Influence of future zoning on flood risks

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ABSTRACT:

In this paper we assess flood risks in an study area for three different causes of flooding: by failure of primary or secondary flood defences or by lack of regional discharge capacity due to extreme rainfall. To illustrate the influence of future zoning on flood risks, a future urban development area was located on two different locations. Some fictive assumptions were made to assess flood risks.

1. Introduction

The Netherlands are situated in the delta of four rivers: the Rhine, the Meuse, the Scheldt and the Eems. As a result of this, the country has developed into an important, densely populated nation. But living in the Netherlands is not without risks. Large parts of the Netherlands are below mean sea level or below water levels, which may occur on the rivers Rhine and Meuse. High water levels due to storm surges on the North Sea, or due to high discharges of these rivers are a serious threat to the low-lying part of the Netherlands. During early inhabitancy, mounds were built to give shelter in case of flooding, but as land use became more intensive, dikes were built to protect the land and the people. Nowadays, proper construction, management and maintenance of flood defenses are essential to the population and further development of the country. The flood disaster of 1953 showed the vulnerability of the Netherlands when flood defences fail. The dikes protecting the Southwest of the country were breached by the joint onslaught of a hurricane-force northwesterly wind and exceptionally high spring tides. An estimated economical damage around up to one milliard euro, and 1836 deaths were the sad result of this catastrophe. In figure 1 an overview is given of the flooded area during this disaster.

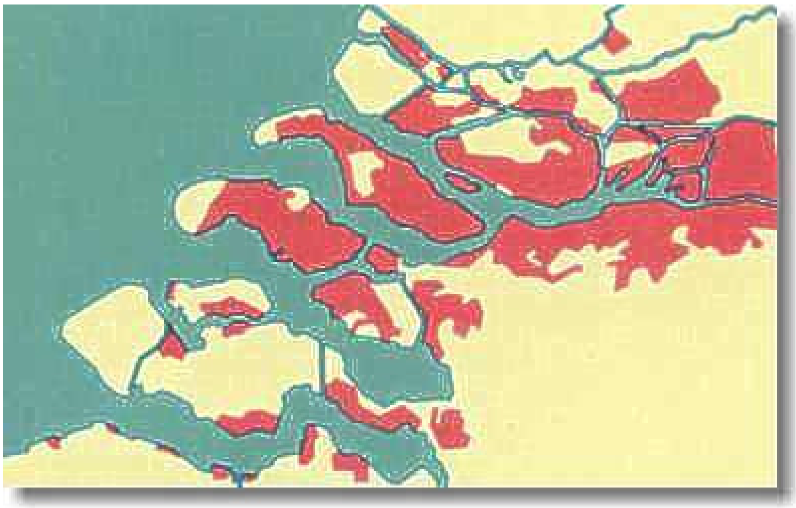

Figure 1. Overview of flood disaster in 1953 in Southwest Netherlands. The dark area is the flooded region.

Flood damage in the Netherlands can also occur because of heavy rainfall or breaching of local flood defences.
A recent example of a flood hazard was the breakthrough of a local flood defence at Wilnis (2000), due to extreme dry weather conditions. A polder reservoir was discharged and the area lying behind the breach in the dike flooded, resulting in an estimated damage of 10 million Euro.

Several examples of flooding by heavy rainfall are present in the last decade. Although flood damage is not as severe as by failure of major flood defences, it may cause many financial problems and failed harvests. A major example of flood damage due to extreme rainfall occurred on the 21 and 22 of September 1998 in the area known as Delfland. The discharge water capacity was exceeded, and large hosti- and agriculture areas were drowned.

In summary, there are in the Netherlands three different causes leading to flood damage:

1. flooding from the sea, lakes and major rivers by failure of 'primary' dikes
2. flooding from regional channels by failure of 'regional' dikes
3. local flooding because of lack of discharge capacity - directly due to extreme rainfall.

All three sources have resulted in the past to flood damage, and the question we will address in this paper is how the risk of flooding is estimated for these three sources and who future zoning influence these flood risks. Here, we will define risk as the product of the risk of flooding and the consequences of flooding. In this paper we will limit ourselves to these three causes of flood damage.

2. Laws and guidelines to prevent flood damages.

After the flood disaster of 1953, the need of establishing the safety of the ***primary flood defences*** (dunes, sea dikes, dikes around IJsselmeer and the important rivers), was obvious. The Delta Committee recommended the protection of important regions using water levels with an exceedance frequency of 1 in 10.000 years. This norm is partly based on en economic cost-benefit analysis (by estimating the flood damage and the cost of engineering works). Later on, safety standards for major lakes and rivers were also defined in the Law on Flood Defences. In figure 2 the present safety norms for the Netherlands are shown as given in the Law on Flood Defences. Nowadays, the primary dikes are tested every five years against these standards.

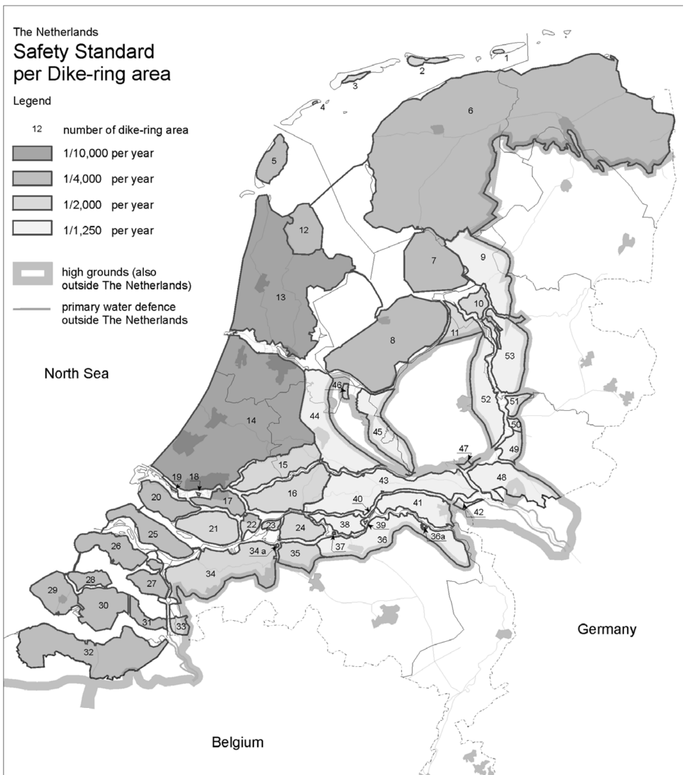

Figure 2. Dike-ring areas in the Netherlands

Safety norms for ***regional flood defences*** are not stated in Dutch law, but the commission IPO (InterProvinciaalOverleg) has defined guidelines. These guidelines state that provinces and waterboards will have defined safety standards for all secondary flood defences in their region before the year 2006. In table 1 an overview is shown of the safety norms for regional flood defences as stated in the IPO-guideline (IPO, 1999). The categorisation of the flood defences into the different classes is described by the waterboards and has to be confirmed by provinces.

class	**Flood damage (Meuro)**	**Safety Standard (1/yr)**
I	0-8	10
II	8-25	30
III	25-80	100
IV	80-250	300
V	>250	1000

Table 1. Overview of the IPO safety standards

The establishment of protection standards of flooding of regional water systems caused by ***extreme rainfall*** has just recently become a subject of interest (Unie van Waterschappen, 2001). The demand of explicitly stating these norms has been started after extreme rainfall events in the end of 1998. It has been chosen that the standards are set for different types of land use. See figure 3 for an overview. The extreme water levels are calculated with a rainfall-discharge model, and if the waterlevels are too high, measures are necessary to reduce the water levels.

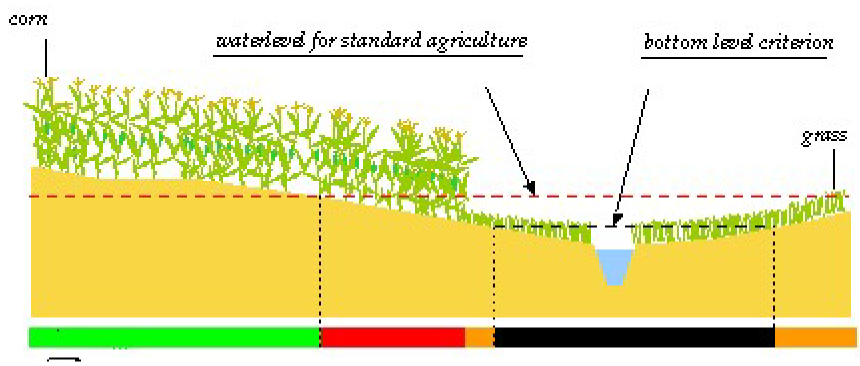

Figure 3. Overview of standard of extreme waterlevels caused by extreme rainfall

If a certain area has more than one land use type, then each land use type is tested against the standard. The standards are given in table 2. A complication of these standards is the bottom level criterion: that is the part of the area that is not considered when applying the standard. The reason for this is that for the lowest parts it is often accepted that some flooding occurs. The standards are not yet applied in all areas in the Netherlands, but they are used as a starting point to carry out an economic cost benefit analysis.

Landuse	**Bottom level criterion**	**Standard (1/yr)**
Grass	5%	1/10
Agriculture	1%	1/25
High value agriculture	1%	1/50
Greenhouses	1%	1/50
Urban area	0%	1/100

Table 2. Standards for extreme rainfall events

The safety standards have an implicit a relation with the flood damage. A combination of the two is risk. Risk is often defined as the product of the flooding probability and the consequences. This can also be used the other way round: given an accepted level of risk, safety norms can be calculated from the estimated flood damages. Moreover, optimal risk levels can be calculated using the cost of measures to reduce the flood risk. The Delta Committee followed this approach for the first time (Van Dantzig, 1956) and recently this method has been extended (CPB, 2005).

The determination of acceptable levels of risk, flood damages and safety standards is complex and leads to various questions. In this paper we do not pretend to present the final answer, but we only give some notes on flood risk levels of three different causes. Vrijling et al (1998) stated that the risk level can be based either on individual risk (the probability of being killed by a flood), group risk (the probability of a group to be killed by a flood) or economical optimisation (minimisation of total costs, including expected flood damage). In this paper we consider only the economical part of the flood damage.

3. Estimating flooding probability and flood damage

The flooding probability is in general not equal to the safety standard. The reason is that the safety standards for flood defences are exceedance frequencies of water levels. Because of the free board (of minimal 0,5 meter at the primary water defences and 0,1 meter at the regional flood defences) there is no direct failure of the flood defence if the water level is exceeded. Moreover, overflow and overtopping of the flood defence is only one failure mechanism, but there are more mechanisms of failure, such as piping and stability (TAW, 1998 and TAW, 2000). In this paper we will follow a simple approach. It will be assumed that there are not weak links in the dike ring, and the dikes are up to the design standard. In practice this is, unfortunately, not always true. For the primary water defences we use the estimates as given in Bannink et al (2004) and Klijn et al (2004). The flooding probability of the regional water defences are assumed to be a factor 10 lower than the safety standard and for the standards of extreme rainfall events the flooding probability is equal to the safety standard (there is no free board in this case).

The assessment of the flood damage is carried out using damage assessment module of HIS (High Water Information System) module and the maximum of expected economical damages was taken as input for the model. The calculated damage with the HIS module calculates for direct financial damage as well as indirect damage (outside the flooded area).

4. Study area - *Brielse Dijkring*

A part of the area 'Brielse Dijkring' is chosen as study area. In figure 4 the area and the major flood defences and local water storage capacities (regional water system) are shown. Several compartment dikes (local dikes, most usually the remains of past flood defences) are present in this area. Flooding can appear in three ways, being: failure of primary or regional flood defences or flooding of the regional water system. The study area is chosen because all three flooding causes are possible. As shown in figure 4, the area is situated near primary and regional defences.

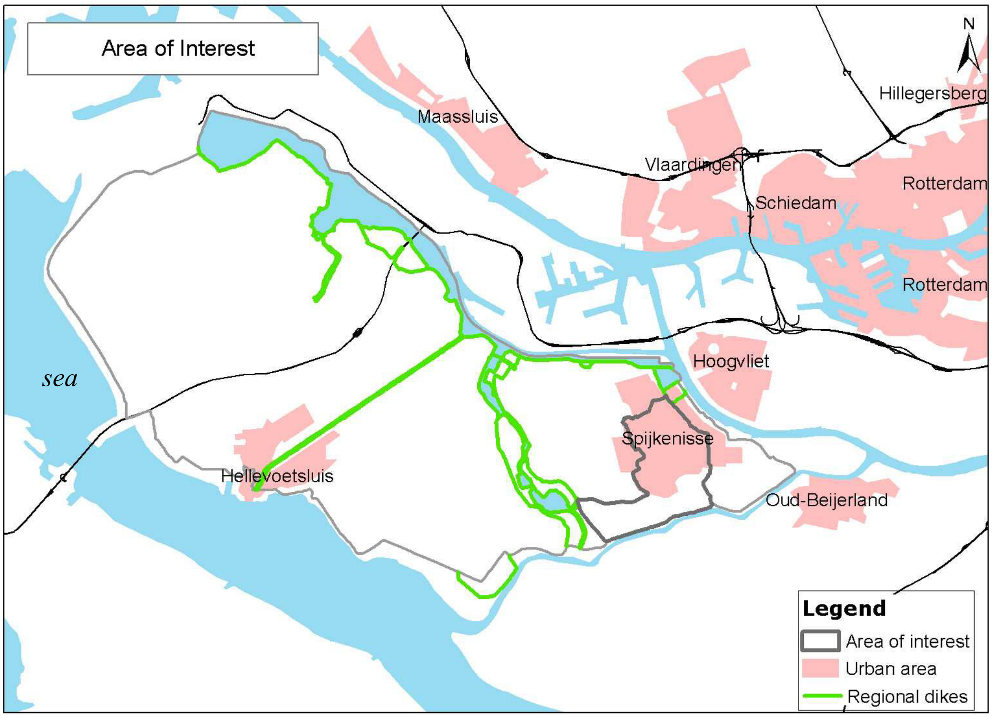

Figure 4: Overview of the study area. The blue coloured area is water.

In bannink et al (2004), a rough estimate is given of the total flood damage of the Brielse Dijkring (the area surrounded by the grey line) by failure of primary defences. The flood damage is estimated at a minimum of 2 milliard Euro and a maximum of 10 milliard Euro.

This estimate is calculated on a large spatial scale. The spatial scale is an important factor when modelling flood damage. Decision-makers in local government might be interested in the total amount of flood damage for a certain area, whereas civilians are interested in the expected damage on a specific location. In this study we have chosen to calculate the total amount of damage for our study area.

This section addresses for each cause of flooding (failure primary and regional flood defences and exceedance discharge capacity due to extreme rainfall) the values of the flooding probabilities, the economical flood damages and the estimated risk levels.

In figure 5 the schematised breach (the black spot) and flood inundation depth are given for the primary flood defences. A relative large area is flooded, and flooding depths till 4 meters are present. Flooding depths are determined by surface and water level.

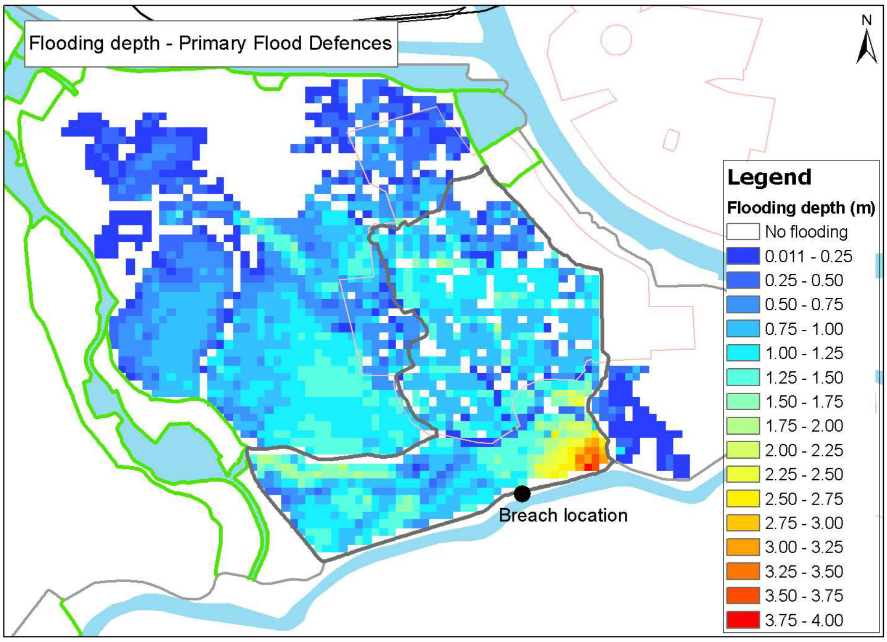

Figure 5: Overview of the inundation depths in the study are by flooding through failure of the primary flood defence system.

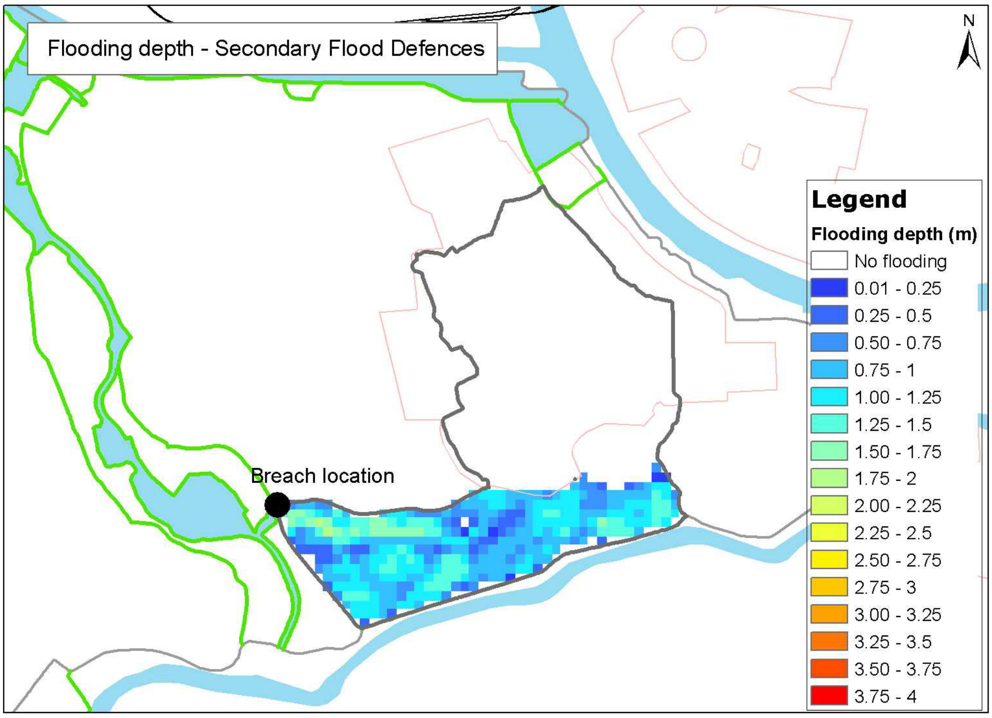

Figure 6: Overview of the inundation depths in the study area by flooding through failure of the regional defence system

In figure 6 the schematised breach and flood inundation depth are given for the regional flood defences. Here a compartment dike prevent that the most northern part of the study area is flooded. Flooding depths till a maximum of 2 meters are reached.

Finally, in figure 7 the flooding depths are given for the exceedance of local water storage capacities. It is obvious that flooding depths are relative low in comparison with the other two causes.

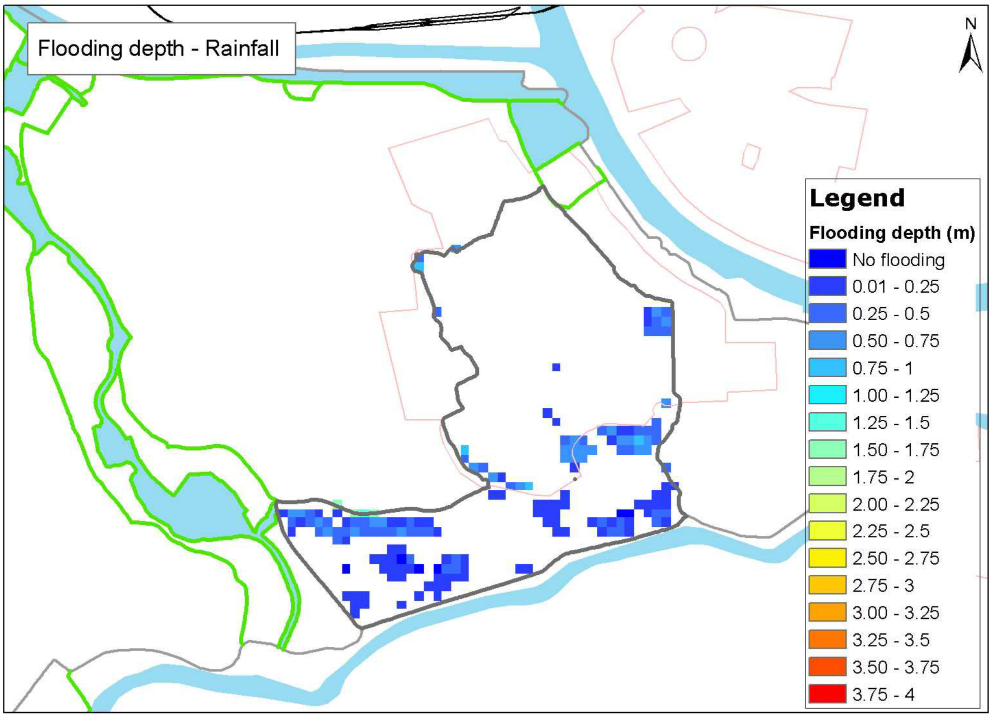

Figure 7: Overview of the inundation depths in the study area by flooding caused by lack of discharge capacity due to extreme rainfall.

Using flooding depths and land use for the three flood causes, the flood damage was calculated using the damage module of HIS. In table 3 the flood damages are shown.

Cause	**Maximal Flood damage** (10^6 Euro)
failure of primary dikes	1125
failure of regional dikes	21.5
Extreme local rainfall (urban area)	5.1

Table 3. Flood damage for three causes

In order to calculate risk maps we need to determine the flood damage and the flooding probability. The flooding probability of the causes ‘failure of primary dikes’ and ‘failure of regional dikes’ are related to the exceedance frequency of water levels, used in the design of the dike. We did not have the possibility to calculate the flooding probability, and therefore we assess the flooding probability using literature (TAW, 2000). In this assessment it is assumed that there are no weak spots in the dike ring, and that ‘overflow and overtopping’ is the most important mechanism that leads to failure. As mentioned in paragraph 3, for the cause ‘flood from local extreme rainfall’ it is assumed that the flooding probability is equal to the safety standard: exceedance of water level means that damage appear. The flooding probability of the regional water defences are assumed to be a factor 10 lower than the safety standard and for the primary water defences we use the estimates as given in Bannink et al (2004) and Klijn et al (2004). We assume the flooding probability of primary dikes equal to the exceedance probability.

The flooding probability and the exceedance probability of the water levels of the three causes of flooding are presented in table 4.

Cause	**Exceedance probability**	**Flooding probability**
Failure of primary dikes	1/4.000	1/4.000
Failure of regional dikes	1/30	1/300
Extreme local rainfall (agriculture)	1/10	1/10

Table 4. Flooding probabilities for three causes.

The risk was calculated by multiplying the probability of flooding with flood damage (Table 5). The highest flood risk is due to failure of primary dikes. Minimising the investment in flood defences against flood risks over a certain period is a way to assess the proper flood risks. Decision makers should make a choice whether to follow this economical optimisation or to meet the safety standards.

Cause	**Flood risk** (10^6 Euro/year)
failure of primary dikes	0.28
failure of regional dikes	0.21
Extreme local rainfall (urban area)	0.12

Table 5. Flood risks for three causes.

5 Changes in flood risk

The flood risk will not be constant in the future, because of changes in natural conditions (for example climate change), changes in land use (for example new urban areas) and investments to decrease the flood risk (for example dike strengthening). In this paper, we investigate the influence on the flood risk of urbanising areas. In figure 8 two different fictive future zoning of an urban area are shown. Only the location of the urban areas is different, all other aspects have been assumed to remain similar. For both locations the risk of flooding is calculated by multiplying the flooding probabilities on the specific location with the increase of the estimated economical damage.

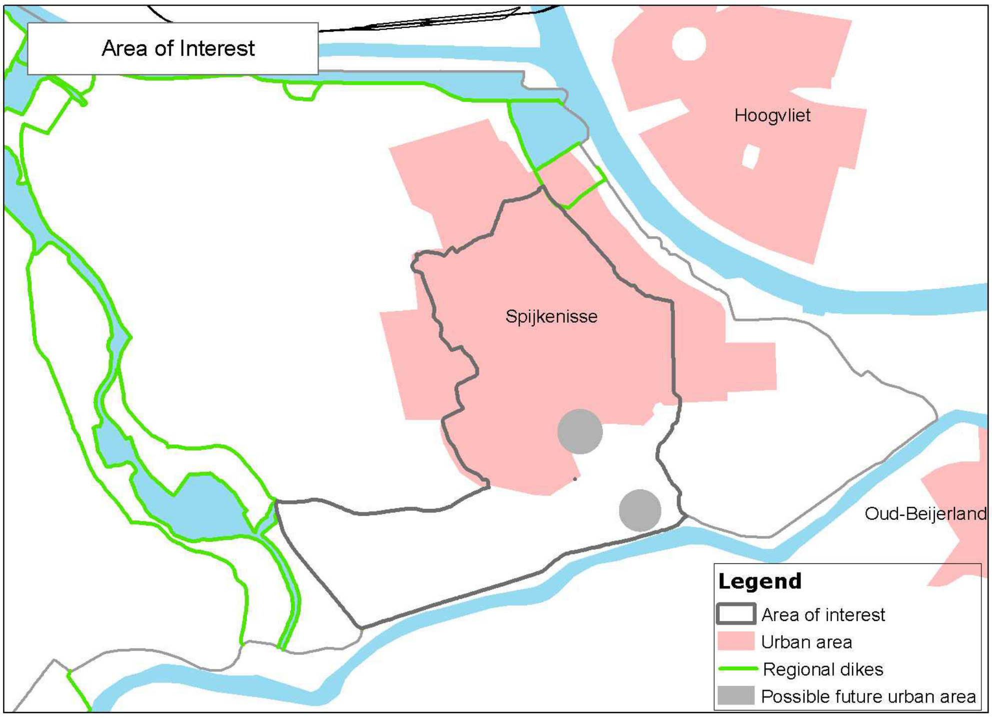

Figure 8. Two possible future urban areas are located on the map. The most Northern location gives only a small increase in flood risk, whereas the more southern location leads to a relative large increase in flood risk by regional flood defences.

Flood damage due to heavy rainfall is not altered with the new future zoning. It is assumed that the urban area is built in such way that the flood damages for heavy rainfall are maintained. Flood damages due to failure of primary and secondary defences increase with the new zoning (see table 6).

Cause	Flood damage - old situation (10^6 Euro)	Flood damage - new situation (location North) (10^6 Euro)	Flood damage - new situation (location South) (10^6 Euro)
failure of primary dikes	1125	1195	1285
failure of regional dikes	21.5	21.5	25.8
Extreme local rainfall (urban area)	5.1	5.1	5.1

Table 6. Flood damage for three causes

When the area is planned in the lower Southern region, the estimated flood damage increase with 160 million Euro for primary dikes and 4.3 million Euro for regional dikes. When the area is planned in the higher Northern region, the estimated flood damage increase with only 70 million Euro for primary dikes and stays the same for regional dikes.

The flood damage for the Southern location amounts 26 million Euro, this means that a higher safety level is required (see table I). The region is no longer distinguished as a class II area, but is levelled up to class III. This implicates that the regional flood defence should be tested against higher safety levels. If the regional flood defence meet the higher safety level, the flood risk drops down since the probability of flooding decrease from 1/300 to 1/1000. As seen in table 7, the flood risk in the new situation amounts around 0.03 Million Euro/year.

Cause	Flood risk - old situation (10^6 Euro)	Flood risk - new situation (location South) (10^6 Euro)	Flood risk - new situation (location North) (10^6 Euro)
failure of primary dikes	0.28	0.30	0.32
failure of regional dikes	0.21	0.21	0.03
Extreme local rainfall (urban area)	0.12	0.12	0.12

Table 7. Flood risk for three causes

6. Conclusions and recommendations

In this paper we assessed the flood risks in an area of the Brielse Dijkring for three different causes of flooding: by failure of primary or secondary flood defences or by lack of regional discharge capacity due to extreme rainfall. To illustrate the influence of future zoning on flood risks, a fictive urban development area was located on two different locations. Assumptions were made to assess the flood risks.

Many factors are important by planning future zoning. One factor is that by urbanising an area the economic value increases, which results in an increase of possible flood damage. When no measures are undertaken to reduce the probability of flooding (e.g. by dike strengthening), the flood risk increases as well.

An increase in flood risk does not mean that the safety norms for primary defences are exceeded – these norms only test the probability of failure and does not concern the flood damage. For regional defences however, a change of the economical value of the area might require a higher safety level. If the regional flood defences do not meet these higher safety levels, investments in defences are necessary. For extreme rainfall in urbanising areas, adequate discharge capacities should prevent flooding.

By future zoning it is recommended to decision-makers not only to meet the present safety norms for flooding, but also to map the influence on flood risks and question if it is necessary to take measures in order to reduce the flood risk. A measure to reduce the increase of flood risks (and preventing possible investments in flood defences) is to plan high-economical zones in areas with low flooding probabilities.

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