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Risk assessment to quantify the interaction between land use and water management

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ABSTRACT

Heavy rainfall in recent years has shown that occasional flooding cannot always be prevented. Moreover, it is likely that the frequency and damage of flood events will increase in the future due to climate change, subsidence, and ongoing urbanization, what makes many water authorities, particularly in low land areas, anxious about the future. So, water authorities want to anticipate on both climate change and spatial planning to control the risk of flooding. The question addressed in this paper is: how do climate change and spatial planning increase the risk of flooding? To answer this question a case study has been carried out for Haarlemmermeer polder. For this area a detailed risk assessment has been carried out, using a combination of hydrological models, GIS and a damage model. The rationale behind risk analyses is explained in our paper, and illustrated with our case study. Vulnerable and robust areas can be identified with risk assessment. It will be shown that both the consequences of spatial developments and climate change may dominate, and may increase the risk of flooding enormously. However, this is not homogenously distributed over the area. The surplus value of risk analysis is that it allows better cooperation between spatial planners and water authorities.

Key Words: flood risk, flood damage, climate change, polders.

INTRODUCTION

The Netherlands is situated in the Delta of three rivers: The Rhine, The Meuse, and the Scheldt. Centuries of land reclamation, water management, and drainage induced land subsidence have created a polder landscape, where large parts are flat, below mean sea level, and need protection against the sea by dunes and levees (See Figure 1).

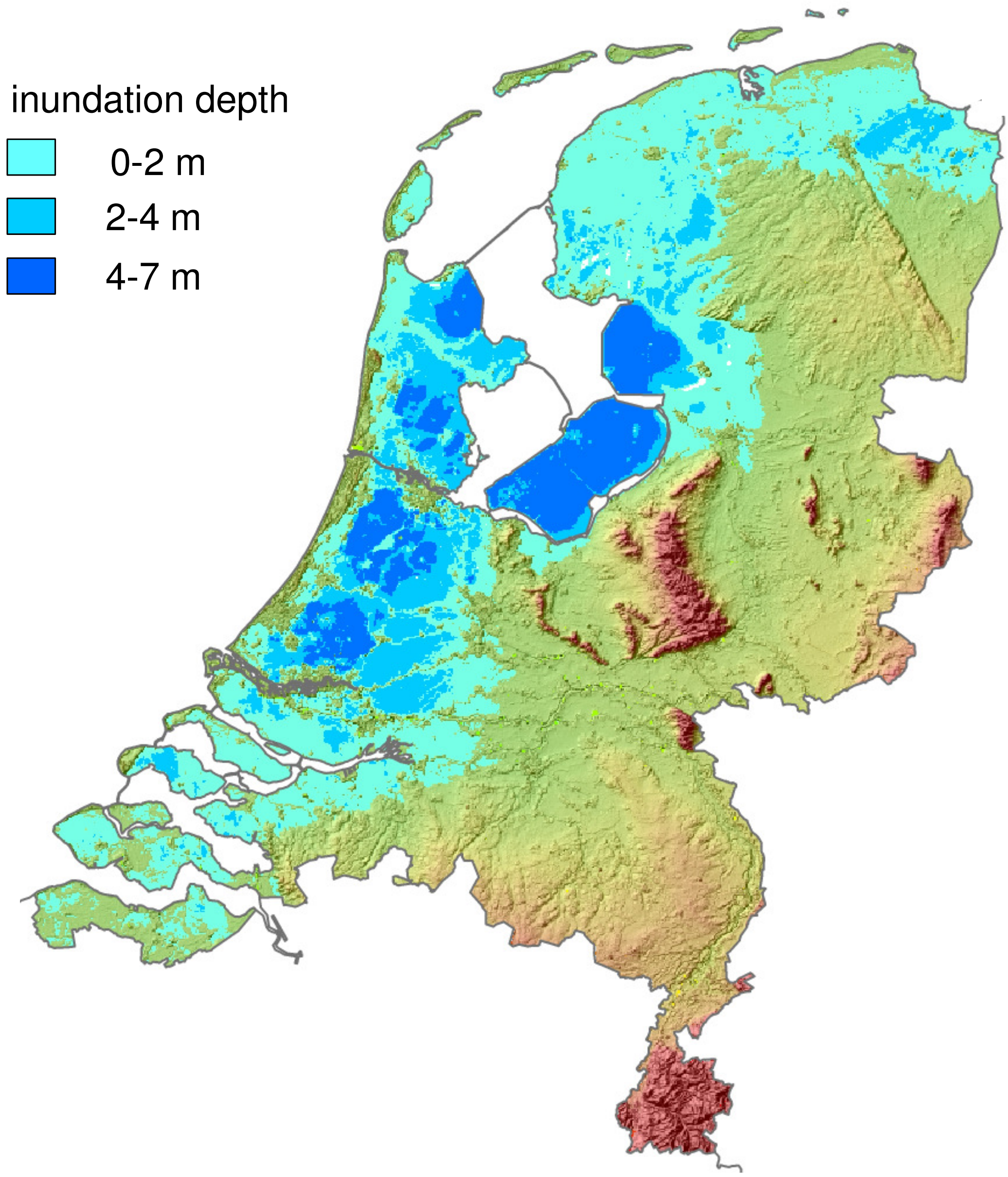

Figure 1 The Netherlands with in blue the areas below mean sea level that would be flooded without dikes, dunes and pumping stations (source: GDI)

Furthermore, each low lying area also needs a network of canals and pumping stations to discharge excess rainfall. So, next to floods caused by breaches of dunes and levees, floods can also occur when rainfall exceeds the limited discharge capacity of the canals or pumping stations. This type of flooding is not life threatening, but can be extremely frustrating when the same farmer sees his harvest washed away in consecutive years.

In recent years this type of rainfall induced floods occurred rather frequently in the Netherlands (1998, 1999, 2000, 2001, 2002, 2004). Furthermore, it is likely that in the future the frequency and damage of these types of flood events will increase due to expected climate change, sea level rise, subsidence, and ongoing urbanization. So, in order to control the risk of flooding, worldwide many water systems have to be upgraded (IPCC, 2001; WB21, 2000).

The research question addressed in this paper is: how do climate change and developments in land use increase the risk of flooding? This is important information, as when the impact of one of the two is negligible, attention can be focused on the development that increases the risk of flooding the most.

To answer this question a detailed case study has been carried out for Haarlemmermeer polder. A 18,500 ha former lake near Amsterdam, reclaimed in 1852 by three steam driven pumping stations. This polder is selected as land use in the Haarlemmermeer polder is diverse, and changing more rapidly compared to other locations in the Netherlands. For this area a detailed risk assessment has been carried out, using a combination of hydrological models, GIS and depth–damage functions to determine the effect of climate change and developments in land use, on the risk of flooding.

Interrelationship between land use and water management

Water management aims at creating clean and safe water systems, to support all surrounding land use functions. This means that water levels in canals are maintained as constant as possible to prevent damage by floods or droughts. Nevertheless, is there always a possibility that the discharge and storage capacity is insufficient, as there might be a rainfall event bigger than the design capacity.

It is possible in theory to build a water system with an extreme low probability of failure. However, such systems are not built in practice, as they need expensive infrastructure, which is not in proportion to the damage prevented in case of an event. So, there is always a certain risk of flooding that we have to accept. This risk, defined as probability of a flood multiplied by the damage, increases in the future by climate change and developments in land use. Firstly, climate change is expected to lead to more often and higher rainfall showers in the Netherlands, what will lead to an increase in number of floods. Secondly, developments in land use lead to an increase of flood risk, as i.e. urbanisation lead to an increase of damage in case of an event, as the economic value increases (See Figure 2). Next, urbanisation may lead to a faster runoff of precipitation, as the paved surface increases.

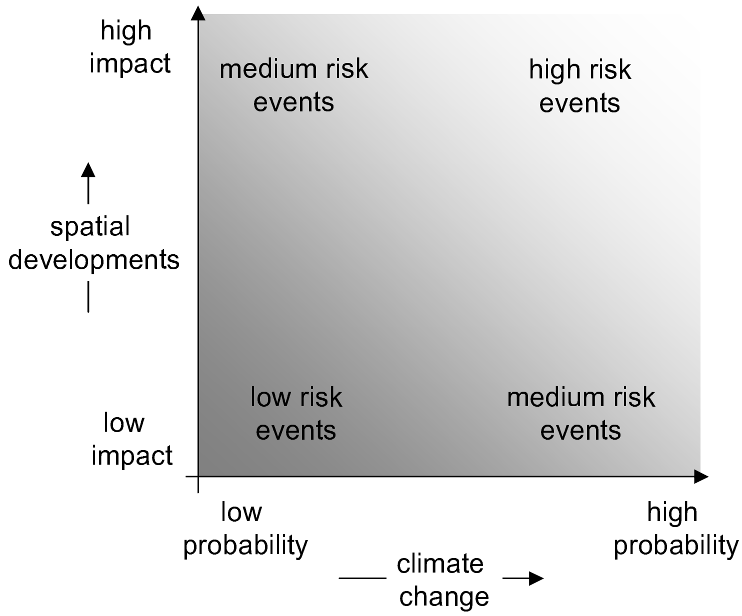

Figure 2 Spatial developments and climate change increase the risk of flooding.

Policy in the Netherlands

Recently, policy is made in the Netherlands to support water authorities in reducing the negative effects of climate change and developments in land use. In 2001 the national government, together with water authorities and provincial governments, developed instrumentation to anticipate on spatial developments. This instrumentation is compulsory by the law on spatial planning as from November 2003, and ensures that water interests are taken into account in among others local and regional spatial and land use planning initiatives. The objective of this instrumentation is to prevent negative effects from spatial developments or that their impact is compensated for elsewhere (RIZA, 2003).

Next to this instrumentation, flood standards are proposed to inform residents on the minimum level of protection that can be expected, and to prepare the Dutch regional water systems for the consequences of climate change (NBW, 2003). The standards consist of a maximum allowable flood frequency for different types of land use.

Both the planning instrumentation and flood standards work well, however the result of this separate approach is that solutions are developed in different directions. Water managers try to reduce the probability of flooding, and spatial planners aim to reduce the impact in case of flooding (See Figure 3). This makes that besides successful projects, sometimes possible win-win situations are overlooked or measures to comply with the standards are proposed without any benefits.

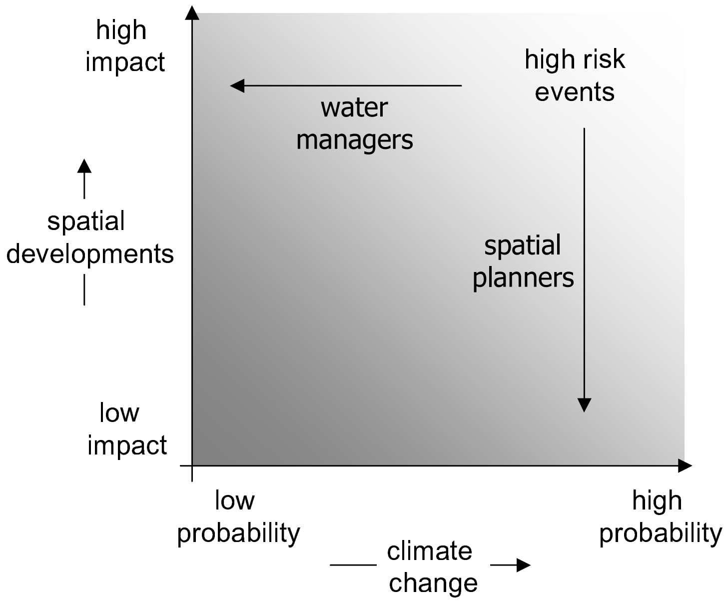

Figure 3 Water managers aim to reduce the probability of flooding, whereas spatial planners aim to reduce the impact of flooding.

FLOOD RISK CONCEPT

Flood risk calculations are based on a multiplication of the probability of failure and consequences in case of failure. Failure occurs when the (meteorological) load exceeds the strength or capacity of the structures protecting the area from flooding. Particularly, river floods and sea floods have been studied regularly (Vrijling 2001, Vis, 2003; Apel, 2004). Risk assessment of these floods are characterized by firstly a classification in dike or dune sections and structures, with each a failure probability. Next, for each section or structure the risk can be determined by a multiplication of the failure probability with the damage in case of failure.

At last, the total flood risk of an area behind a dike or within a dike ring is equal to the joint risk of the sections and structures.

Risk assessment of floods due to precipitation exceeding the drainage capacity of a canal network, as in polders, has not been studied yet in the Netherlands. The difference with the risk of high river discharges or high sea water levels is that the threat is from above, and there is not just one failure probability for an element protecting an area. Failure of the drainage and discharge capacity is a scale from more frequent small floods, with minor damage, to extreme large floods with more severe damage. Moreover, this probability distribution differs for each plot or pixel, depending on elevation. This difference may look small at first sight, but is an enormous increase in calculations, while both probability and damage are spatially distributed. The total risk in an area equals expected annual damage by summing all multiplications from probability and damage.

CASE STUDY HAARLEMMERMEER

Flood probability

To evaluate the water system of the Haarlemmermeer polder a reliable and detailed computer simulation model of the water system was made. With this model, simulations of historic rainfall and evaporation records of the period of 1906-2003 measured at the head office of the Royal Dutch Meteorological institute at the Bilt were used to determine probability distribution functions of water levels. (So nearly 100 years). This kind of long simulations had been uncommon for large-scale water systems, as the computation time to calculate 100 years of water levels was considerable (weeks!). However, the present data availability, computer simulation models and possibility to have computers do parallel calculations make these continuous simulations applicable on a large and detailed scale. The probability distribution functions were determined by fitting a Gumbel distribution through the annual maxima of water levels for each location in the model.

Flood damage modelling

To estimate the damage for all possible floods a unit-loss model was made. In our model only direct first order damage was assessed, which is caused by physical contact with water. Higher order, indirect and intangible damage was neglected (See Figure 4), as it is small in proportion to direct damage for small-scale inundations and hard to estimate as it depends on many more factors then high water levels (Penning-Rowsell, 1986; Parker, 2000).

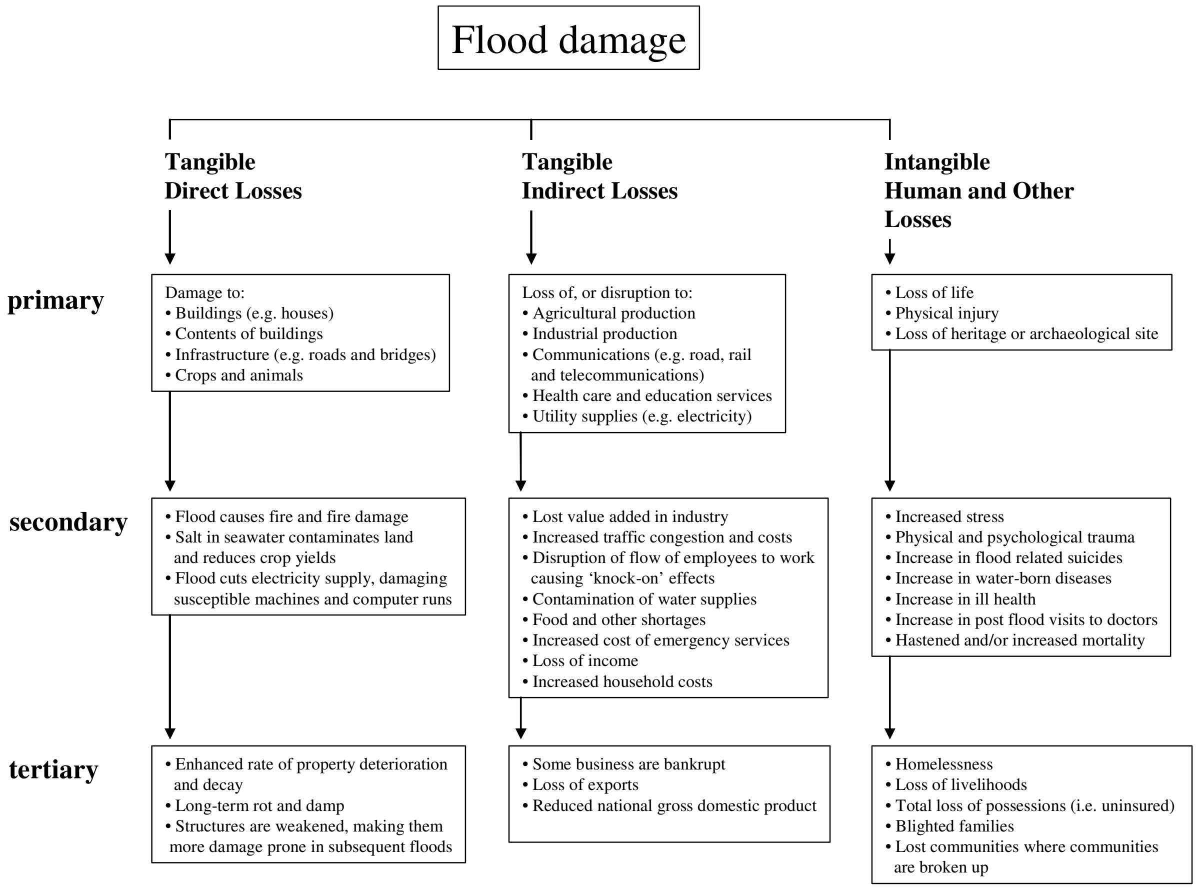

Figure 4 Categorization of flood damage (Parker, 2000)

Table 1 Maximum damage and damage function per class

Class	Damage function	Maximum damage
Water	-	€ 0,- /ha
Nature	-	€ 0,- /ha
Pastures	II	€ 1.000,- /ha
Agricultural crops (i.e. cereals)	I	€ 2.500,- /ha
Horticulture (i.e. flower bulbs)	I	€ 25.000,- /ha
Orchards	I	€ 100.000,- /ha
Main roads and rail roads	III	€ 100.000,- /ha
Greenhouses	III	€ 225.000,- /ha
Residential buildings in rural area	III	€ 225.000,- /ha
Residential buildings in urban area	III	€ 225.000,- /ha
Industrial areas	III	€ 225.000,- /ha

A unit-loss model counts items categorized in terms of relevant units. The relevant units were taken according to the land use functions of Table 1 in raster cells of 25*25 m. The maximum damage per item was based on data from the Dutch Agricultural Economics Research Institute (LEI, 2004). The fraction of damage assigned to every item was calculated with depth-damage functions (See Figure 5).

There is much literature about depth-damage functions, which indicates that much is still unknown (e.g. Penning Rowsell, 1977; Appelbaum, 1985; Smith, 1994; Zhai, 2005). This is not surprising if one considers that even after real floods, the actual damage is difficult to assess. Many of the existing functions focus on damage to buildings, and do not incorporate damage to crops by high ground water levels. However, not calibrated with flood data, we modelled 3 depth-damage functions that incorporate both high ground water levels as surface water levels. The first function reflects agricultural and horticultural crops that are vulnerable for high ground water levels, as flower bulbs and potatoes. The second function represents grass that may be flooded now and then, as long as the duration stays limited to several days. The last function represents damage to buildings, green houses and roads, whereas damage becomes significant when surface becomes flooded with several dm, as many building, and roads are constructed roughly 3 dm above the surrounding surface level.

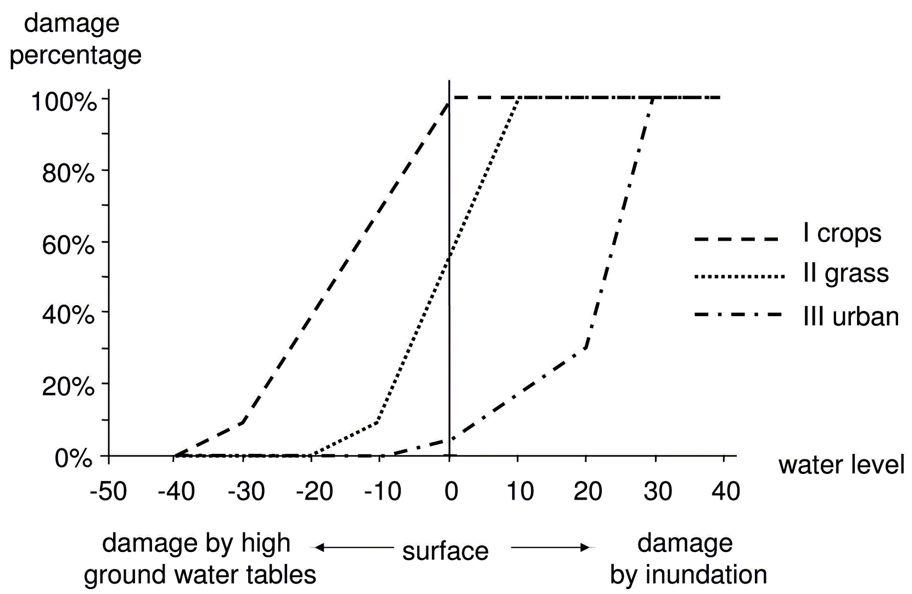

Figure 6 Depth damage functions

Climate change simulations

The earth's average temperature is slowly increasing due to increased emission of green house gasses in the last decades. The exact consequences of this temperature rise are uncertain, but worldwide climatologists agreed upon possible severe changes in climate. For the Netherlands is expected that the future will develop to warmer summers, increased precipitation in winters, and more severe and frequent extreme precipitation events.

To be able to analyze the impact of climate change the Royal Dutch Meteorological Institute at The Bilt has formulated climate change scenarios for temperature rises of 1, 2 and 4 degrees (See Table 2). All water boards in the Netherlands agreed to use a climate scenario in which the average temperature will rise with 1 degree ($\Delta T = 1°C$) as the situation in 2050 (NBW, 2003). For our simulations we adapted the rainfall and evaporation series of 1906-2003 at the Bilt according to changes in Table 2.

Table 2. Climate change scenarios (KNMI, 2003)

	$\Delta T = 1°C$	$\Delta T = 2°C$	$\Delta T = 4°C$
Annual precipitation	+3%	+6%	+12%
Summer precipitation	+1%	+2%	+4%
Winter precipitation	+6%	+12%	+25%
High 10 day precipitation sum in the winter	+10%	+20%	+40%
Evaporation	+4%	+8%	+16%

Developments in land use

The risk of flooding alters by spatial developments. For example, the potential damage increases when an agricultural area is changed to greenhouse horticulture. Furthermore, a change in spatial planning may – besides potential damage - also increase the probability of flooding. An increase of the paved surface by urbanisation will decrease the possibility of rainfall to infiltrate and increase the rapid runoff to surface water, what may alter the flood extent in case of extreme precipitation.

Estimates on land use over terms of 30-50 years are difficult to make. For large infrastructure projects the term between initiative and completion is in the order of 20 years, and the term of small-scale projects is only several years. Therefore, a map with future land use involves large uncertainties. Nevertheless, when we want to anticipate on negative effects of spatial developments on water management, and want to make reservations for future measures, we need insight in future changes in spatial planning.

Four maps -Global Economy, Transatlantic Market, Strong Europe, and Regional Communities - were used to estimate the influence of future developments in land use in the Haarlemmermeer on the risk of flooding (See figure 7). The basis of the scenarios are developed by the Netherlands Bureau for Economic Policy Analysis and describe four futures of Europe (CPB, 2003). The National Institute for Public Health and the Environment (RIVM) has worked out the sustainability aspect of these four scenarios (RIVM, 2004) and translated to 4 land use maps for the Netherlands in year 2030 (RIVM, 2005).

The translation from spatial impressions from the Netherlands to spatial impressions of the Haarlemmermeerpolder was made by combining the RIVM data with maps from the Dutch National Mapping Agency (TOP10NL), and Centre for Geo Information (LGN) and maps of the Haarlemmermeer Municipality.

Table 3 Surface of different types of land use per scenario

	Present Land Use Yr 2000 [ha]	Global Economy yr 2030 [ha]	Strong Europe yr 2030 [ha]	Transatlantic Market yr 2030 [ha]	Regional Communities yr 2030 [ha]
Water	400	400	**1 800**	400	400
Nature	300	300	300	300	300
Grass land	2 700	5 300	4 900	3 900	**6 000**
Agriculture	**7 900**	1 700	3 700	3 000	4 700
Horticulture	300	**3 500**	400	**3 500**	200
Build-up areas	6 700	7 100	7 200	7 200	6 700
Total	18 300	18 300	18 300	18 300	18 300

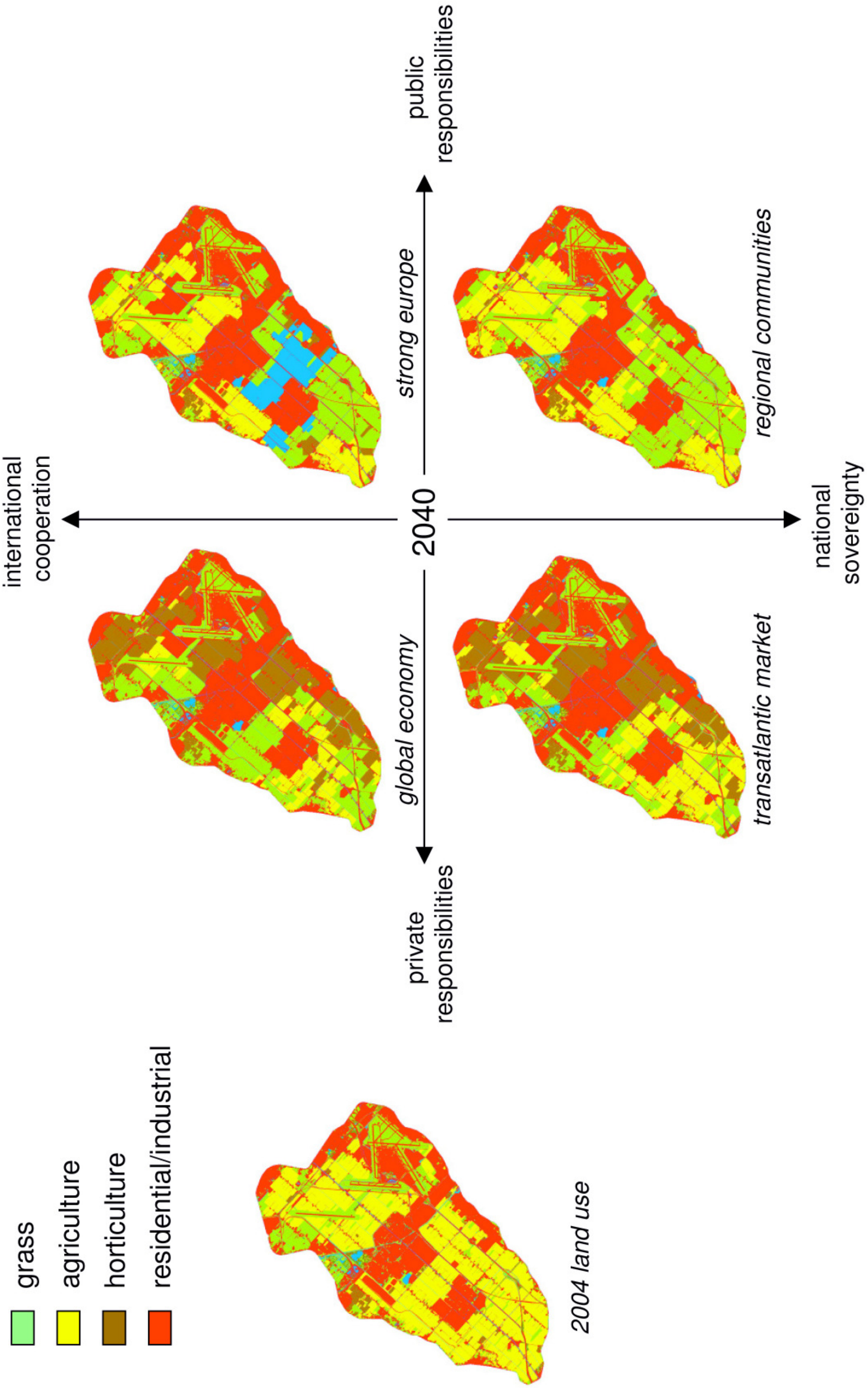

Figure 7 Four future spatial maps of Haarlemmermeerpolder (based on MNP-data)

According to these scenarios, both rural and urban environment will change thoroughly during the next decades. Each scenario shows a deterioration of present agricultural areas, depending upon the degree of government protection assumed in a scenario (See Table 3). Fairly large areas of arable farming will be superseded by horticulture in scenarios of Global Economy and Transatlantic market. A large lake on the bottom of the Haarlemmermeer is foreseen in the scenario Strong Europe. Less development takes place with the Regional Communities scenario were only agricultural areas are replaced with pastures

Results

The results of simulated scenarios are summarized in table 4. The risk in the Haarlemmermeer polder amounts nearly € 2 Million a year in the present situation. The results show that the increase in risk due to climate change ($\Delta t=1°$ in 2050) was estimated at 20 %, whereas the expected increase of the rainfall intensities was only about 10%. The larger increase of risk can be explained by that the return periods of heavy rainfall events (and floods) decrease more than the 10% change in intensity; extreme events will happen more often.

The shift from agriculture to horticulture in the scenarios Global Economy and Transaltantic Market cause an increase in risk, as the damage in case of the same event became larger. Analyses of the data showed that this increase is not homogeneous, but counts particularly for flood prone areas. The risk decreases in the Strong Europe scenario, because of the shift from agriculture to grass land, and the enormous increase of open water. The present value of this decrease, after climate change, amounts euro 12.5 M, which can be considered as the benefit from the new lake in the Haarlemmermeer polder.

Table 4 Expected annual damage per scenario in the Haarlemmermeerpolder

Climate	Risk [euro/year]	Increase [euro/year]	Present Value ($r=4\%$; $T=\infty$)
2000	2,000,000		
2050 climate + present land use	2,400,000	+ 400,000	+ 10,000,000
2050 climate + Global Economy	2,500,000	+ 500,000	+ 12,500,000
2050 climate + Strong Europe	1,900,000	- 100,000	- 2,500,000
2050 climate + Transatlantic Market	2,600,000	+ 600,000	+ 15,000,000
2050 climate + regional communities	2,300,000	+ 300,000	+ 7,500,000

The spatial variation of risk over the area ranges from € 0 to €10,000 per hectare per year (See Figure 8). The risk spread throughout the area shows vulnerable and robust areas. This kind of risk spread maps is highly useful to explain to non-engineers that the impact of climate change, and the differences between land use options are not homogenous for each plot within a polder.

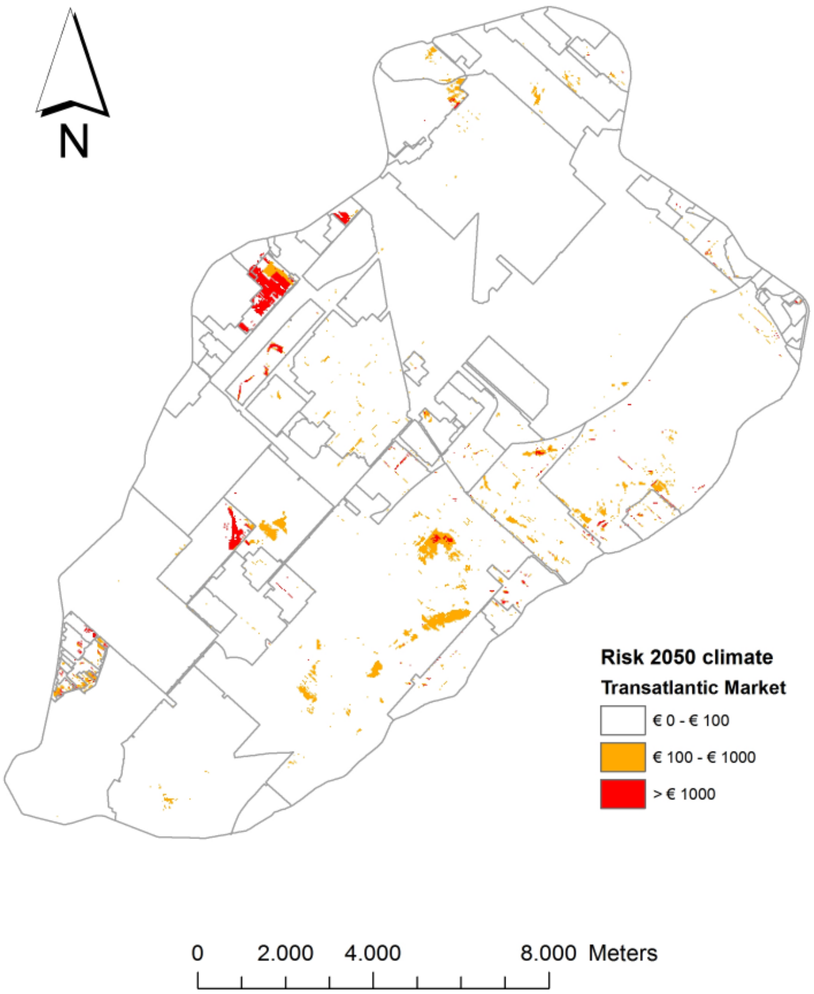

Figure 8 Risk map for 2050 climate scenario and land use scenario Transatlantic Market

CONCLUSION

The research question of this study was: how do climate change and spatial planning increase the risk of flooding? This paper has outlined a method of estimating the risk of flooding due to precipitation under different scenarios. The case study of the Haarlemmermeer showed that the impact of climate change will increase the risk significantly, but the risk change may become larger, depending on the scenario.

Limitations of the presented methodology are the uncertainties in the data used and the ignorance of others then direct damage. Uncertainties are present in the probability distribution functions, depth damage functions, and model with which water levels were simulated. The analyses should be improved by taking into account all these uncertainties, before these type of simulations are used for decisions in water management. The ignorance of others then direct damage, like indirect and intangibles, may become a problem, as these may increase the benefit of spatial developments enormously. For this reason it is recommended to let risk analyses only be a part of e.g. a multi criteria analyses.

Land use planning is in practice far more complex as spatial planners do not only have to deal with flood problems, but with many other functions, like recreation, nature development and urbanization. The benefits of these developments cannot only be expressed in terms of flood risk reduction. The value of risk analysis for land use planners is therefore to give clear arguments on to what extent water authorities benefit from spatial developments, and to what extent they may expect water authorities to contribute to spatial developments.

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