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FLOOD RISK IMPACT OF SPATIAL DEVELOPMENTS, CLIMATE CHANGE AND SUBSIDENCE: CASE STUDY IN THE NETHERLANDS

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ABSTRACT: Polder areas are vulnerable for inundations by extreme precipitation, as runoff may temporarily exceed the limited discharge capacity of drainage canals and pumping stations. This type of flooding is not life threatening, but can cause considerable economic damage. Furthermore, it is likely that frequency and damage of this type of flood events will increase in the future. The research question addressed in this paper is whether there is any need to improve water systems with respect to climate change, subsidence and spatial developments. To answer this question the case of the Flevo polder was studied. It will be shown that the risk increase of spatial developments, subsidence and climate change simultaneously is larger then the sum of the individual risk increase per category.

Keywords: Climate change, spatial developments, subsidence, risk, impact, damage

INTRODUCTION

The Netherlands has been created after centuries of land reclamation, water management, and drainage induced land subsidence in the Delta of three rivers: The Rhine, The Meuse, and the Scheldt. Large parts of the present landscape are below mean sea level, and need protection against the sea by dunes and levees (See Fig. 1). Furthermore, each area is equipped with a network of canals, weirs and pumping stations to discharge excess rainfall.

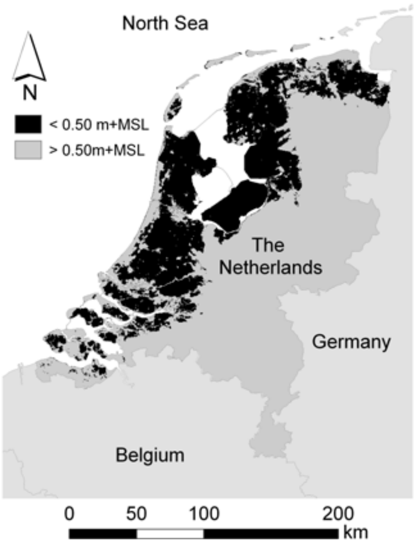

Fig. 1 The Netherlands: in black the areas below 0.50m+mean sea level that would be flooded without dikes, dunes and pumping stations

A polder water system is functioning well when it is able to withstand high outside water levels and discharge excess rainfall to the sea. The system fails when inundations occur by e.g. dike collapses or high (ground) water levels caused by extensive precipitation in combination with limited discharge capacities.

Rainfall induced floods occurred rather frequently in recent years in the Netherlands (1998, 1999, 2000, 2001, 2002, 2004). This type of flooding in polder areas is not life threatening, but can be extremely frustrating when the same farmer sees his harvest washed away in consecutive years. Furthermore, it is likely that in the future these types of flood events will happen more often, and cause more damage then nowadays. The frequency of flooding is expected to increase because of climate change. Besides, the damage in case of an event will increase due to an intensification of land use and shifts towards more expensive land use functions.

This (potential) sequence of events has started a discussion in the Netherlands whether currently available discharge capacities should be reviewed and adapted. One of the problems recognized is that the improvement of existing systems is more difficult than adapting design rules for new water systems. The necessity is determined by the robustness of the present system, the potential damage to be prevented, and financial possibilities of water authorities to invest in measures.

The research question addressed in this paper is whether there is any need to improve water systems with

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Note: Discussion on this paper is open until June 2008

respect to climate change, subsidence and spatial developments. To answer this question we need to know what the increase in damage will be and whether it is worthwhile to invest in measures to reduce the risk of flooding. Perhaps these measures themselves are more expensive than the flood damage.

To answer this question a detailed case study has been conducted for the Flevo polder. This 97,000 ha polder is the largest in the Netherlands; it was selected because land use in the polder is diverse and changing rapidly compared to other locations in the Netherlands. For this area a detailed risk assessment was made, using a combination of hydrological models, Geographical Information Systems (GIS) and depth–damage functions.

FLOOD RISK

In an optimal water system there is equilibrium between costs and benefits. In other words, inundations causing damage may occur now and then in this system, but will not be a real problem as long as extra costs for measures for a better system are equal or larger then the damages prevented by these measures (please note again that this paper discusses flooding caused by extensive rainfall, which do not result in human casualties). If a too extraordinary meteorological event is used to design the dikes, canals and pumping stations, a too expensive water system will be the result. So, there is always a certain risk of flooding that we have to accept. This risk is defined as the probability of a flood multiplied by the consequences in case of failure, and is equal to the expected annual damage (EAD) (USACE, 1996; Penning-Rowsell, 2003). The exact procedure to determine the risk of flooding depends on the type of water system studied. In general, flooding risks for river and sea systems have been studied regularly (Vrijling, 2001; Vis, 2003; Apel, 2004). Polder systems in relation to extensive rainfall are much less studied.

To evaluate the Flevo polder water system a detailed lumped rainfall-runoff model of the water system was made. With this model, 188 years of historic (hourly!) rainfall and daily evaporation records were introduced to determine 188 years of water levels. Such long term simulations are still uncommon for most Dutch polder water systems, as still not long ago computation times to determine the probability distribution functions were considerable (weeks!). However, present data availability, available computer simulation models and the possibility to have computers performing parallel calculations make long term continuous simulations applicable on a large and detailed scale. The probability distribution functions were determined by fitting a Generalized Extreme Value (GEV) distribution through the annual maxima of water levels for each location in the model.

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, as it is usually small compared to direct damage for small-scale inundations. Furthermore, it is relatively difficult to estimate indirect damages as these depend on many more factors then high water levels (Penning-Rowsell, 1986; Parker, 2000).

A unit-loss model counts items categorized in terms of relevant units. The relevant units were defined according to the land use functions of Table 1 in raster cells of 25*25 m. The maximum damage per item was based 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 Fig. 2).

Table 1 Maximum damage per land use class

Land use class	Damage function	Maximum damage
Water	-	€ 0.- /ha
Nature	-	€ 0.- /ha
Pastures	II	€ 1,000.- /ha
Arable crops	I	€ 2,500.- /ha
Horticulture, flower bulbs	I	€ 25,000.- /ha
Orchards	I	€ 100,000.- /ha
Main (rail) roads	III	€ 100,000.- /ha
Residential buildings	III	€ 225,000.- /ha
Industrial areas	III	€ 500,000.- /ha

There is much literature about depth-damage functions, basically indicating that much is still unknown (e.g. Penning-Rowsell, 2003; Appelbaum, 1985; Smith, 1994; Zhai, 2005). This is not surprising if one considers that even after real floods actual damages are difficult to assess. Many of the existing functions focus on damage to buildings and do not incorporate damage to for example crops caused by high ground water levels. We modelled 3 depth-damage functions incorporating both high ground and surface water levels. The first function reflects the replacement value of arable 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 recovery costs of buildings, green houses and roads, with damage becoming significant when surface becomes flooded with several decimeters, as many building and roads are constructed roughly 30 centimeters above the surrounding surface level.

Determination of a proper depth-damage function usually invokes a lot of discussion and limits the accuracy of the absolute risk. The applied model does not make any sub-distinctions in flood durations or seasons, or between new expensive urban areas and old houses without real economic values. However, when these functions are applied consistently, comparisons between different scenarios are possible and some impreciseness is acceptable.

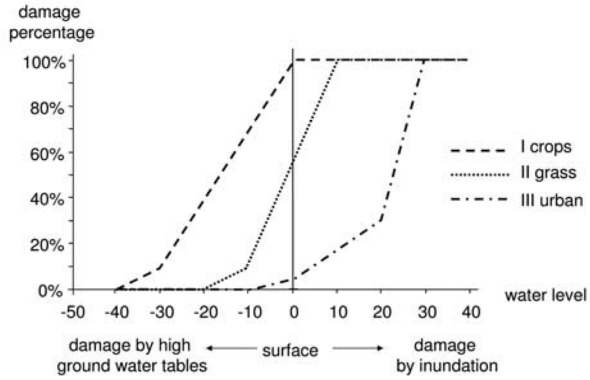

Fig. 2 Depth-damage functions

CASE STUDY FLEVO POLDER

The Flevo polder is a 97,000 ha large polder situated in lake IJsselmeer in the centre of the Netherlands (Figure 3). The polder was constructed in two phases. In the 1950-1957 period the 54,000 ha North-East part of the Flevo polder was constructed; the second 43,000 ha South-East part was realized between 1959 and 1968.

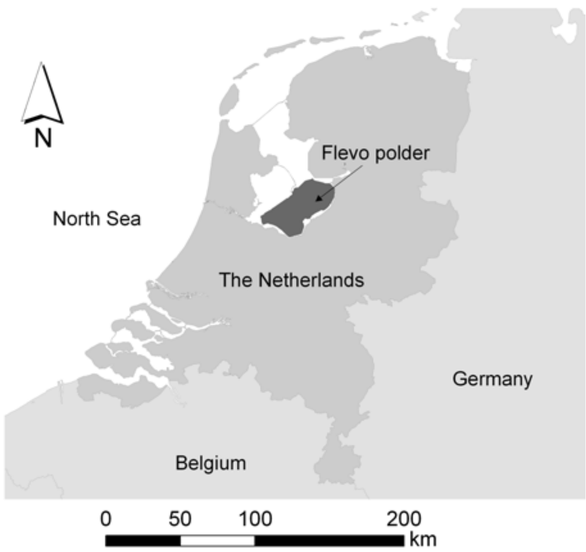

Fig. 3 Location of the Flevo polder in the Netherlands

The polder area includes two cities for which the first houses were built in 1976. Lelystad was founded in 1980 (currently with 72,000 inhabitants) and Almere was founded in 1984 (180,000 inhabitants). It is a national policy that the city of Almere may build 45,000 houses until 2030. Furthermore, a famous wetland area of 60 km^2 is located in the polder. This area accommodates amongst others some 30 rare bird species and a game population of 3,000 animals.

Climate Change

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 it is expected that the future will bring warmer summers, increased precipitation in winter and more severe and frequent extreme precipitation events. To be able to analyze the potential impacts of climate change, the Royal Dutch Meteorological Institute at The Bilt has reformulated the IPCC 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 ($\Delta T = 1°C$) in 2050 (NBW, 2003). For our simulations we adapted the rainfall and evaporation series according to changes in Table 4.

Table 2 Expected consequences of a global temperature rise (Können, 2001)

	ΔT=0.5°C	ΔT=1°C	ΔT=2°C
Yearly precipitation	+1.5%	+3%	+6%
Summer precipitation	+0.5%	+1%	+2%
Winter precipitation	+3%	+6%	+12%
Intensity in showers	+5%	+10%	+20%
Evaporation	+2%	+4%	+8%
Sea level rise	+10 cm	+25 cm	+45 cm

Spatial Developments

The expected annual damage in case of flooding over time is influenced by spatial developments. For example, the potential damage increases when an agricultural area is changed to 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.

In the case study, four maps each showing a possible future economic scenario (Global Economy, Transatlantic Market, Strong Europe, and Regional Communities) were used to estimate the influence of future developments in the Flevo polder on the risk of flooding (See Figure 4). The bases of these scenarios were developed by the Netherlands Bureau for Economic Policy Analysis; they describe four futures of Europe (CPB, 2003). The National Institute for Public Health and the Environment (RIVM) has included sustainability aspects of the four scenarios (RIVM, 2004) and translated them to land use maps for the Netherlands in 2050 (RIVM, 2005). The translation from spatial impressions of the Netherlands to spatial impressions of the Flevo polder was done by combining the RIVM data with maps from the Dutch National Mapping Agency (TOP10NL), Centre for Geo Information (LGN), and maps of the Municipalities.

Table 3 Surface in km^2 of different types of land use per scenario in year 2050

	Present land use	Global Economy	Strong Europe	Transatlantic Market	Regional Communities
Water	50	60	100	50	50
Nature	240	260	260	250	260
Meadows	90	180	230	120	260
Arable land	460	200	180	390	210
Horticulture	20	80	30	-	30
Built-up areas	110	190	170	160	160
Total	970	970	970	970	970

According to these scenarios, both the rural and urban environment will change thoroughly during the next decades. Each scenario shows a deterioration of present arable areas and an expansion of built-up 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 the Global Economy scenario. In total agriculture (meadows, arable land, and horticulture) will remain dominant, but the expectation is that, to stay ahead of East-European competitors, more expensive crops have to be cultivated more closely together. A large lake in the Flevo polder is foreseen in the Strong Europe scenario. Less development takes place with the Transatlantic Market scenario, in which agricultural areas are replaced with pastures

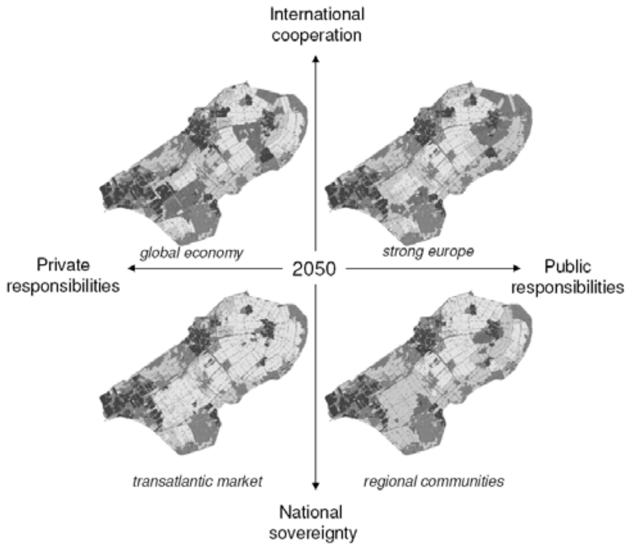

Fig. 4 Four future spatial maps of Flevo polder

Subsidence

The surface of the Flevo polder is located at - 4.4 m MSL. At the time of construction was already known, that the surface would descend several decimeters as a result of the sudden drop in ground water tension. To compensate for this surface subsidence at the same target levels, all canals were constructed deeper than necessary. To analyze the effect of subsidence on the expected annual damage the calculations were repeated with an adapted digital elevation model of the polder. Figure 5 shows the expected subsidence in the coming 50 years. The subsidence is considerable because of the relatively young age of the polder. The expected lowering of the surface until 2050 amounts from 2 to 12 cm in the North Eastern part of the polder. In the South Western part the lowering amounts from 20 up to 35 cm (Figure 5).

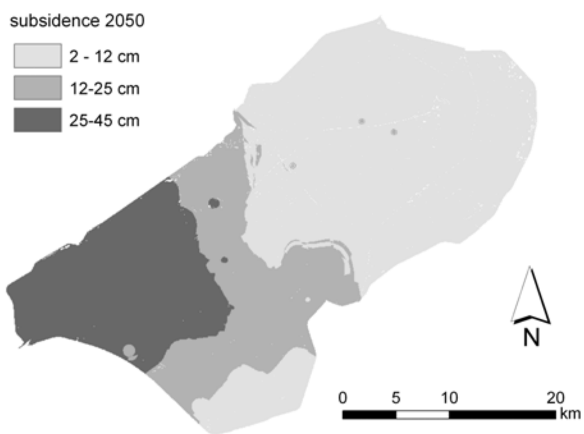

Fig. 5 Expected subsidence until 2050

RESULTS AND DISCUSSION

The results of simulated scenarios are summarized in table 4. The risk in the Flevo polder amounts to nearly M€ 1.0 a year in the present situation (taking into account land use, elevation and climate). The results show that the increase in risk due to climate change (Δt=1° in 2050) was estimated at M€ 1.7 a year (70 %), whereas the expected increase of the rainfall intensities was only about 10% (See table 4). The larger increase of risk can be explained by the fact that the return periods of heavy rainfall events (and floods) decrease more than the 10% change in intensity; extreme events will happen more frequently! Analyses of the data show that this risk increase is not homogeneous and shifts particularly to less robust areas within the water system of the polder.

Table 4 Expected annual damage in M€/year per scenario in the Flevo polder

Spatial Scenario	present climate (2005)		Δt=+1°C (2050)	
	present elevation	+ subsidence	present elevation	+ subsidence
Present Land Use	1.0	3.2	1.7	5.2
Global Economy	1.6	7.3	2.6	11.3
Strong Europe	1.5	6.6	2.2	9.2
Transatlantic Market	1.6	5.9	2.6	9.7
Regional Communities	1.9	7.5	3.0	11.0

An increase in built-up areas and shifts in agriculture (not taking into account climate change and subsidence) causes an increase in risk from M€ 1.0 to M€ 1.5 up to M€ 1.9 depending on the scenario, as damage for similar events becomes larger. This increase is of the same order of magnitude as the increase in risk due to climate change (Δt=1° in 2050).

The simulations show that the increase in risk by subsidence is dominant compared to climate change and spatial developments. The main explanation for this result is that when the surface subsides, target water levels are maintained at present levels, as these are defined in relation to Mean Sea Level and not to land surface levels (which was the reason to construct deep canals some 40 years ago). In practice, subsidence will never end, as target levels have to be revised at minimum once every ten years by law.

The combined effect of spatial developments and climate change is worse than the sum of their separate effects. To take one example, the shift from present land use towards regional communities combined with climate change and subsidence shows this combined effect:

1) The risk increase by climate change, at present land use and elevation, amounts M€ 0.7/year (See table 6);
2) The risk increase by spatial development from present land use towards regional communities, at present climate and elevation, is M€ 0.9/year;
3) The risk increase by subsidence, at present land use and climate, is M€ 2.2/year.

So the sum of their separate effects (M€ 0.7/year + M€ 0.9/year+ M€ 2.2/year) is M€ 3.8/year. When simulated together the increase in risk amounts to M€ 10.0/yr, which is larger. This effect of a larger risk increase when combining processes is visible in all scenarios studied. The cause of the influence of combining effects is the multiplication of damage and consequences.

The spatial variation of risk over the area ranges from € 0 to €10,000 per hectare per year (See Figure 6). The risk spread throughout the area shows vulnerable and robust areas. This kind of maps showing the spatial risk pattern is very useful to explain to several stakeholders (citizens, politicians, usually not being engineers) that impacts of climate change and differences between land use options are not similar for each plot within a polder. Risk patterns are not homogeneous.

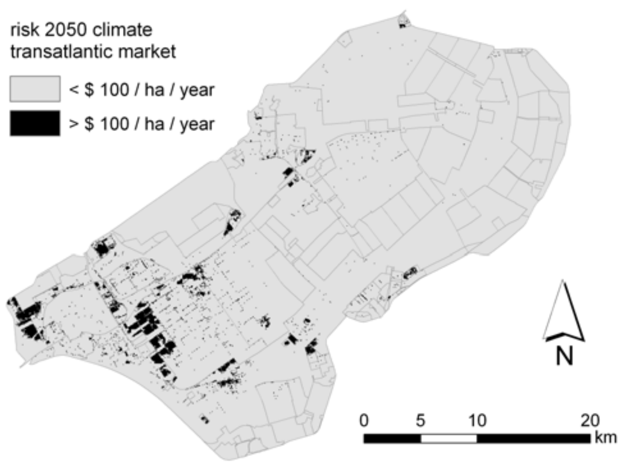

Fig. 6 Risk map for scenario Transatlantic Market, 2050 climate and subsidence

CONCLUSION

The research question addressed in this paper was whether there is any need to improve the water system with respect to climate change, subsidence and spatial developments. To answer this question we need to know what the increase in damage will be and whether it is worthwhile to invest in measures to reduce the risk of flooding.

This paper has outlined a method for estimating the risk of flooding due to precipitation under different scenarios. The case study of the Flevo polder showed that the impact of climate change will increase the risk significantly, but that, depending on the scenario, changes of the land use may have more influence. However, dominant is the increase caused by subsidence.

Limitations of the methodology presented are the influence of uncertainties in the data used and taking into account only direct damage. Ignoring indirect damage may become a problem, as avoiding these risks may increase the benefit of spatial developments enormously. For this reason it is recommended to include risk analyses only as a part of decision making procedures, to prevent measures that are absolute unfeasible.

Although the results of this study are based on future scenarios, which do not show the 'real' future, the case study clearly shows the feasibility of this type of analysis. The results allow stakeholders to monitor spatial developments in polder systems and anticipate on the effects of possible future developments on their water systems in terms of risks, costs and benefits. An important result of this study is that it is vital to take into account the combined risks of future developments. It was clearly shown that the sum of the individual risks of the three categories climate change, land use and subsidence was lower than the combined risks when taking into account all three categories simultaneously, in all scenarios. Thus, despite all uncertainties, it is certain that any decision making process concerning future water management aimed at risk reduction should not be based on separate tracks of analysis, as this will tend to underestimating risks.

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