAG data. This update requires the use of new business categories and thus new maximum damage values and damage functions.
  - The proposed new damage values were derived from the CBS database as explained in chapter 4.
  - The damage functions must be improved significantly, as was proposed in chapter 4. It is proposed to use different damage functions for the different business categories.
  - The calculation of damage due to business interruption should be changed: it is advised to explicitly estimate negative and positive indirect business interruption effects per sector. This is done by estimating multiplier effects and substitution factors per sector. Using this approach, SSM2015 estimates for business interruption will be in the order of the magnitude of 20% of the total damage.
- Residences (see chapter 5):
  - It is advised to update the data on residences with BAG data. This data is up-to-date and free to use. This update also provides the opportunity to improve the damage calculation of apartments: it is now possible to take into account the height of buildings and the floor at which the apartments are located. To do so, the damage functions need to be adapted as discussed in chapter 5.
  - It is advised to introduce the damage category ‘damage due to interruption of housing services’.
- Infrastructure (see chapter 6):
  - It is advised to update the data and to differentiate between main railways and small local railroads (many of which are located in industrial areas such as the Rotterdam harbours).
  - The category ‘other roads’ in urban areas was neglected since damage to these roads is also included in the damage category ‘urban area’.
  - The large bridges and tunnels which cross the main rivers and lakes were removed from the database. It was found that including those leads to unrealistic damage figures (e.g. the roads on the bridges across the Hollands Diep were placed in the Hollands Diep and thus faced a very large water depth).

- Others: The damage function of vehicles should be converted to a more realistic one (see chapter 7)
- Non-tangible identification of affected objects and areas: It is advised to identify the flooding of critical infrastructure and very vulnerable objects and areas, although it is difficult to link this to a damage figure. Damage is difficult to quantify since it is often related to indirect damage, or to ecological or cultural aspects. It is proposed that SSM2015 identifies, counts and maps the number of affected persons and the number of fatalities (as HIS-SSM did). It is also recommended that SSM2015 identifies, counts and maps flooded sections of main roads, railroads, hospitals and nursing homes, schools, IED installations and those protected areas which also need to be reported for the Flood Directive.

Furthermore, we strongly advise to make a manual and a document which describes the method, values and functions included in the tool and which refers to studies in which the method is motivated and compared with internationally used methods.

The proposed improvements were tested on Dordrecht and the Netherlands as a whole. They result in total damage values which are generally comparable with the HIS-SSM outcomes. However, the distribution over the damage categories changes significantly. The contribution of residences to the total damage decreases and the contribution of businesses increases a lot.

Applicability
The method is applicable for large scale flooding in the Netherlands. With small changes it can be made applicable for the unprotected floodplains as well. Different land use classes should be assigned to nature, recreation and agriculture in the unprotected areas and these should be linked to lower maximum damage values than comparable land use types in the protected areas. The business interruption damage of businesses and residences should also be neglected in the areas in the unprotected floodplains (Slager et al., 2013). These adaptations could be made in the standard tool of SSM2015.

SSM2015 may be applicable to floods caused by breaches of defences along regional waterways, if these result in floods which are comparable to large-scale floods. If the duration is much smaller, or depths are very small, the method must be adapted to make it applicable. The method is not applicable to drainage problems, water logging, or other very local rainfall induced events. The method of SSM2015 could be applied in foreign areas and in future situations of the Netherlands if new data would be used. This can be done in the experimental tool.

9.2 Recommendations

The most important recommendation is to implement the proposed improvements in SSM2015.

Furthermore, it is recommended to do more research on the short term for the SSM2015 on:
- The duration of business interruption and interruption of housing services.
- Assessment of the uncertainty and accuracy of the outcomes in a quantitative way.
- Furthermore, De Bruijn & Slager (2013) advise to improve the mortality functions.

On the long term the recommendations in chapters 4 to 7 should be considered. The most important recommendations are:

- For businesses:
  - reconsider the function for office buildings by including information on the height of the buildings
  - consider a more systematic method to create new damage functions,
  - study what percentage of the value of the capital goods can actually be damaged.
- For residences:
  - The maximum damage value of furnishing could be better motivated. It is relevant for the total damage. It is therefore recommended to study this value and the uncertainty in this value.
  - Study whether residences may still collapse due to large water depths and adapt the damage function according to these insights
  - The costs related to the impossibility to use residences (for the rent of alternative space) were estimated roughly. It should be studied further.
- For infrastructure:
  - The potential damage to infrastructure, especially to objects as traffic lights and information systems, should be studied further. RWS may have additional useful information to improve these estimates.
- For other categories:
  - The category ‘urban area’ should be studied better. This may be done by a case study of a certain urban area and all elements in it. Data of recent flood events in England or Eastern Europe and of ‘flooding’ in Dordrecht may also be used.
  - Damage to agriculture is not very relevant to the total damage of large-scale floods. However, for local floods this damage may be crucial. Damage assessment for agriculture may be improved by studying the rationale behind the current assessment, the recommendations of Morselt et al. (2006) and elements of the proposed method for businesses.
  - Damage to recreation may be reconsidered. The values for intensive and extensive recreation are very similar. The rationale behind them could be studied and reconsidered.

10 References

Anonymus (2002). *Inschatting extra economische landbouwschade bij overstroming met zout in plaats van met zoet water.*

Austroads (2004). *Guide to Project Evaluation — Part 4: Project Evaluation Data*, Austroads.

Bakker, D., Van der Doef, M., Van Donkelaar, J., Kind, J., Van Der Linde, G., Mourik, H., (2006). *Economische waardering van mobiliteitseffecten van een dijkdoorbraak. Quick-scan voor dijkring 36. Land van Heusden/ de Maaskant*. Rijkswaterstaat.

Billah, M. (2007). *Effectiveness of flood proofing domestic buildings*. Msc. Thesis. Dura Vermeer Business Development and UNESCO-IHE.

Briene, M., Koppert, S., Koopman, A., Verkennis A. (2002). *Financiële onderbouwing kengetallen hoogwaterschade.* NEI B.V.

Burzel, A. (2013) *Conversion of TOP10-NL information into DID datasets for HIS-SSM assessment*.interne Deltares Memo, 2013.

Cappendijk P. and van der Doef, M. (2006). *Memo: Kwaliteit van de bedrijfsgegevens in HIS-SSM.* DWW, Rijkswaterstaat, Delft.

Caresell, K., Pingel, N., Ford, D. (2004). *Quantifying the benefit of a flood warning system. Natural Hazard Review*. August 2004.

CBS (2014). *Standaard Bedrijfs Indeling 2008*, versie 2014.

Chatterton, J., Viavatenne, C., Morris, J., Penning-Rowsell, E., Tapsell, S., 2010. Delivering benefits through evidence: The costs of the summer 2007 floods in England. Environmental Agency.

Comrisk (Common Strategies for Storm Flood Risk) (2007). *Risk Assessment for the Wadden Sea, Final report Comrisk Subproject 7*, Danish Coastal Authority, Lemvig (Denmark).

CROW (2001). *Beheerkosten weginfrastructuur*. Ede.

De Bruijn, K.M. (2005). *Resilience and flood risk management . A system approach applied to lowland rivers.* PhD Thesis – Delft University of Technology, Delft.

De Bruijn, K.M., Van Der Doef, M. (2011). *Gevolgen van overstromingen – Informatie ten behoeve van het project Waterveiligheid 21^{e} eeuw*. 1204144-004 Deltares, Delft.

De Bruijn, K.M., Slager, K. (2013). *Mortality functions in the flood impact module. Sensitivity analysis and discussion*. Report 1207814-005. Deltares, Delft.

De Bruijn, K., J. Kind, K. Slager, R. van Buren en Marcel van der Doef (2012a). *Verbetering van de gevolgenbepaling van overstromingen buitendijks in de regio Rijnmond-Drechtsteden.* Report 1206053-000, Deltares, Delft.

De Bruijn, K., K. Slager, D. Wagenaar en R. van Buren (2012b). *Verbeteren schadebedragen en schadekaarten van het buitendijkse gebied van Rijnmond-Drechtsteden*. Memo, Deltares, Delft.

De Bruijn, K.M., Wagenaar, D.J., Slager, K., De Bel, M., & Burzel, A. (2014). *Updated and improved method for flood damage assessment.* Report 1207814-005, Deltares. Delft. The Netherlands.

De Moel, H., Aerts, J.C.J.H. (2011): Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. *Natural Hazards*, 58(1): pp. 407-425. doi:10.1007/s11069-010-9675-6

De Moel de, H., Asselman, N.E.M., Aerts, J.C.J.H. (2012). Uncertainty and sensitivity analysis of coastal flood damage in the west of the Netherlands. *Natural Hazards and Earth System Sciences,* 12, 1045-1058, 2012.

De Moel, H., Bouwer, L.M., Aerts, J.C.J.H. (2014): Uncertainty and sensitivity of flood risk calculations for a dike ring in the south of the Netherlands. *Science of the Total Environment*, 473-474(1), 224-234. 10.1016/j.scitotenv.2013.12.015

DNRM (Department Natural Resources and Mines) (2002*). Guidance on the Assessment of Tangible Flood Damages*. Queensland Government, Australia.

Duiser, J.A. (1982). *Een verkennend onderzoek naar methoden ter bepaling van de inundatieschade bij dijkdoorbraak*. 82-0644, TNO.

Egorova, R., van Noortwijk, J., & Holterman, S. (2008). Uncertainty in flood damage estimation. *International Journal River Basin Management*, 6(2), 139-148.

FEMA (2009). *HAZUS-MH MR4 Technical Manual*, USA.

Gauderis, J., J. Kind & R. van Duinen (2013). Robustness of economically efficient flood protection standards,Monte Carlo analysis on top of cost-benefit analysis. In: *Comprehensive Flood Risk Management* – Klijn & Schweckendiek (eds) © 2013 Taylor & Francis Group, London, ISBN 978-0-415-62144-1.

Gauderis, J. (2009). *Schade ten gevolge van productie-uitval bij overstromingen.* Discussienotitie in het kader van de KBA Waterveiligheid 21^{e} eeuw. Deltares, Delft.

Gauderis, J. (2012). *Verbetering schadebepaling buitendijkse bedrijven Rijnmond-Drechtsteden.* Discussiememo waarderingsprincipes schade bedrijven. Rebel Group.

Gauderius, J., Kind, J. (2011). *Maatschappelijke kosten-batenanalyse Waterveiligheid 21^{e} eeuw. Bijlage D: Bewerking van schade gegevens*. 1204144-006. Deltares, Delft.

Groot et al, S. (1999) *Standaardmethode Schade- en Slachtofferbepaling. Definitiestudie.* WL|Delft Hydraulics, Delft.

Guan, D. (2014): *Flood Footprint: Method and Applications*. Presentation on the BASE general assembly 2014, Delft, The Netherlands (unpublished)

Hallegatte, S. (2008): An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina. *Risk Analysis*, 28.

ICPR (2001). *Atlas of danger and potential damage due to extreme floods of the Rhine*, International Commission Protection of the Rhine, Koblenz, Germany.

Islam, K.M.N. (2000) Micro and macro-level impacts of floods in Bangladesh. In Parker, D.J.(ed.) *Floods, Volume I*, Routledge, London, UK. Pp. 156 -171

Jongman, B., Kreibich, H., Apel, H., Barredo, J.I., Bates, P.D., Feyen, L., Gericke, A., Neal, J., Aerts, J.C.J.H., Ward, P.J. 2012. Comparative flood damage model assessment: towards a European approach. *Natural Hazards and Earth System Sciences*, 12, 3733-3752, 2012.

Kind, J. (2011). *Maatschappelijke kosten-batenanalyse Waterveiligheid 21^{e} eeuw*. 1204144-006. Deltares, Delft.

Klijn, F, De Bruijn, K.M., Knoop, J. & Kwadijk, J. (2012). Assessment of the Netherlands' Flood Risk Management Policy Under Global Change. *Ambio* 2012. DOI 10.1007/s13280-011-0193-x.

Kok, M., Huizinga, H.J., Vrouwenvelder, A.C.W.M, van den Braak, W.E.W. (2005). *Standaardmethode 2005, Schade en Slachtoffers als gevolg van overstroming*. HKV, Lelystad.

Kreibich, H., Piroth, K., Seifert, I., Maiwald, H., Kunert, U., Schwarz, J., Merz, B., Thieken, A., (2009). Is flow velocity a significant parameter in flood damage modelling? *Natural Hazards and Earth System Sciences*, 9 , 1679-1692, 2009

Kreibich, H., Seifert, I., Merz, B., Thieken, A. (2010). Development of FLEMOcs – A new model for the estimation of flood losses in companies. *Hydrological Sciences Journal*, 55, 1302-1314,2010.

Lamond, J., Proverbs, M., Escarameia, M., Tagg, A., 2014. Towards improved guidelines for drying flood-damaged buildings. *Journal of Flood Risk Management* 7 (2014) 195-204

Merz, B., Kreibich, H., Thieken, A., & Schmidtke, R. (2004). Estimation of uncertainty of direct monetary flood damage to buildings. *Natural Hazards and Earth Sciences* 4: pp. 153-163. doi:10.5194/nhess-4-153-2004.

Merz, B. (2006): Hochwasserrisiken - Grenzen und Möglichkeiten der Risikoabschätzung. Stuttgart: Schweizerbart'sche Verlagsbuchhandlung. ISBN 3-510-65220-7.

Morselt, T., Engelsman, G., Lobbes, E. (2007). *Estimating cost functions for evacuation, emergency services and cleanup in case of floods.* RebelGroup.

Morselt, T., Evenhuis, E. (2006). *Review Standaardmethode Schade en Slachtoffers. Eindrapport.* Dienst Weg- en Waterbouwkunde, Rijkswaterstaat, Rebelgroup

Müller, U. (2010) Hochwasserrisikomanagement – *Theorie und Praxis* (in German). Vieweg Teubner, Germany.

NEI, 2002. Financiele onderbouwing kengetallen hoogwaterschade. Rijkswaterstaat.
Park, J.Y., Cho, J., Rose, A., 2010. Modeling a major source of economic resilience to disasters: Recapturing lost production. Natural Hazards. *Published Articles & Papers.* Paper 191.

Nijland, H., Wortelboer-van Donselaar, P.M., Korteweg, J.A.C., Snellen, D. (2010). *"Met de kennis van nu": Leren evalueren. Een casestudy A5 Verlengde Westrandweg*. Planbureau voor de Leefomgeving (PBL), Bilthoven.

NRE (Natural Resources and Environment) (2000): *Rapid Appraisal Method (RAM) for Floodplain Management.* State Government of Victoria.

NS (2001). *Jaarverslag*, Railinfrabeheer.

Parker, D.J. (2000). *Floods, Volume I*. Routledge, London, UK.

Penning-Rosewell, E., et al. (2005). *The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques*.

Peterman and Anderson (1999): Decision analysis: A method for taking uncertainties into account in risk-based decision making. *Hum. Ecol. Risk Assess. 5(2) pp.* 231-244.

Provinciale Griffie Gelderland (1973). *Berekening Inundatieschade voor de provincie Gelderland.*

Reese M., H.-J. Markau, H. Sterr (2003). *MERK (Mikroskalige Evaluation der Risiken in überflutungsgefährdeten Küstenniederungen), Abschlussbericht (in German*). Forschungs- und Technologiezentrum Westküste, Kiel, Germany.

Risicokaart (2014). www.risicokaart.nl (last seen at June 19, 2014)

Rolfe, J., Gowen, R., Kinnear, S., Flint, N., Liu, W., 2011. *Assessing the regional economic impacts of flood interruption to transport corridors in Rockhampton*. CQUniversity, Australia.

Roos, W. (2003). *Damage to buildings*. Delft Cluster, DC1-233-9. TNO-Bouw, Delft.

Seligson, H., 2008. *HAZUS: The Shake Out Scenario: Supplemental Study*. United States Geological Survey.

Slager, K., De Bruijn, K.M., Burzel, A., Bouwer, L., Wagenaar, D.J. (2013). *Verbeteringen gevolgenbepaling van overstromingen in buitendijkse gebieden Rijnmond-Drechtsteden*. Report 1208261 Deltares, Delft.

Slager K. & van der Doef, M. (2014). *Mogelijkheden BAG als geografisch bronbestand voor bedrijven*. Deltares. Memo voor SSM2015, Deltares, Delft.

SKRIBT (Schutz kritischer Brücken und Tunnel im Zuge von Straßen) (2012). *Bauwerksbezogene Objektanalyse: Tunnel* (public version, in German), Bundesministerium für Bildung und Forschung (BMBF).

Sluijs, L., Snuverink, M., van den Berg, K., Wiertz, A. (2000). *Schadecurves industrie ten gevolge van overstroming*. Tebodin.

Snuverink, M., Van Den Berg, K., & Sluijs, L. (1998). *Schade bij inundatie van buitendijkse industrie*. Tebodin.

Teulings, C.N., Koopmans, C.C. (2004). *Rendement publieke belangen. De besluitvorming bij Betuweroute en HSL-Zuid.* Onderzoek in opdracht van de 2[e] kamer.

Thieken, A., Muller, M. (2005). Flood damage and influencing factors: New insights from the August 2002 flood in Germany. *Water resources research*, Vol. 41, 2005.

Thieken, A., Olschewski, A., Kreibich, H., Kobsch, S., Merz, B. (2008). Development and evaluation of FLEMOps – a new flood loss Estimation model for the private sector. *WIT Transactions on Ecology and the Environment.* Vol 118, WIT press.

Scawthorn et al. (2006). HAZUS-MH flood loss estimation methodology II. Damage and loss assessment. *Natural Hazards Review*. May 2006.

USACE (1992): *Guidelines for risk and uncertainty analysis in water resources planning.* Fort Belvoir, VA: Institute for Water Resources 92-R-1.

Veerbeek, W., C. Zevenbergen en B. Gersonius,. (2010). *Flood risk in unembanked areas: Part C Vulnerability assessment based on direct flood damages*. Unesco-IHE.

VIF (Verkehr und Infrastruktur) (2012): *Empfehlungen zum Freibord*. Kommission für Hochwasserschutz KOHS des Schweizerischen Wasserwirtschaftsverbandes. Kanton Luzern, Bau-, Umwelt und Wirtschaftsdepartement (in German).

Vilier, J.J.T.A. 2013*. Assessment of the costs of business interruption due to large scale floods: A comparison of methods*. Master Thesis Delft University of Technology – HKV.

Vrouwenvelder, A.C.W.M., Waarts, P.H. (1994). *TAW-E Rapport Risico-Analyse*; TNO-Bouw, Delft.

Wagemaker, J.B. (2006). *Inventarisatie schadefuncties en maximale schadebedragen ten behoeve van de doorontwikkeling van HIS-SSM*. HKV lijn in water, Lelystad.

Wagenaar, D.J. (2012). *The significance of flood duration for flood damage modelling.* Master thesis, TU Delft, Delft.

Wagenaar, D.J. (2012). *Flood damage assessment in the Netherlands compared to other methods*. Report 1207183.005, Deltares, Delft.

Wagenaar D.J. (2014). *Damage Function Library*. Deltares Memo, Deltares, Delft.

Wagenaar, D.J., De Bruijn, K.M., De Moel, H. (2016) *Uncertainty in flood damage estimation: Explanations, quantification and implications. Accepted for publication in NHESS.*

Wind, H., Nierop, T., de Blois, C., de Kok, L. (1999): Analysis of flood damages from the 1993 and 1995 Meuse floods. *Water Resources Research* Vol. 35, No. 11, 3459-3465.

A Overview of categories, data and calculations in HIS-SSM

Table A1 shows the damage categories in HIS-SSM and table A2 the data sources used per category group.

The damage categories are sorted into four main categories with ascending order of attribution to total damage: businesses, residences, infrastructure and others. The table shows which damage type is calculated for each category. The damage types are (1) direct physical damage, (2) damage due to business interruption (3) and indirect damage. Next to damages HIS-SSM also assesses the number of affected persons and the number of fatalities (see De Bruijn and Slager, 2014).

Table A.1 Damage categories assessed in HIS-SSM (1 = direct physical damage, 2 = business interruption, 3 = indirect damage)

Impact categories (English)	**Schadecategorieën (Dutch)**	**1**	**2**	**3**
Businesses	Bedrijven			
Meeting facilities (pubs, hotels, churches, etc.)	Bijeenkomstlocaties (café's, kerken, etc.)	X	X	X
Offices	Kantoren	X	X	X
Health services	Gezondheidszorg	X	X	X
Industries	Industrieën	X	X	X
Education facilities	Onderwijsfaciliteiten	X	X	X
Sport facilities	Sportfaciliteiten	X	X	X
Residences	Woningen			
Low-rise buildings	Laagbouw	X	X	
Middle-range buildings	Middenbouw	X	X	
High-rise apartment buildings	Hoogbouw	X	X	
Farms	Boerderij	X	X	
Single-family houses	Eengezinswoning	X	X	
Infrastructure	Infrastructuur			
Regional roads	Autowegen	X		
Motorways	Rijkswegen	X		
Other roads	Overige wegen	X		
Railroads	Spoorwegen	X	X	
Other categories	Bodemgebruik, Overig			
Agriculture	Landbouw	X		X
Greenhouses	Glastuinbouw	X		X
Recreation intensive	Intensieve recreatie	X		
Recreation extensive	Extensieve recreatie	X		
Urban area	Stedelijk gebied	X		
Airports	Vliegvelden	X	X	
Vehicles	Voertuigen	X		
Pumping stations	Gemalen	X		
Wast water treatment plants	Zuiveringsinstallaties	X		

Table A.2 Datasources for the category groups in HIS-SSM

Id	Category (Dutch)	Source name	Format*	Unit in raster
A	Land use categories	Bestand Bodemgebruik CBS	Polygon	Surface (m^2 per cell)
B	Roads and Railroads	Nationaal wegenbestand RWS	Line	Length (m per cell)
C	Residences	Bridgis adreslocaties	Dbf	number per 6PPC*
D	Number of inhabitants	Geo-marktprofiel	Dbf	Number per 6PPC
E	Businesses	Dunn & Bradstreet	Dbf	number per 6PPC
F	Pumps & water treatment plants	WIS RWS	Point	Number per cell

* all files are converted internally to rasters with cell size of 100m; database files (dbf) are first joined to centroid locations of 6 position postcode areas;

** for residences, only the dominant housetype is used in the analysis: all residences of all residence types are summed and assigned to the house type which is most dominant in that postal code area (6 PPC)

HIS-SSM calculates flood impacts at a spatial resolution of 100m cell size. When a raster with water depths with a smaller cell size (e.g. 50 m) is used as input variable, the model first converts this input raster to a cell size of 100m. The spatial resolution is altered using a nearest neighbour interpolation resampling method. Figure A1 demonstrates this method. Centroids of the output cells (A, B, C and D) with a cell size of 100m are linked to the nearest coloured input raster dataset (cell size 50m). Information of the other input cells is neglected. Nodata values are not ignored in this process. Detailed linear features may be smoothed and distorted in the output raster dataset (see figure A1 right side)

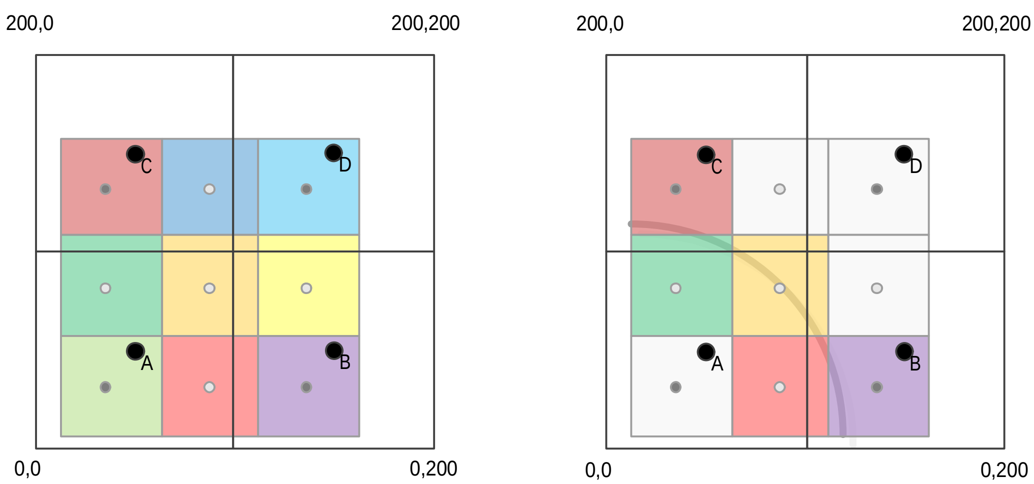


Figure 10.1 Nearest neighbour resampling (left); linear features become distorted (right)

B Damage function for businesses interruption

B.1 Need for damage function business interruption

The method to estimate the business interruption as proposed by Gauderius (2012) assumes an interruption of 1 year for all categories. This interruption duration proposed by Gauderius is independent of any flood parameter. The business interruption is, however, variable between and within flood events. It would therefore be an improvement if that variability good be captured in the flood damage model.

The water depth is already widely used in SSM2015 and is therefore the most practical parameter to use to improve the duration estimate. The duration of business interruption is related to the water depth: Larger water depths cause more damage, and therefore also a larger restoration duration. Furthermore, areas facing larger water depths typically stay wet during a longer period and therefore business interruption will be larger there.

B.2 Derivation damage function

Little information is available about the relation between business interruption duration and water depth. Duiser (1982) and Wagenaar (2012) both found a relationship between flood duration and water depth, but they did not include restoration duration in that relationship.

HAZUS has estimates of the flood duration plus restoration duration for commercial buildings for different water depths (see table B1). Because other business categories have estimates in the same order of magnitude, the estimate for commercial and government buildings may also be applied as rough estimate to all business categories of SSM2015.

Table B1 Estimates of the flood duration plus restoration duration for office buildings from HAZUS (FEMA, 2008 table 14.12). From these durations the damage function for business interruption was derived.

Water depth [m]	Flood duration plus restoration duration [month]	Fraction of longest duration (calculated) [-]
0 – 1.21	16	16/25 = 0.64
1.21 – 2.42	21	21/25 = 0.84
2.42 +	25	25/25 = 1.00

The HAZUS estimates are used only to find the relative interruption duration for different water depths. For the absolute interruption duration the estimate of Gauderius (2012) of (one year) is assumed to be better, because this duration is made for the Dutch situation and with Dutch data. The damage function is based on the three values in table B1. The function is further improved by adding a threshold to avoid overestimation at low water depths. The threshold was set to 30 cm water depth. From 50 cm water depth table B1 is followed. This results in the green function in figure B1.

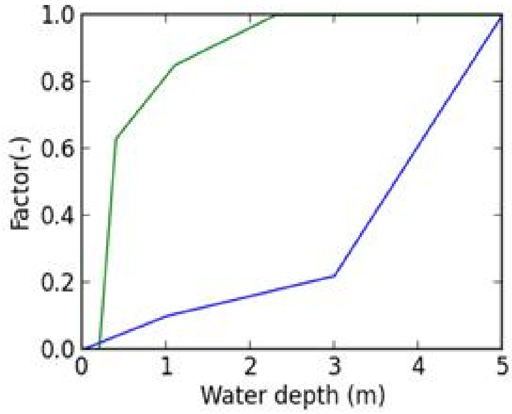


Figure B1: Green: The business interruption function as proposed for SSM2015. Blue: The business interruption function as was used in HIS-SSM.

C Correction factor as used in WV21 and DPV

In the WV21 project (Kind, 2011) a correction factor was used to translate HIS-SSM outcomes for the price level of 2000 to 2011 and to correct for missing damage categories. The outcomes of the SSM2015 do not need to be corrected for price level, since they are already for 2011. Also the assessment of some of the missing damage categories is improved in SSM 2015, which means that the correction factor needs to be adjusted. This memo makes an assessment of which factors of the correction factor are still applicable after the update.

The HIS-SSM outcomes for price level of 2000 were corrected with a factor of 1.4 to translate them to 2011 and with a factor of 1.6 to correct for missing damage categories. The total correction factor was 2.24 (1.4x1.6=2.24).

Translation of outcomes for 2000 to 2011

SSM2015 is based on the price level and the economic situation of 2011. To translate the outcomes to 2011, they are multiplied with 1.22 for inflation and 1.18 for economic growth (see table C1). The total correction is 1.4. In chapter 4 to 7 only inflation is corrected when the effect of changes are studied. In chapter 8 the factor 1.4 is used to compare outcomes of HIS-SSM and SSM2015. SSM2015 provides outcomes for 2011 by default.

Table C1. Update of outcomes to 2011.

Correction	Correction factor applied to HIS-SSM outcomes (price level 2000)	Correction factor applied to SSM2015 outcomes (price level 2011)
Inflation correction: the same objects have now a higher value	1.22	1
Economic growth: Increase in the number of objects or in their productivity	1.88	1

Correction for missing damage categories

To correct for missing categories the outcomes of HIS-SSM was increased with 60%. If the same approach would be followed, the SSM2015 figures should be raised with 42% (see table C2 below). This has not been done in the report.

Table C2 Correction for missing damage categories

Missing category	**% added to total damage in WV21**	**Correction factor in SSM2015**
Cost of evacuation, assistance, cleaning and aftercare.	10	10
Damage from business interruption	14	0 (improved in SSM2015)
Indirect effects of disrupted infrastructure	8	8
Other: Handling expenses, interruption of housing, Interruption of communication, long term impact on investment climate, damage to landscape, nature and cultural values.	18	14 (about 20% of these categories are now included)
Risk premium: People are naturally risk averse	10	10
Sum of all missing categories	60	42
Correction factor	1.6	1.42

If these corrections are added to the damage figures for HIS-SSM and SSM2015 they correspond very well. They have a correlation of about 98% (see figure C1). SSM2015 is then about 2% below the corrected estimates of HIS-SSM.

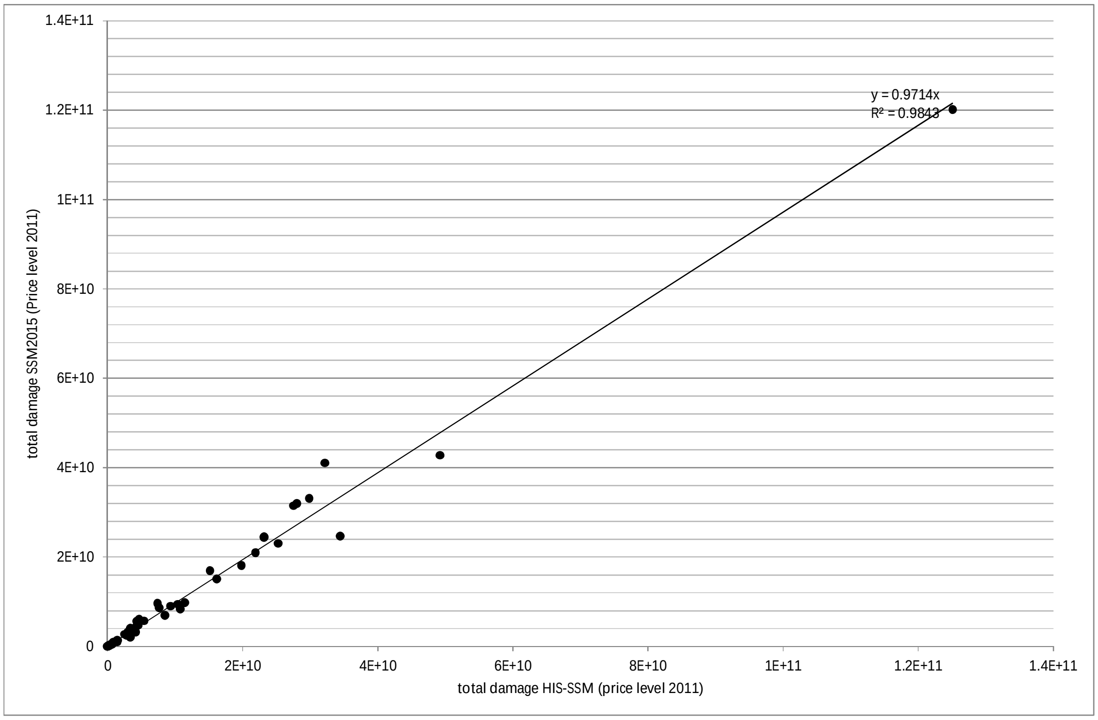


Figure C1. Comparison of damage calculated with SSM2015 and HIS-SSM. In both methods the corrections as mentioned in this annex C are included (2.24 for HIS-SSM and 1.42 for SSM2015)

D Uncertainty in flood damage estimates and its potential effect on investment decisions