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An economical optimal investment strategy in a multi-layer flood risk approach

B. Kolen
HKV consultants, The Netherlands
Nijmegen School of Management, Radboud University Nijmegen, The Netherlands

M. Kok
HKV consultants, The Netherlands
Delft University of Technology, The Netherlands

ABSTRACT: Flood risk reduction can be obtained in many ways and by many measures. A common approach in The Netherlands is to divide the measures in three layers: flood prevention, land use planning and emergency measurement. An important question is how to select the measures among these layers, and whether it is necessary to select measures in all three layers. In this paper we follow an economic approach: the selection of measures is guided by minimizing the total costs (for example investments, risk and maintenance). The method is applied for the Dutch context. It can be concluded that in the Dutch polder context, the main part of the investments is in flood prevention, but it is often also optimal to invest (in our examples < 1% of the total costs) in improvements for the organization of emergency management. As a general rule of thumb, the results of our method show that the smaller the optimal flooding probability, the smaller the part of the investment is invested in the organisation of emergency management. Investment in physical measures (land use planning, emergency personnel, road capacity) are in general not cost effective with regard to flood risk management. Possibly, coalitions (and combination of budgets) for these measures can be organized to fulfill other objectives, which will, however result in more complex projects. In addition, multi layer flood risk is not only about the design of the measures, but also about the question how to maintain and how to periodically inspect them. The maintenance (inspection and repair) can be costly for specific measures. It can for example be questioned if regulation to minimize flood risk by land use planning should applied in entire areas or only in specific zones.

1 INTRODUCTION

Different approaches for flood risk management have been adopted in various parts of the world. Coastal floods from storm surges threaten countries around the North Sea in Northwestern Europe. A detailed review of coastal management policies in the Northsea area (Safecoast, 2008) showed that most countries mainly rely on protection against flooding by means of defences and nourishments, whereas the UK takes a more holistic approach to manage the flood risks. In other parts of the world tropical depressions (also referred to as hurricanes, typhoons or cyclones) can lead to significant coastal flooding. For example, in the coastal regions in the US, the risks of these events are managed by a combination of hard defences (e.g. the levees in New Orleans), flood insurance and warning, evacuation and emergency management (Pilkey, 2005). Other parts of the world, e.g. Bangladesh, have a lower level of protection from physical flood defences and warning, shelter and evacuation are a key factor in reducing the loss of life (Chowdhury,, 1993). An important element in coastal planning and policy in various parts of the world concerns the assessment of the effects of climate change and sea level rise on flood risks and vulnerability (Nicholls et al., 2011).

Flood risk is defined as the product of the probability of flooding and the consequences of flooding. Consequences are often expressed as economic costs and loss of life. Both indicators are important and are to be considered in discussing acceptable (or tolerable) risk. The consequences of a flood depend on the characteristics of natural phenomenon, the demographics and economic activity of the exposed area and emergency measures.

A flood risk management strategy can consist of multiple layers, such as prevention with levees, land use planning, building codes, insurance and emergency management. A multiple layer safety approach as followed in The Netherlands consists of three layers: (1) prevention (2) land use planning and (3) emergency management (VenW, 2009). In the US, see for example (Lopez, 2006), and Canada, see for example (Council, 2008), similar approaches are used and called 'multiple lines of defense'.

The concept of multiple layer safety distinguishes the probability for flooding as well as the consequences. Therefore the risk as the probability × consequences is the central element, such an approach can be used to evaluate flood risk management (ten Brinke et al., 2008a).

In a cost-benefit analysis the costs of loss of life is expressed in an economical loss. In addition to decision with regard to the allowed numbers of casualties per year or group of casualties per year a cost benefit can be used to verify if investments are effective with regard to prevention of loss of life.

Although investments in each layer can contribute to flood risk reduction, it is not clear what the optimal mix of investments is in an exposed area, from a cost-benefit point of view. The probability of a flood event can be reduced by strengthening levees (in the prevention layer). The consequences can also be influenced positively or negatively by human actions. Movable goods, people and animals can move to places outside the exposed area (Vrijling, 2009) in case when there is a reliable flood warning and enough time is available. Moreover, these can be replaced to relative safe places inside the exposed area.

It can be questioned if investments in multiple layers have to been done using an economical perspective. A system as a safety chain or multiple layer safety system should not be interpreted as a serial system: the safety chain or different layers are not as weak as its weakest link (Jongejan and Vrijling, 2006). Research of (Vrijling, 2009) shows that if a multiple layer system is considered as a parallel system consisting of layers; the layer with the lowest marginal costs is applied, the other is omitted. However, in the model of Vrijling the benefits of emergency management is modeled as a reduction of the probability of flooding, whereas in our model these benefits is modeled as a reduction of the consequences of flooding, which seems more appropriate.

This paper describes a cost-benefit method to optimize investments in a flood risk management strategy based on a cost benefit approach in a multiple layer system. The costs are the required investments of the measures, and the benefits are the reduction in flood risk. The method is applied for two different areas: an area with a high and low economical value. The cost benefit method results in optimal investment strategy that can be applied in deltas worldwide. We also consider some non-economical criteria that may justify investments in a multiple layer safety approach.

2 METHODOLOGY

2.1 *Introduction*

A cost benefit analyses assesses the optimal investment strategy for flood risk management. Based on a cost benefit approach the need to invest in multiple layers can be defined related to their reduction to the risk, and the costs of measures. In addition these measures can also contribute to other objectives of a society. For example when a dike can be used for multiple forms of land use and a firemen can also be used for other purposes then flood risk management. We focus on a three layer system: flood prevention (reducing the probability for flooding), land use planning and emergency management (both reducing the consequences of a flood). The key question is how much investments are justified in each layer in an optimal investment strategy.

Flood risk management is mainly relevant for areas with some kind of man-made value. A flood is considered is a (often low frequent) event which is a disturbance of 'normal' life in an existing system, and which causes damage. There are systems where floods can be beneficial (for example in large agricultural systems where growth of the crops is dependent of water and fertile soils) but in this paper we consider areas where people live and work (for example urban areas). In other words: a flood is considered to be a crisis based on the common used definition 'a serious threat to the basic structures or the fundamental values and norms of a system, which under time pressure and highly uncertain circumstances necessitates making vital decisions' (Rosenthal et al., 1989). Hence, also emergency services are therefore part of the system. These services are often focused on incidents and small disasters as fire in buildings, car accidents etc. In case of floods, these services can be used to mitigate the impact of a flood.

We consider three types of measures to keep the model as simple as possible. The first type of measure improves flood defences and reduces the probability of flooding. The second type of measure improves the quality of the emergency services by a better organization (by investment in planning, knowledge etc). The third measure are investments in emergency resources and road infrastructure or buildings. The second and third group of investments reduces the consequences of a flood. Of course, much more types of measures can be defined, but this will make the analysis more complex.

2.2 *Effectiveness of emergency management and land use planning*

In a one-layer prevention approach no specific attention is made for emergency management or land use planning with regard to flooding. This does not mean that no land use planning, emergency management, or citizen response, will take place in case of a possible flood event. Existing emergency services and citizens (although they have a very low risk perception very (Terpstra, 2009)) will act based on their local expertise and perception of the risk as well will citizens (Helsloot and Ruitenberg, 2004). Historical analyses of land use planning also show that the possibility of flooding is sometimes taken into account.

For the Dutch situation a flood is considered to be a national crisis because of the impact of the event and the involvement of many stakeholders. This means that many stakeholders have to work together in an uncommon, never experienced, situation. The impact on the society will be enormous, large scale areas will flood for multiple weeks or months. Even when buildings are elevated economic and social processes will stop and damage will occur (people who cannot go to school, businesses that will go bankrupt etc).

In our reference strategy, no special preparation for flooding measures will be taken by emergency organisations or by land use planners.

However it is assumed that emergency services are available because of other threats for the society. Accordingly, it is only by accident that the outcome will result in optimal actions of emergency management. In case of fire in buildings it is known that a lack of understanding of the threat and incorrect expectations about the infrastructure, people (and rescue workers) put themselves into danger (Proulx, 2001). However, measures by rescue workers and citizens for emergency management in flood risk management will improve the effectiveness of emergency management, by for example: improvements in the organization of emergency management, and increase of the available recourses, personal and available infrastructure.

For developed areas it is assumed that no specific attention is given to how and where to build in our reference situation. Despite some high buildings or floors of houses will not flood.

2.3 *Measures to reduce flood risk*

2.3.1 *Reduction of flood risk*

The probabilities of flooding can be reduced by strengthening flood defenses (see Vrijling, 2009).

2.3.2 *Organization of emergency management*

Mass response of authorities and measures by rescue workers can create better and worse circumstances to prevent loss of life in case of large scale flooding (Haynes et al., 2009; Kolen et al., 2010a). A better understanding of uncertainties and biases improves the outcome of decision making (Tversky and Kahneman, 1974). The theory of Distributed Decision Making (defined as the design and coordination of connected decisions (Schneeweiss, 2003)) describes the optimisation of multiple decisions and multiple organisations. The theory states can be used to describe the complexity (or impossibility) for a central body to control a society because tasks are differentiated over several bodies. The theory becomes more relevant when more stakeholders are involved. This means that stakeholders should take other decisions of other stakeholders into account in such a way that they do not frustrate their own decisions.

The improvements of the organization of emergency management result in better overall decisions, and possibly better use of knowledge of uncertainties. Decision makers and crisis managers can create better circumstances to conduct emergency measures and citizens response. These measures can be taken in the period between the first warnings and when all stakeholders will act based on their own perception of the risk. This period is called the 'transition phase'(Kolen et al., 2010a). Examples of measures are:

- Better use of early warnings for decision making;
- A more early implementation of national traffic management by traffic management services
- A more clear line of communication and instruction to the public and rescue services
- A risk based approach so more attention is paid to high risk areas.

Investments in the organization can result in a reduction in loss of life because of the better use of available rescue services, means and infrastructure. These investments are relatively cheap because these are mainly related to development and maintenance of new knowledge about the organization (for example: making decisions together, use of available resources and infrastructure). It is not possible to reduce the risk for loss of life to zero because of limited infrastructure, resources and unexpected events, further improvement becomes very difficult because all means are used optimal (Kolen and Helsloot, Accepted, scheduled for 2012).

2.3.3 *Increase of the available recourses, emergency personal and available infrastructure*

Examples of this type of measures are the increase of the capacity of physical infrastructure (as road capacity) and investments in extra ambulances, fire trucks and personnel. The available resources and infrastructure is in the current situation overloaded by far in case of a mass evacuation (AGS, 2008; Kolen and Helsloot, Accepted, scheduled for 2012; ten Brinke et al., 2010). Investments in these measures will increase the already existing capacity (designed for other purposes then flood risk). For example the resources of emergency services are based on a one in five year event, a far higher frequency than the frequency of a flood (AGS 2008).

2.4 *Mathematical description*

The optimization model we use is well known, and is for example applied in (Dantzig, 1956; Vrijling, 2009). However, we will adopt a few changes in the model, which will later be explained.

We model the probability of flooding by the annual probability of exceedance of the crest level h of the dike is given by an exponential distribution with parameter A and B:

$$P(h) = 1 - F(h) = e^{-\frac{h-A}{B}} \tag{1}$$

The consequences of flooding in the reference situation is modeled as the economic damage D_0 (for example damage to houses, infrastructure, etc) and loss of life s_0 (number of victims). In order to perform the cost-benefit analyses, each victim is economically valued as V. For sake of simplicity it is assumed that the damage is not influenced by the strength of the flood defenses. The risk of flooding R is defined as the probability of flooding multiplied with the consequences of a flood:

$$R = e^{-\frac{h-A}{B}} \cdot \left(D_0 + V \cdot s_0\right) \tag{2}$$

The risk is calculated per year, and in a cost-benefit analysis we have to sum the yearly risk. We calculate the present value over an infinite period with r the discount rate:

$$PV(h) = \sum_{i=1}^{\infty} e^{-\frac{h-A}{B}} \cdot \frac{D_0 + V \cdot s_0}{(1+r)^i} = e^{-\frac{h-A}{B}} \frac{\left(D_0 + V \cdot s_0\right)}{r} \tag{3}$$

The risk can be reduced by measures in the first layer (prevention) by a reduction of $P(h)$ by increasing the height h (and other strength variables) of the flood defense system. The required investment is defined as $I_1(h)$, the investment is a function of the height of the levee system. We will assume the following investment function:

$$I_1(h) = a + b \cdot \left(h - h_0\right) \tag{4}$$

where h_0 is the current height of the dikes, $h \geq h_0$.

In our model, emergency management and land use planning can cause a reduction of loss of life indicated by the variable s and/or a reduction of economical damage (D). The required investment for this reduction of the consequences is defined as the combination of:

- Measures with regard to buildings (e.g. building codes, elevation of surface level etc) as G.
- A better organization of emergency management (e.g. planning, exercises, coordination structures). The costs of these measures are yearly costs, defined by E.
- More equipment, personnel and infrastructure regarding to flood risk, the investments are defined as F.

The number of victims in the current situation is equal to s_0. The present value of the flood risk is a function of the parameter s and D_1

$$\begin{aligned} PV(h,D,s) &= \sum_{i=1}^{\infty} e^{-\frac{h-A}{B}} \cdot \frac{(D_0 - D) + V \cdot \left(s_0 - s\right)}{(1+r)^i} \\ &= e^{-\frac{h-A}{B}} \frac{\left((D_0 - D) + V \cdot \left(s_0 - s\right)\right)}{r} \end{aligned} \tag{5}$$

The total investments costs related to investments costs in emergency management and land use planning are:

$$I_2(D,s) = c + d \cdot (D_0 - D) + e \cdot \left(s_0 - s\right) \tag{6}$$

The total Investments are defined as:

$$\begin{aligned} I(h,D,s) &= I_1(h) + I_2(D,s) \\ &= a + b \cdot \left(h - h_0\right) + c + d \cdot (D_0 - D) + e \cdot \left(s_0 - s\right) \end{aligned} \tag{7}$$

The total cost TC are the combination of the total investment costs and the Present Value of the risk with three decision variables h, D and s:

$$\begin{aligned} TC(h,D,s) &= PV(h,s) + I(h,s) \\ &= e^{-\frac{h-A}{B}} \frac{\left((D_0 - D) + V \cdot \left(s_0 - s\right)\right)}{r} \\ &\quad + a + b.\left(h - h_0\right) + c + d \cdot (D_0 - D) + e \cdot \left(s_0 - s\right) \end{aligned} \tag{8}$$

Applying $TC(h,D,s)$ for different values of h,D and s (applying complete enumeration) gives the opportunity to compare these results with the one layer optimization approach as given by (Vrijling 2009). There, the optimal probability is given as (substituting this solution in the optimal number of the reduction of loss life, we obtain $D^* = 0$ and $s^* = 0$):

$$P\left(h^*\right) = \frac{b \cdot B \cdot r}{(D_0 + V \cdot s_0)} \tag{9}$$

Given a value of h^*, the Present Value of the yearly risk, which takes the probability for flooding into account, gives an upper limit of the allowed cost (investment and maintenance) for emergency management and land use planning based on an economical cost benefit analyses. When the economic value for loss of life is taken into account the cost benefit analyses can also be applied for investments to reduce loss of life. If all measures in layer 2 (land use planning) and layer 3 (emergency management) are more costly than the upper limit of the allowed costs, it can be concluded that all investments should be spent on layer 1 (prevention). However, if the costs of one measure in layer 1 or layer 2 is lower the the PV of the costs, than it is also attractive to take measures in layer 1 and 2. Hence, in our approach the crucial question is whether the measures are cost effective.

An investment can economically be justified when (given the optimal value of h^*, the values s^* and D^* have to determined):

$$P\left(h^*\right)\left(V \cdot (s_0 - s^*) + (D_0 - D^*)\right)/r \\ > c + d \,.\left(D_0 - D^*\right) + e \,.\left(s_0 - s^*\right) \tag{10}$$

Because the probability for flooding is never equal to zero this means that some emergency or land use planning measures can be justified if the PV of the costs is less than the PV of the reduction in the yearly risk. Note also that the maximum allowable costs for these measures decrease with the flooding probability.

3 NUMERICAL EXAMPLES

In this chapter we described two examples applied for the Dutch context. The first example focuses on reduction of only loss of life by investments in the organization of emergency management and investments in additional emergency capacity and physical road infrastructure. The second example focuses on investments in land use planning to reduce the consequences of flooding.

3.1 *Reduction of loss of life*

We choose the following numerical values of the parameters (partly based on (Dantzig, 1956; Vrijling, 2009) which are applied for one particular dikering area (14) in The Netherlands). The economic value for loss of life is based on recent research (Bočkarjova et al. 2010) which is also applied in discussion about new safety standards in The Netherlands (De Bruijn et al. 2010):

$B = 0,301$;	$V = 6,7$ M€;
$s_0 = 1000$ persons;	$a = 110$ M€;
$b = 40$ M €/m;	$A = 2,329$;
$h_0 = 2,3$ m;	$r = 1,5\%$

We take two different areas into account:

1. An area with high economic value D_0 = 24.000 M€,
2. An area with low economic value $D_0 = 5.000$ M€.

Figure 1 shows the relation between costs and benefits (including the optimum) in a one layer approach for these areas and presents the differences when the economic value for loss of life is taken into account. In a multi-layer approach loss of life can be reduced by emergency management. In our simple model emergency management can only reduce loss of life, Figure 1 shows the maximum result by the line when loss of life is not taken into account. This illustrates that measures that reduce loss of life has (in general) more potential in a low value area than in a high value area because the optimal flooding probability is higher in low value areas compared with high value areas.

In our model we estimated the costs and benefits of emergency management and land use planning. Not much literature is available for the costs and benefits of organization of emergency management.

We used the method EvacuAid (Kolen et al,. 2010a) to effectiveness of preventive evacuation and the relation with improvements in emergency management. The expected number of people that can evacuate preventive is at this moment estimated at 15% for dikering 14 in The Netherlands (Maaskant et al., 2009). Improvements in the organization in emergency management can be determined on a scale of 1 to 5 (with 3 as the current situation and 1 as the best case) for the combination of citizen response, decision making and use of physical infrastructure.

Improvements in the process of decision making also reduce the necessary time for decision

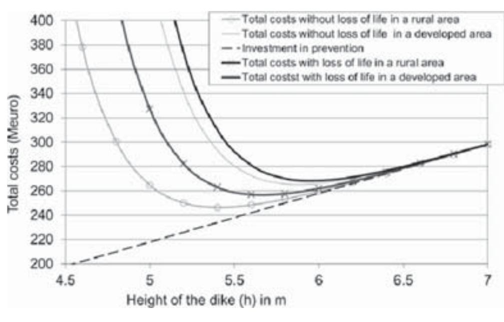

Figure 1. Cost and benefits relation for an area with high economic value and low economic value.

Table 1. Evacuation fraction related to investments.

	Conditional probability for the available time for the current situation (Maaskant et al. 2009)	Conditional probability for the available time after improvement to scale 2	Conditional probability for the available time after improvement to scale 1 (best case)
4 days	5%	10%	12,5%
3 days	10%	15%	25%
2 days	30%	35%	37,5%
1 days	45%	30%	20%
No time	10%	10%	5%
Evacuation fraction	15%	29%	39%

making declines. A better understanding about the risk reduces the time needed for coordination and measures can be implemented more quickly. Table 1 presents the conditional probabilities of the available time we used in the current situation and after investments in the organization of emergency management. Because of extreme wind speeds before a possible dike breach (ten Brinke et al,. 2010) we assumed that no measures can be executed during the last day before the dike breach.

Table 1 also presents the consequences of the evacuation fraction after investments from the current situation to scale 2 and scale 1 (best case).

The costs to increase the number of rescue workers, resources and infrastructure (*F*) are relatively high compared the costs for the organization for emergency management (*E*). The PV of the yearly expected loss of life risk already indicates that high investments do not seem cost effective, therefore most attention is paid to *E*. In our model therefore we assume, using above analyses, that *c* is 0€ because no initial costs are taken into account (emergency services already exists). *d* is de combination of costs *E* (better use of available personnel and equipment) and *F* to increase the number of personnel, equipment and road capacity. The costs and effectiveness of these investments in terms of reduction of loss of life are however uncertain. In de period 2007–2008 the national Task Force Management invested 15,7 Meuro to invest in preparation for flooding (research, workshops, planning, communication and large scale exercises) and several improvements (TMO, 2009). The cost of the development of a regional emergency planning for flooding (Dikering area 22) is estimated at 0,1 Meuro (Stone, 2011). TMO also state that further improvements are possible and necessary. The costs of the national exercise Waterproef in 2008 were aimed at 1,5 Meuro (of which about 0,7 Meuro for a risk campaign). During these exercises some general procedures are tested (for all kind of threats) and some specific elements for flooding. The costs of the next national exercise for flooding in 2012 are estimated at about 0,9 Meuro. Assuming that the average budget for a national exercise is about 0,8 Meuro, that these are held each 4 years, 50% can be related to flooding and these are spread over 25 safety regions makes about 4.000 euro per year per safety region (equal to a contact value of about 0.25 Meuro.

Literature (Jonkman, 2007; Jonkman and Vrijling, 2008) shows that a first estimation of mortality rates for coastal areas is about 1%. An analyses of dikering 14 (Jonkman 2007) shows that mortality rates can decrease up to 0,1% by taking measures. Mortality rates in EvacuAid are related to different locations where people can lose their life during a flood event: because of traffic accidents as when being exposed while at home (prepared or not), in a shelter, in a car (Kolen et al., 2010a). These figures are based on (Jonkman, 2007; Jonkman et al., 2009).

A better organization of emergency management is also expected to result in a reduction of mortality rates: people are better prepared. Therefore we also assume that mortality rates decrease by a factor 2.

Even in a best case situation a 100% evacuation is not realistic; therefore the number of casualties cannot be reduced to zero. Because of unexpected events (zero lead time) and unforeseen events as car accidents the risk will never be reduced to zero, even after an increase of the number of resources and infrastructure. Therefore always a risk for loss of life will remain. The cost-benefit function therefore does not apply up to a complete reduction of casualties. Because of the used function the costs will increase dramatically and therefore are economical not attractive. Based on the assumptions above we used the following relation between investments and reduction of loss of life:

- An investment of 0,35 Meuro in planning and exercises will increase the effectiveness of evacuation by 15% (scale 2 in EvacuAid), combined with better citizens response because we assume also loss of life will decrease by 15% (150 persons).

- An investment of another 0,35 Meuro will decrease loss of life by another 100 persons (10%)
- An investment of another 1 Meuro will result in an maximal effectiveness of improvements in the organisation of emergency management which results in another reduction of 100 casualties
- Additional emergency personnel, equipment and road capacity will only result in less loss of life when the increase is significant to existing capacities. To make is simple we assume that the costs for each additional reduction of loss of life of 50 persons increases the costs by a factor 10.

No additional investments are made in buildings to reduce flood risk, therefore G and D_0 are equal to zero. The costs c and e and benefits s are assumed equal for the areas with high and low economic value.

Table 2 presents $P\left(h^*\right)$ for multiple layer approach in our method and $P\left(h^*\right)$ using the one layer approach model of (Vrijling, 2009). The lowest marginal costs are a combination of the layers prevention and the organization of emergency management. The contribution of the investments in the layers 'emergency management' is the most for area with the lower economic value. This was already expected because as could be seen in Figure 1. The required investments in emergency management are improvements of the organization (instead of investing in additional emergency personnel, equipment). The investments in land use planning (in the example additional road capacity) are not cost effective in the shown example.

Table 3 presents the costs given levels of h and s for the urban area. It is shown that given a level of h an investment in the organisation of emergency management can reduce the total costs. In the chosen example it can be seen that when h is 3.5 m even investments in the physical measures in the layer land use planning (additional road capacity) and additional emergency resources and personnel in the layer emergency management contribute to the lowest total costs.

For h = 6.0 m, investments in emergency management and prevention (but no investments in land use planning) results in the same total costs as when investments are only made in the layer prevention: the reduction in risk costs is equal to the costs of the measures. When h is relatively higher, the budget for investment in the organization of emergency management with regard to loss of life declines (with the present value for loss of life) but will never reduce to 0. Non expensive measures in the field of emergency management as planning, training and research and education, or those who are also financed because of other purposes (as fire in buildings, extreme weather or crisis communication structures etc.) will contribute to the lowest marginal costs.

When only limited budget is available for flood risk management, our model can also be used to optimize the investments. Investments in the layer of prevention require a minimum budget for the initial costs (a). When the available budget is less investments in emergency management can be an alternative.

For areas where a reduction of the probability is not allowed or when it is decided not to invest a reduction of the probability investments in physical measures can be cost effective. However in these cases it is chosen not to invest in strategies that give more value for money to reduce flood risk.

3.2 *Reduction of damage by land use planning*

Land use planning and specific (structural) measures to constructions can reduce the economic damage after a flood. Based on the same reference

Table 2. Optimal level of prevention in a one and multi-layer safety approach that focuses on reducing loss of life.

	With loss of life		Without loss of life	
	High value area	Low value area	High value area	Low value area
One layer approach (Vrijling, 2009)				
$P(h^*)$ per year	**5,96E-06**	**1,56E-05**	**7,52E-06**	3,59E-05
h in m	5,95 m	5,66 m	5,88 m	5,41 m
s (persons)	0	0	0	0
TC (h,s) in Meuro	268,21	256,59	265,24	246,35
	High value area		Low value area	
Multi layer safety approach with regard to loss of life				
$P(h^*)$ per year	**6,59E-06**		2,11E-05	
h in m	5,94 m		5,62 m	
s (persons)	150		250	
TC (h,D,s) in Meuro	268,15		255,43	

Table 3. Total costs in M€ for values of h and s, in an urban area.

h → s ↓	3.50	4.50	5.50	6.00
0	4.20E+04	1.71E+03	2.92E+02	2.68E+02
150	4.06E+04	1.66E+03	2.91E+02	2.68E+02
250	3.97E+04	1.63E+03	**2.90E+02**	**2.69E+02**
400	3.84E+04	**1.59E+03**	3.05E+02	2.84E+02
450	**3.80E+04**	1.73E+03	4.57E+02	4.37E+02
500	3.91E+04	3.24E+03	1.99E+03	1.97E+03
600	2.07E+05	1.72E+05	1.70E+05	1.70E+05
900	–	–	–	–

Table 4. Optimal level of prevention in a multi-layer safety approach that reduces the damage by 25% (with loss of life).

	High value area	Low value area
$P(h^*)$ per year	7,28E-06	1,73E-05
h in m	5,89 m	5,63 m
TC (h,D,s) in Meuro	265,58 + investments for land use planning	255,2 + investments for land use planning

situation as used for loss of life we assume that the damage can be reduced by for example 25% when structural attention is given for a longer period to land use planning and building codes. For the high value area D_1 = 6.000 M€, for the low value area D_1 = 3.750 M€. A reduction of loss of life is not taken into account. Table 4 presents the optimal h based on the combination of investments in prevention and land use planning. Because of the investments in land use planning the optimal dike level reduces with 6 cm in the high value area and 3 cm in the low value area.

The cost of the investments in land use planning are not defined. However the available budget for cost effective measures can be defined. For the area with high economic value the 25% reduction of damage has to accomplished for 2,6 Meuro or less to be cost effective. For the low value area the budget is 1,4 Meuro. It is clear that the available budget with regard to reduce flood risk by land use planning is minimal.

3.3 *Combination of prevention, land use planning and emergency management to reduce the risk*

In de the examples above we focused on a reduction of loss of life and on a reduction of economic damage. Both strategies can also be combined

Table 5. Combination of all layers.

	Combination of example 1 and 2	
	High economical area	Low economical area
$P(h^*)$ per year	7,78E-06	2,04E-05
h in m	5,87 m	5,58 m
s (persons)	250	250
TC (h,D,s) in Meuro	265,44 + investments for land use planning	253,83 + investments for land use planning

using the same approach. Table 5 shows the remaining risk and total costs. The economic most optimum combination is a combination of all layers. Because of the reduction of the consequences of both emergency management and land use planning these measures become more efficient. The reduction of the remaining optimal dike level is more than when both measures than the sum of the individual measures. However the far majority of the investments are foreseen in layer prevention.

4 DISCUSSION

4.1 *Non-economic reasons for emergency preperation to reduce loss of life*

The previous chapter describes the optimization of investments in a multi layer safety system consisting of the layers 'prevention', 'land use planning' and 'emergency management'. Earlier research concluded that for The Netherlands the flood defense strategy (prevention) cannot be replaced by measures in other links of the chain, but more pro-active measures and additional efforts on preparation, response and recovery can be added to the policy to reduce flood risk further (ten Brinke et al., 2008b). This conclusion is supported by the results of our model by economic reasons. However when the flooding probability is low, the contribution of the layer emergency management to the total marginal costs will decline as well. Because of the limited contribution, and possible impact of uncertainties in costs and benefits, consequences and human failure, still a discussion might rise about the need for investments in (the organization of) emergency management to reduce loss of life. Therefore a wider perspective can be given for the need for attention for the layer 'emergency management' as a second layer next to prevention. Emergency planning, training and exercise, research and education are low cost measures because these do not require investments in physical infrastructure and could improve the use of existing infrastructure and better strategies for evacuation and better use of available time.

In democratic societies citizens expect of their (chosen) leaders to take care for them in case of a crisis (Boin et al., 2005). Even when it is clear that not all the consequences can be prevented (BZK and VenW, 2008), responsible measures, based on the available information, knowledge, resources and infrastructure, should be taken by the government. This means that also in case of a threat for flooding, the public expects measures by the government for their safety. A survey in 2009 in the area of Zeeland (which faced a flood in 1953 with about 1800 casualties) showed that the majority of the public expects the government to invest in disaster management and risk communication. Only 5% stated that these investments were not important and the entire budget should be invested in prevention (Terpstra, 2009). Research (Gutteling et al., 2010), supported with surveys among citizens during a period with a (temporary) increase of attention for flooding in The Netherlands (Baan et al., 2009), concluded that fear and panic by the public after communication about flood risk is a myth.

A survey among Dutch majors and crisis managers (top advisors of the majors) showed that the accountability is also one of the key drivers for emergency preparation (Kolen and Helsloot, in review). When only the accountability is used as a driver for emergency preparation this could result in fantasy documents (Clarke, 1999). (Helsloot, 2007) even states that emergency preparation for flooding is in fact symbolic because the plans are not connected to each other and the consequences are unknown.

The question however remains if the investment E is realistic related to the reduction of loss of life. More research is needed on this topic.

4.2 *Land use planning in perspective*

Efficient investments in infrastructure as levees will be implemented for a long period, often 50 years.

As for emergency management also for land use planning measures can be justified when the marginal costs are less than the marginal benefits. Also coalition with other purposes of land use planning (living, business, tourism, ecology etc.) could create opportunities to minimize the costs when budgets and purposes are combined although this increases complexity of these land use planning and development processes. An expert session organized by the Dutch Government however showed that the costs of land use planning measures increase by multiple %. When areas are partly (50% of the area) elevated the cost increase by about 5%, when these are completely elevated the cost increase by 10%. Investments for buildings (so called wetproof and dryproof developments) raise costs for buildings by 5–20% but for these measures it is assumed that water depths are limited to about 1 to 1.5 m and the water is removed in a couple of days to some weeks (RWS, 2008). The total consequences of the measures as foreseen in the example have to reduce the economic damage by 25% for a budget of maximal 2,6 Million Euro for the high value area and 1,4 Million Euro in the low value area.

Land use planning and especially (re)developments of urban areas are (more or less) continuous activities. Each year measures are foreseen to develop or reconstruct areas where the question might raise how to deal with flood risk. This requires a mechanism that can handle these questions. This mechanism has to be able to define criteria or standards (related to the required level for flood risk), architects and land use planners have to take these criteria into account while developments are also made for other purposes. Recent policies (as (IenM, 2012)) about land use planning focus on decentralization. Most developments are made on local scale therefore permits or buildings codes are also developed on the local level. The entire mechanism to cope with flood risk and land use planning therefore requires significant numbers of people to be able to implement physical measures. The costs of the management of this mechanism might already exceed the available budget when regulation is made to complex. Note that the presented available budget as presented in the example is a one-time investment and not a yearly investment.

In addition the policy for land use planning has to be applied for multiple years to become effective (note that the frequency of a flood is less then 1000 year). It can be questioned if the structure for land use planning will remain that long. During the during in the aftermath of the flood event Xynthia in France it was shown that zoning policy failed over time because local decision makers allowed development in high risk areas over time (while risk perception reduced) for economic development of local communities (Kolen et al., 2010b).

4.3 *Acceptable level of risk*

The acceptable level of risk is a political decision that includes values. (Jongejan, 2008) states that no scientist can claim to possess the knowledge about risks that are acceptable for all but this is also no fundament for mindless relativism. Therefore the economical approach in this paper is information for policy makers to make tradeoffs with expectations of the public and the use of symbols. An economical approach could also contribute to connect several planning documents because an economic approach forces to define the results in terms of loss of life and damage. When this is known also improvements can be made and the organization of emergency management can be optimized.

5 CONCLUDING REMARKS

This research describes a method how to optimize investments in a multi layer safety approach that can be used to minimize the total costs. The method shows that when the consequences reduce investments are more spread over all layers. When the value of an area increases the role of prevention increases as well related to the other layers as land use planning and emergency management. Investments that focus on physical measures (additional personnel, emergency equipment, elevation of surface level, adaptive building etc.) have to reduce the consequences significantly because of the high costs. Investments in the organization of emergency management (that focus on better use of infrastructure, emergency personnel and resources and citizen response that are already in place) by planning, training, education and research are relatively low cost and therefore more cost effective.

The paper shows that prevention is in the Dutch context the most important layer for the already protected areas, but that other layers as emergency management can contribute to the lowest total costs. Especially when the probability of flooding is relatively low, the contribution of emergency management is also relatively low. However, given the optimal safety level of the flood defense system, emergency measures will reduce the total costs. When budgets for investments are limited our method can be used to prioritize investments.

This research also shows that there are other objectives that supports investments in emergency management than an economical perspective. Expectations of the public how their leaders will respond in case of a crisis and expectations of decision makers about their role also require attention for emergency management. Therefore it is recommended to pay attention to emergency management even when only limited budget is available using a marginal cost approach. Flood risk management can be a parameter that influences land use planning. Land use planning and urban development is a more structural and local process then prevention and emergency management. Therefore it requires a mechanism that defines regulation, design and develop, inspection and how to cope with changing circumstances over time etc. Such a mechanisms can be costly because of the number over people involved. History also shows that zoning policies are not always applied perfectly over time. Because of local interest exceptions can be made which in is in fact failure of the policy.

The results of the economical approach can be used in a tradeoff discussion about the acceptable level of risk and to develop criteria for all layers. We recommend starting a debate about the development of criteria in terms of acceptable risk (and damage) for each layer or all layers integrated.

More research is also recommended to the relations between the costs and benefits of emergency management and land use planning. More research is recommended for the relation between emergency management and reduction of damage in case of a flood. We modeled the impact of emergency management to reduction of casualties. Emergency management might also reduce the damage after a flood (movable goods). This will increase the potential benefits for emergency management and therefore influence the combination of investments in emergency management and prevention.

REFERENCES

AGS. 2008. "Risicobeleid en rampenbestrijding. Op weg naar meer samenhang. Adviesraad Gevaarlijke Stoffen." Den Haag.

Baan, M.E., M. Kiekvik, J.M. Gutteling and Terpstra`. 2009. "Risk perception and risk communication for flooding. report of data collection during mass exercise Waterproef organised by Taskforce Management Flooding (in Ductch)." Enschede: University of Twente.

Bočkarjova, M., P. Rietveld and E.T. Verhoef. 2010. "Instruments for decision-making: Immaterial damage valuation in flood risk context." In paper presented at the International Conference "Delta's in Times of Climate Change". Rotterdam, The Netherlands.

Boin, A., P. 't Hart, E. Stern and B. Sundelius. 2005. The politics of crisis management. Public leadership under pressure. Cambridge, UK.: Cambridge University Press.

BZK and VenW. 2008. "Capacity analysis for the task large-scale evacuation. Report National Security (in Dutch)." The Hague.

Chowdhury, A., Mushtaque, R., Bhuyia, A.U., Choudhury, A.Y., Sen, R. 1993. "The Bangladesh Cyclone of 1991: Why So Many People Died." Disasters Vol. 17(No. 4):291–304.

Clarke, L. 1999. Mission improbable, using fantasy documents to tame disaster: Chicago: University of Chicago Press.

Fraser Basin Council. 2008. "Lower fraser communities at risk from Fraser River flooding."

De Bruijn, K., J. Beckers and H. Van Der Most. 2010. "Casualty risks in the discussion on new flood protection standards in The Netherlands." In Flood Recovery, Innovation and Response II, ed. D. De Wrachien, Proverbs, D., Brebbia, C.A., Mambretti, S.

Gutteling, J.M., M.E. Baan, M. Kiekvik and K. Stone. 2010. "Don't panic; risk communication from the perspective of a citizen (in Dutch)." In View on watersafety (in Dutch), eds. H. v. d. Most, S. d. Wit, B. Broekhans and W. Roos.
Haynes, K., L. Coates, R. Leigh, J. Handmer, J. Whittaker, A. Gissing, J. McAneney and S. Opper. 2009. "Shelter-in-place versus evacuation in flash floods." Environmental Hazards 8(4):291–303.
Helsloot, I. 2007. Behind the symbolics (inauguration speech for Free University Amsterdam, in Dutch). The Hague: Boom Juridische uitgevers.
Helsloot, I. and A. Ruitenberg. 2004. "Citizen response to disaster; a review of literature and some applications." Journal on Contingency and Crisis Management 12(3):98–111.
Ien M. 2012. "Structuurvisie Infrastructuur en Ruimte, Nederland concurrerend, bereikbaar, leefbaar en veilig." Den Haag.
Jongejan, R. and J.K. Vrijling. 2006. "To prevent or to cure? Emergency response as an exchangeable risk reduction strategy'." In Paper presented at the European Safety and Reliability Congress. Estoril.
Jongejan, R.B. 2008. "How safe is safe enough? The government's response to industrial and flood risks." In Civil Engineering. Delft: Delft University of Technology.
Jonkman, S.N. 2007. "Loss of life estimation in Flood risk assessment. Theory and applications. PhD Thesis. Delft University of Technology."
Jonkman, S.N., B. Maaskant, E Boyd and M.L. Levitan. 2009. "Loss of Life Caused by the Flooding of New Orleans After Hurricane Katrina: Analysis of the Relationship Between Flood Characteristics and Mortality." Risk Analysis Vol. 29(No. 5):676–698.
Jonkman, S.N. and J.K. Vrijling. 2008. "Loss of life due to floods." Journal of Flood Risk Management 1:43–56.
Kolen B. and I. Helsloot. Accepted, scheduled for 2012. "Time needed to evacuate The Netherlands in the event of large-scale flooding: strategies and consequences." Disasters: Journal of Disaster Studies, Policy & Management 36(4). in review. "To decide or not to decide for evacuation: Influence of the involved decision maker(s) requires probabilistic evacuation planning." Disasters (submitted).
Kolen, B., I. Helsloot, B. Maaskant and B. Thonus. 2010a. "EvacuAid: a probabilistic evacuation model to determine the expected loss of life for different mass evacuation strategies." In INTERCEPT 2010, ed. P. Albores. Birmingham.
Kolen, B., R. Slomp, W. Balen, T. Terpstra, M. Bottema and S. Nieuwenhuis. 2010b. Learning from French experiences with storm Xynthia, damage after a flood. Lelystad: HKV lijn in water.
Lopez, J.A. 2006. "The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana." Lake Pontchartrain Basin Foundation.
Maaskant, B., B. Kolen, R. Jongejan, S.N. Jonkman and M. Kok. 2009. "Fractions of preventive evacuation in case of flooding in The Netherlands (in Dutch)." Lelystad: HKV consultants.
Nicholls, R.J., N. Marinova, J.A. Lowe, S. Brown, P. Vellinga, D. de Gusmão, J. Hinkel and R.S.J. Tol. 2011. "Sea-level rise and its possible impacts given a "beyond 4 degree world" in the 21st Century" " Philosophical Transactions of the Royal Society, A(369): 161–181.
Pilkey, O.H., Young, R.S. 2005. "Will Hurricane Katrina Impact Shoreline Management? Here's Why It Should." Journal of Coastal Research Vol. 21 Issue 6, pp.iii-x.
Proulx G. 2001. "Occupant behaviour and evacuation." In Proceedings of the 9th International Fire Protection Symposium. Munich.
Rosenthal, U., M.T. Charles and P. 't Hart. 1989. Coping with crisis: the management of disasters, riots and terrorism: Springfield: Charles C. Thomas.
RWS. 2008. "Kosten van Waterrobuust bouwen, quickscan kosten van waterrobuust bouwen en inrichten voor waterveiligheid in de 21e eeuw." ed. R. Waterdienst. Rotterdam.
Safecoast. 2008. "Coastal flood risk and trengs for the future in the North Sea Region, Synthesis report." ed. S. p. team. The Hague.
Stone, K. (2011) Tabellen met kostenposten strategieën. Deltares.
Schneeweiss C. 2003. "Distributed Decision Making—a unified approach." European Journal of Operational Research 150:237–252.
Ten Brinke, W.B.M., B.A. Bannink and W. Ligtvoet. 2008a. "The evaluation of flood risk policy in The Netherlands." Journal on Watermanagement Volume 151(Number 4):181–188.
Ten Brinke, W.B.M., B. Kolen, A. Dollee, H. van Waveren and C.A.H. Wouters. 2010. "Contingency planning for large-scale floods in The Netherlands." Journal of Contingencies and Crisis Management 18(1).
Ten Brinke, W.B.M., G.E.M. Saeijs, I. Helsloot and J. Van Alphen. 2008b. "Safety chain approach in flood risk management." Municipal Engineer 161(4):181–188.
Terpstra T.. 2009. "Flood preparedness; Thoughts, feelings and intentions of the Dutch public." Enschede: University of Twente.
TMO (Task force management flooding) 2009. Rapport van bevindingen (in Dutch).
Tversky A. and D. Kahneman. 1974. "Judgment under Uncertainty: Heuristics and Biases." Science New Series, Vol. 185 (No. 4157. (Sep. 27, 1974)):1124–1131.
van Dantzig D. 1956. "Economic decision problems for flood prevention." econometrica 24.
Ven W. 2009. "Nationaal Water Plan." Den Haag.
Vrijling J.K. 2009. "The lesson of New Orleans." In Risk and decision Analysis in maintenance optimization and flood management, ed. M.J. Kallen, Kuniewski, S.P. Amsterdam: IOS press.