Ministry of Water Resources

Ministry of Environmental Protection

EU – China
River Basin Management Programme

Technical Report 072

Efficient Safety Standards for Ring-Dike Areas

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May 2012

Document Information:

Document No:	T-072
Date of Draft:	08 May 2012
Date of Issue	29 May 2012
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Summary

As part of the Strategic Knowledge Exchange between EU and China in the EU-China RBM Programme this report describes the way in which new efficient safety standards for flood control have been calculated in the Netherlands in 2011. The approach is completely novel and based on an optimizing Cost-Benefit Analysis (CBA). The report describes very shortly the outlines of this CBA and then gives the complete formulas for setting efficient protection levels, for areas protected by dikes as well as for areas protected by other water resources infrastructure such as reservoirs. The formula for reservoirs was developed during this project. The report ends with the calculation of examples for areas that differ in investment costs or damage costs. The last examples may become closer to real life situations in China and give results that – in the opinion of the writer - make sense. Some of the calculated safety standards, expressed as flood recurrence intervals, may look very high indeed. Nevertheless one has to realize that acting according to these standards, will in the long run, result in the lowest welfare losses that are possible. However, in decision making on flood standards not only economic efficiency that is important but, for instance, equity as well. In the end setting flood standards is a political decision, not the outcome of a calculation alone.

The standards for flood control that exist in China date back to 1994. Since that year real GDP in China has increased by a factor 5.3. Efficient flood protection standards expressed as recurrence intervals are proportional to the potential damage by flooding. All other things equal updating the 1994 standards to 2010 the recurrence intervals should be increased by factors ranging probably between, between 3 for low density rural areas up to maybe 9 for big cities.

Although in China there is a large backlog to bring flood water defences in conformity with the existing standards, it seems nevertheless useful to assess what efficient flood standards in China would be in order to recommend upgrades to the right size infrastructure or to reserve enough space for broadening riverbeds to prevent bottlenecks to occur in the future, especially in fast urbanizing areas.

Key recommendations are:

- Calculate the efficient flood standards by using the formula given in the report.
  To do that numerical information is needed especially on the costs of efficient improvements and on the effect that these improvements have on the probability of flooding. Further, information is needed on the potential damage by flooding. This information is not readily available now. However, probably a lot is already available somewhere, but needs to be brought together and organized in the way as indicated by the formulas.

- Consider revision of the existing standards for flood control in China, since they date back to 1994.

1 Introduction

This report is prepared as part of the Strategic Knowledge Exchange of Flood Security between EU and China in the EU-China River Basin Management Programme. It describes the way in which new efficient safety standards for flood control have been calculated in the Netherlands.

The report focuses on two general questions:

1 What is the most efficient investment strategy for flood protection of a ring-dike area?

2 How can the theoretical results be translated into legal safety standards for the prevention of flooding?

The assessment makes use of a Cost Benefit Analysis (CBA) model. The starting points for such modelling are:

- Absolute safety against flooding is impossible. There will always be damage by flooding.
- More safety and less risk of damage are ALWAYS possible, but at rising costs.
- Making choices is possible and necessary, for instance on the height or relocation of dikes. Therefore, the safety problem for ring-dike areas is an economic question with a rational solution.
- However, in the end the decision on legal standards for flood protection is political, since there are many factors that experts and politicians are reluctant to assign a monetary values to, for example the value of human lives or the extent of risk aversion.

It needs to be stressed that the Cost-Benefit Analysis should encompass ALL welfare changes and not be limited to a financial calculation only. Therefore, in the model and calculations it is assumed that all welfare changes can be assigned a monetary value, including the loss of human lives by using a concept known as Value of a Statistical Life (VOSL).

Chapter 2 provides the current status of flood standards in the Netherlands and China, while Chapter 3 describes the theory behind the Cost Benefit Analysis. Chapter 4 describes the CBA model, which in Chapter 5 is applied to some numerical examples, which hopefully can be adapted to situations that can be found in China. Chapter 6 contains conclusions and recommendations.

2 Background

2.1 The importance of legal flood standards

In China, like in the Netherlands and many other countries, specific actions to improve flood security are guided by legal safety standards. In China the numerical values of these standards differ depending on the type of area protected (see PR China, 1994). The larger the potential loss, the higher the safety standard is. This is the case in many other countries as well, but not everywhere. In the USA, for instance, the only standard is the 1/100 flood standard, even after the recommendation in the report by Galloway et al. (2006) that for built-up areas the standard should be changed to at least a frequency of 1/500[1].

Obviously, in many countries the decision making on flood protection measures is organized in another way than decision making on other infrastructure like roads or railroads. In these fields legal standards do not exist and decision making takes place on an *ad hoc* basis: piece by piece. However, there are good reasons to have legal safety standards for flood risk. Flood risk is generally seen as a crucial issue for the government; since floods can have extremely serious effects on people's life and on society as a whole. The fact that in the Netherlands even the numerical values of the safety standards are mentioned in the Water Act, is clearly the recognition of this important responsibility of the central government. It serves also as a kind of guarantee to the people that the government will take care that these standards continuously are met. A second reason not to use an *ad hoc* procedure is to prevent that imbalances will arise in the water defence system as a whole. An improvement in one place cannot be at the expense of another location without compensating measures. A last consideration is that an explicit safety standard makes a clear distinction possible between the political process of establishing the nationwide safety standards at central level and the implementation by regional and local agencies, which have the task to execute the law by maintaining the flood standards in their own area.

2.2 Legal safety standards in the Netherlands

Like in China, the legal safety standards in the Netherlands differ between areas. Still there are two aspects in which the Dutch legal standards differ from the standards of most other countries. The first is already obvious in looking at the figures for the flood standards shown in Figure 1. They are by far the

[1] G.E. Galloway, G.B. Baecher, D. Plasencia, K.G. Coulton, J. Louthain, M. Bagha and A.R. Levy, 2006, Assessing the adequacy of the national flood insurance program's 1 percent flood standard. Report of American Institute for Research. It contains a table with an overview of flood standards in many countries.

highest safety standards in the world: 1/10,000 and 1/4,000 for ring-dike areas[2] along the coast and 1/2,000 and 1/1,250 along the rivers Rhine and Meuse, respectively. The second deviation is that, to some extent, these standards have been based on efficiency calculations, so called Cost-Benefit Analysis (CBA), where in most other countries the standards do not have any scientific background at all.

In fact, this last claim is only partly correct. Indeed, sometimes CBA's for the prevention of floods have been made, but their outcomes did not have much influence on the actual values adopted as standards[3].The first standards along the coast have already been established before 1960 in the Delta Plan. The others along the main rivers have been added later on. They do not have a common basis. Further, the standards do not adequately seem to reflect the actual flood risks as shown on maps recently made in conformity with the EU directive. Moreover, the general feeling is that nowadays these standards are outdated, since they have never been revised.

[2] A ring dike is an uninterrupted ring of water defences, like dikes or dunes, and high grounds (that are grounds which will not be flooded even under the most unlikely circumstances). The area within a ring dike is called a ring-dike and is sometimes also referred to as a 'polder'.

[3] The most well-known is the pioneering and many times cited paper of Van Dantzig on this problem: D. van Dantzig, 1956, Economic decision problems for flood prevention, Econometrica, 24:276--287. However, his solution is not correct, see Eijgenraam (2006).

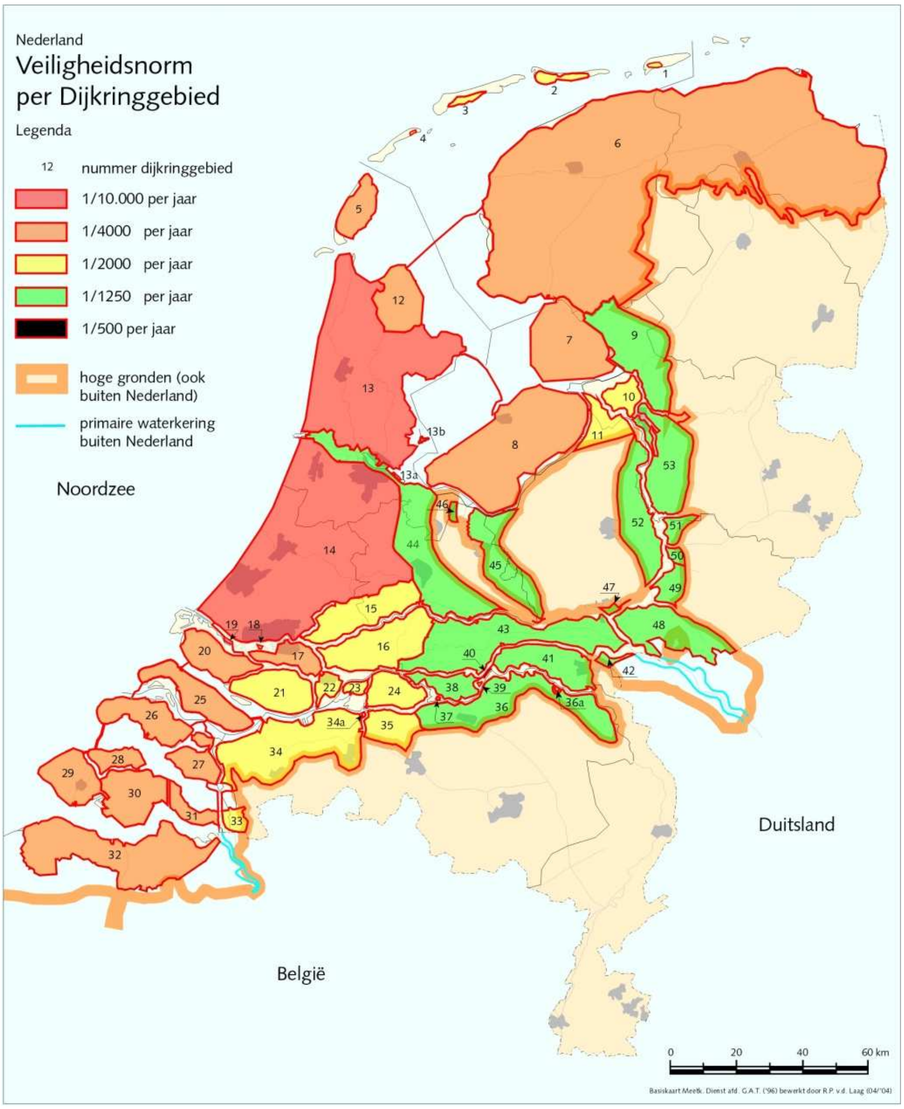

Figure 1 *Map of ring-dike areas in the Netherlands, classified by flood safety standard. The non-coloured parts in the east and south of the country are 'high grounds' above flood levels.*

Therefore, a revision project of the legal safety standards in the Netherlands has been started, called 'Water Safety 21st Century'. One of the most important building blocks is a CBA based on a new CBA approach to derive optimal safety standards. This approach has been developed by Eijgenraam while making the CBA of the project Room for the Rivers in 2003-2005. A description of the new methodology can be found in Eijgenraam (2006). In November 2011 the Vice Minister on Water submitted the results of the CBA 'Water Safety 21st Century' to Parliament and had a preliminary discussion with the Water Committee in April 2012. The government will decide on new standards in 2014 and the Water Act will be changed accordingly before 2017.

In the National Water Plan the Dutch government has stated that CBA is indeed an important basis for establishing new standards, yet not a sufficient one. Personal and societal risk should also be taken into consideration. Moreover, CBA looks at efficiency only, while equality between people also plays an important role in decision making on flood standards. In the discussion with the Water Committee, the Vice Minister indicated that he wants to base the new standards on the outcomes of the CBA, but with a minimum limit for safety. There should be no location where the probability of dying due to flooding would exceed 10^{-5}, or 1/100,000. Since in the Netherlands the probability of dying in case of a flood is estimated at roughly 1% of the people still present in the area when a flooding begins, the minimum safety limit corresponds to an upper limit for the flood probability of every normal ring-dike of 1/1000 per year.

Because decision making on flood standards requires more than a calculation, this type of decisions take time and should be taken at the national level. Still, in every country, governments face the problem how to spend their money in the most efficient way. Therefore, the fact that from an economic point of view an optimizing CBA gives the most efficient solution of the safety problem makes it very worthwhile in itself. Therefore, within the framework of the EU - China Strategic Knowledge Exchange this report is meant to give a brief introduction and description of this new scientific basis for the legal safety standards in the Netherlands.

It needs to be stressed that the Cost-Benefit Analysis should encompass ALL welfare changes and not be limited to a financial calculation. Therefore, in the model and calculations it is assumed that all welfare changes can be assigned a monetary value, including the loss of human lives by using a concept known as Value of a Statistical Life (VOSL).

Here two additional remarks should be made. Since the Netherlands lie along the sea, only the last 100-150 km of the big rivers cross the country. The rivers flow across a delta without river valleys, so in the Netherlands the predominant type of water defence is dikes. Reservoirs for instance, are not applicable at all. Therefore, the CBA model for flood control has originally been formulated in terms of dike heightening, but the model can also be considered in terms of 'measures to lower water levels', for instance by broadening river beds. In Chapter 3.2 a suitable formula for reservoirs will be given. The second remark is that in the Netherlands it is not at all possible to insure against flooding. People can only hope that in case of a flood the national government will compensate a large part of the material damage, say 80-90%.

2.3 Legal safety standards in China

In China the legal safety standards for flood protection differ depending on the type of area being protected. Urban, rural and industrial areas are distinguished (see Appendix 1, PR China, 1994). The recurrence intervals range from 10 years for sparsely populated rural areas and small scale industry to more than 200 years for Very Important Cities, which are cities with more than 1.5 million inhabitants. In general, the larger the potential loss (human as well as material), the higher the safety standard is. This makes sense and is in accordance with the theory on efficient safety standards. The standards are only available in the format of a table (see Appendix 1), not in the format of a map. Nor does there seem to be any maps on the actual flood risks in China.

As will be shown in Chapter 4.3, the recurrence intervals of efficient standards for flood control are proportional to the potential loss by flooding. When the potential loss becomes larger, then – *ceteris paribus* – it follows that the recurrence interval should be increased by the same factor. So, even if the national standards for flood control established in 1994 were exactly the right standards for 1994, they certainly no longer are the right safety standards for, say 2014. As in the Netherlands, the standards are outdated and need revision. Moreover, it has to be taken into account that an industrial society is less resilient to flooding than a rural one. See for example the flooding in Thailand in 2011. The water not even came that high, but nevertheless completely knocked out a large part of Thailand's industrial capacity for many months and in some cases for more than a year. The linkages between industrial facilities all around the world are nowadays intense and a breakdown in one location seriously affects other locations up and downstream in the production chain. In "Current Situations and Challenges of the System on Flood Control in China" (DRC, 2012) the same type of remarks are made, also referring to the increasing vulnerability of cities and the steady increase in the amount of losses per flood.

It is possible to illustrate this argument by some figures from the China Statistical Yearbook 2011 in which Table 2-1 shows that the nominal GDP has increased from 4,820 billion yuan in 1994 to 40,120 billion yuan in 2010, which is a factor 8.3, while Table 9-2 shows that the Consumer Price Index increased from 339 in 1994 to 536 in 2010, which is a factor 1.6. Hence real GDP has grown by a factor 5.3. All other things equal the recurrence intervals given in the 1994 standards should by 2010 have been increased by factors ranging between, say 3 for low density rural areas to maybe even 9 for big cities. Also the fact that on average the losses by flooding in China are a relative high percentage of GDP (DRC, 2012) points in the direction of standards that are too low compared to the wealth that is presently protected.

Of course, this report cannot indicate what efficient flood standards for China should be by 2014. This section only shows the well-known fact that China in 2012 is not the China in 1994 and that this situation also can have a profound influence on the value of efficient flood standards. Like in the Netherlands, there are in China likely to be good reasons for a revision of the standards for flood control.

2.4 Standards and real situations

Having flood standards is one thing, keeping the water defences in conformity with these standards is clearly another thing. In the Netherlands in 2011 more than one third of the water defences was not in conformity with the standards and has to be improved. According to China Water Statistical Yearbook 2011 approximately 120,000 km of the 290,000 km dike was conforming to the standards by end of 2010. That year 4,700 km of dikes were added to the category Conforming-to-Standard, but there was also a decrease by 1,940 km.

The EU directive on flood protection asks for a national report on the condition of the water defences every six years. In addition a report has to be made how the parts that do not conform to standards will be improved. In the Netherlands there are even proposals to lower the frequency of the complete monitoring procedure to once in twelve years. Such a complete monitoring cycle begins by establishing new hydraulic boundary conditions for all major water systems and an updated set of procedures how to evaluate the different types of water defences. Then the regional Water Boards do the evaluation of all primary dikes and report to the Ministry. Based on these regional reports the Ministry makes the national report and sends it to Parliament, followed by a plan for improvements and how these are to be financed.

In China, there is annual monitoring. It is important indeed to monitor how much progress has been made. However, there is still a long way to go before the whole system is near a situation of conforming to standard. This stresses the point made before that efficiency in spending government money is an important issue, not only in China, but everywhere. Even if a revision of the flood standards would be postponed, it is useful to know the magnitude of efficient standards. This can influence decisions on the scale of an improvement or to reserve enough space for broadening riverbeds to prevent bottlenecks to occur in the future, especially in fast urbanizing areas.

3 Theory on the investment strategy

3.1 Static problem

The static problem can most elegantly be illustrated with the graphs in Figure 2. The larger the heightening of the dike, the more the investment costs increase from left to right and the more the flood probability and hence the expected loss by flooding decreases. The total minimum costs can be found in point A leading to the most efficient heightening X. Mathematically point A can be found by differentiating the total costs with respect to X and putting the first derivative to zero. Or, as economists formulate it, in point A the marginal benefits are equal to the marginal costs. The heightening X solves the safety problem once and for all, since in the static model there are no future changes in any variables.

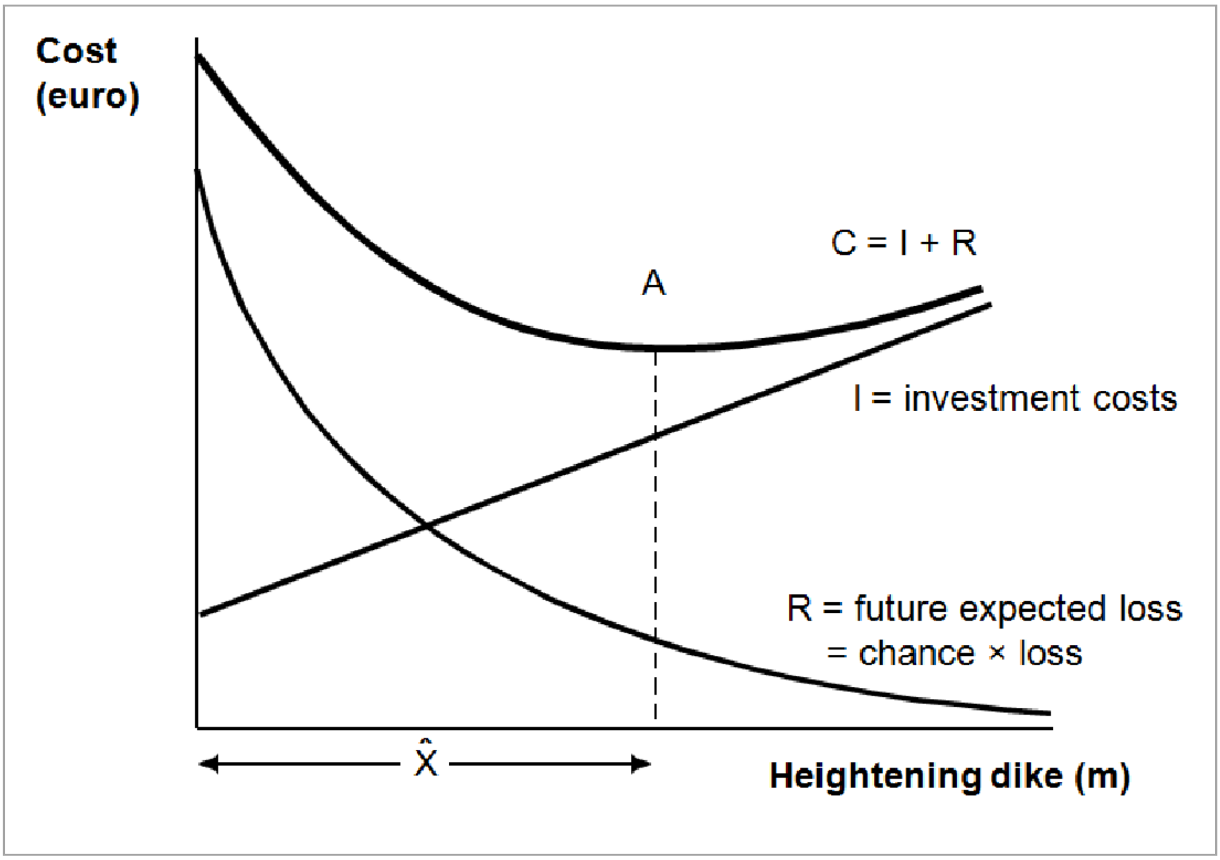

Figure 2 Cost minimization in the static case

3.2 Cost minimization dynamics

The actual problem obviously is more complicated that the theory, because there are changes in the future:

- Deterioration of the water system, for instance by climate change, sea level rise or subsidence of land. The consequence is that the probability of flooding rises;

- Growth of population and wealth, therefore the loss by flooding increases.

In combination this leads to an increase of the expected loss since expected loss = probability of flooding x loss by flooding. Conclusion is that the changes in the variables lead to more than one decision on investment.

3.3 Driving forces of the investment strategy

There are two additional factors that influence the investment decision:

- Discount rate: Since there is a positive discount rate ($\delta > 0$) postponing investments as much as possible lowers the present value of the total costs.

- Economics of scale: On the other hand, there are fixed investment costs meaning that if an investment is going to be made, it is cheaper to do a lot at one time.

The consequence of the fixed costs is that heightening of dikes usually is done in large steps. As a result the safety level is not constant, but varies over time. As long as there is no action, the expected losses will increase due to climate change and economic growth (including population growth). This process will go on until a decision is taken on an upgrade. Then the flood probability will jump back to a lower level. So we have to answer two questions

- **When should upgrades be made?**

- **How extensive should upgrades be?**

3.4 Sketch of the solution

3.4.1 Simple investment cost function

If a simple investment cost function could be used, in which each repetition of the same size upgrade would cost the same amount of money, the solution is as sketched in Figure 3. The vertical axis shows the expected loss and the horizontal axis displays time. Figure 3 shows that in the optimal solution the expected loss has to stay between the boundaries s^- and S^+.

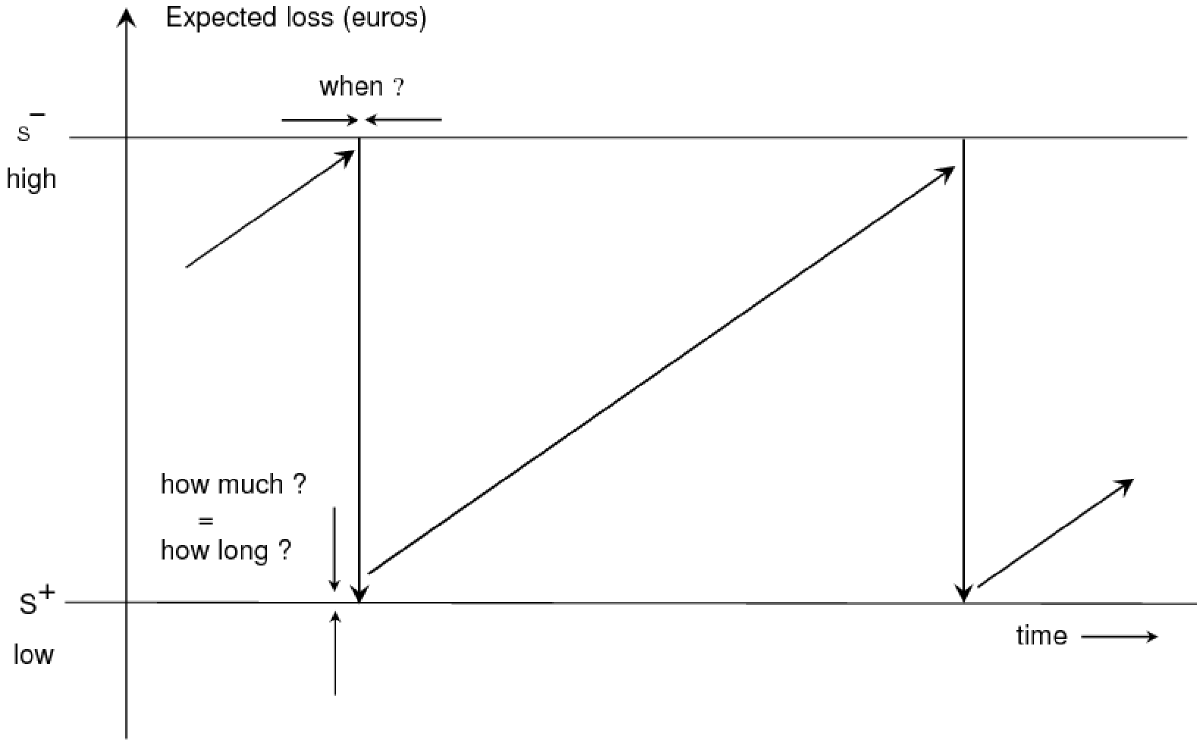

Figure 3 Sketch of the optimal investment strategy in case the investment costs depend alone on the heightening of dikes

The optimal investment strategy shows two remarkable features. Although the expected loss increases as the combined result for instance of climate change and economic growth, the optimal band for the expected loss is constant. It means that the expected loss should not exceed the constant level s^- and that it is not efficient to invest more than is necessary to bring the expected loss down to the constant level S^+. Since the band is constant, also the optimal size height of each upgrade stays the same. Further, the growth rate of the expected loss turns out to have hardly any influence neither on the width of the band nor on the size of the upgrade, but predominantly influences the length of the period between two upgrades.

3.4.2 More realistic investment cost function

In practice the investment cost function is more complicated. Civil engineering data of investment costs assembled for the CBA of improvements along the Rhine show that the engineers use linear cost functions as a first approximation, as long as they think that the same heightening technique can be applied. But every technique has its technical and economic limits, which basically depend on the height of the dike. When the height of a dike increases, one technique eventually has to be replaced by another technique with higher costs. In such cases most of the time the fixed as well as the variable costs will rise. There is also a general argument for making the investment costs a function of the height of the dike. Heightening a dike is only possible in combination with broadening the dike. So, while in the model the influence of the investment on flood probabilities is measured in one dimension (height) only, the costs of the investment are partly proportional to a surface measure. In case the costs of a heightening depends, besides on the size of the upgrade, on the height of the dike too, the solution pattern is as sketched in Figure 4.

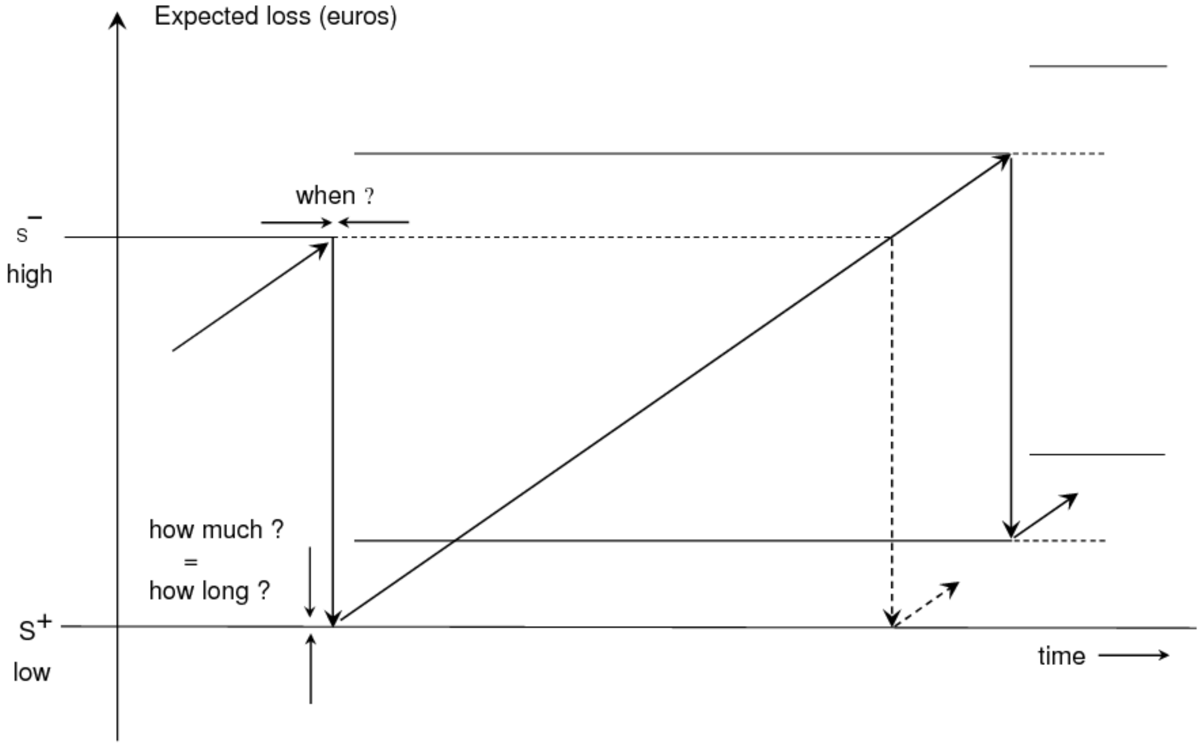

Figure 4 Sketch of the optimal investment strategy if the investment costs also depend on the height of the dike

The upgrades are still the same, but the optimal band for the expected loss increases in proportion to the increase in investment costs.

3.4.3 Example of a real case in the Netherlands

The results in Figure 4 can be transformed to flood probabilities by dividing the expected loss and the optimal boundaries (s^- and S^+) by the potential loss by flooding. This result is shown in Figure 5 for an actual calculation made in the CBA for the project Room for the River. Now on the vertical axis the probability of flooding is displayed. The curve Pmin corresponds with s^- and the curve Pplus with S^+.

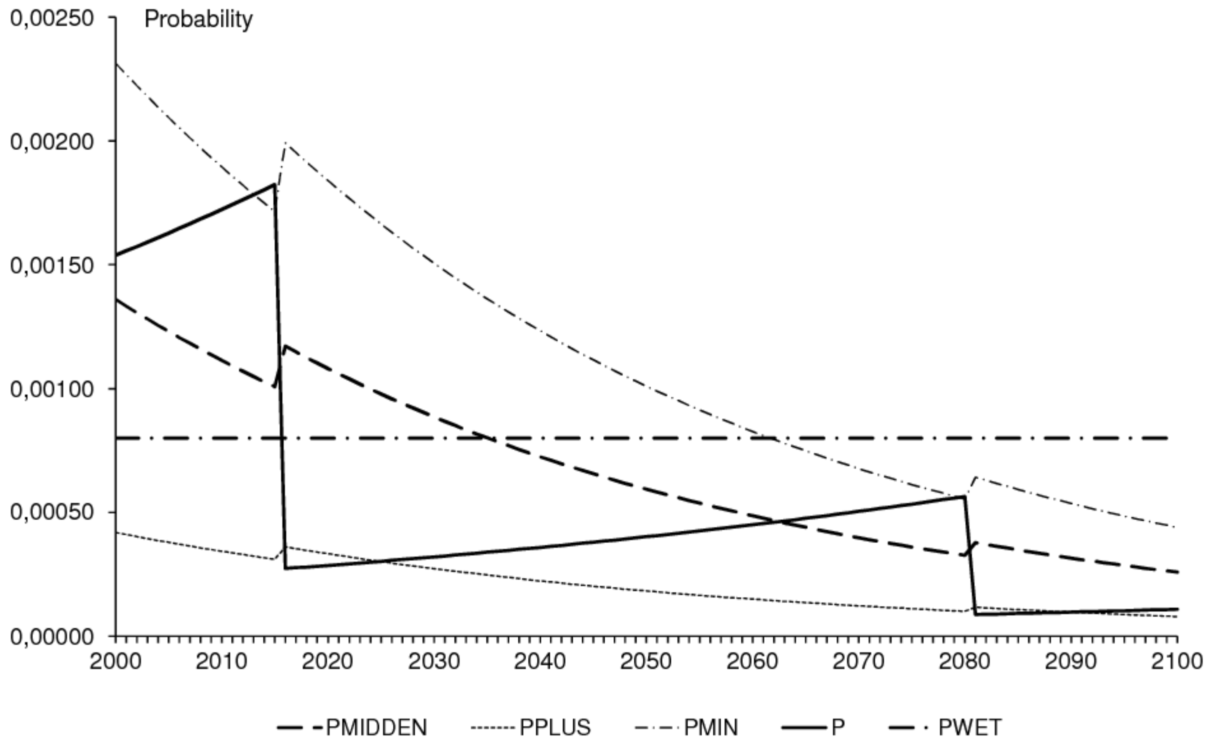

Figure 5 Optimal band for the flood probability of ring-dike area 43 Betuwe.

Legend:

PPLUS	*lower optimal boundary for the flood probability*
PMIN	*upper optimal boundary for the flood probability*
P	*optimal path for the actual flood probability*
PWET	*present legal flood standard for this area*
PMIDDEN	*proposed new legal flood standard, according to formula (2).*

In Figure 5 also the present legal standard PWET is indicated. For this particular ring-dike PWET seems to be adequate till around 2035. In the next section it will be argued that for later years the line PMIDDEN is a better candidate for a legal standard. In the CBA 'Water Safety 21st Century' the value of PMIDDEN in the year 2050 has been proposed as the new legal flood standard in the Netherlands.

4 Legal safety standards

4.1 From optimal to practical safety standards for ring-dike areas

In the Netherlands, like in China, specific actions to improve flood security are guided by legal safety standards. Since the legal safety standards are the guideline, the optimizing model in the previous section is not directly applicable. A translation is needed from this model and its outcomes to the formulation of legal safety standards. The purpose of this section is to derive legal safety standards from the outcomes of the optimizing model.

Here we interpret legal safety standards as ‘indicators’, meaning that when the actual flood probability exceeds the safety standard, an improvement must start. This definition implies that the safety standard will always be exceeded during the period after the exceedance has been recorded. In this interpretation a safety standard is not a minimum level that never may be passed (like s^- or Pmin). Therefore, its numerical value needs to be set at a level that gives ample lead time for the whole organization, design and construction of an upgrade. In the Netherlands lead times of 15 to 25 years need to be taken into account for large programs like Room for the Rivers, starting from the moment the exceedance takes place. Single projects can be completed much quicker. Therefore, the model figures for s^- or Pmin cannot be used.

Several concepts for the formulation of the new legal standards have been discussed and the one presented hereafter has been chosen because it has the best properties. It has actually been applied in the recent official CBA made in the preparation of new legal safety standards in the Netherlands[4]. Since this concept is based on an optimal investment strategy, it has for instance the following important properties. If one is able to keep the actual flood probability of a whole water system near this standard, one can almost be sure that one is following an efficient investment strategy, whatever the particular content of that strategy is. Another good feature is that the standard only depends on average costs, not on the split of total costs in fixed and variable costs. And, not the least: it is quite understandable by itself, without understanding the whole derivation from the optimizing model.

However, a safety standard only gives information on an efficient safety level, no longer on what efficient investment strategies would be. The proposed standard can be seen as a figure summarizing the optimal band in Figures 4 and 5. Therefore, the safety standard does not give any information on the flood probability of a good design.

[4] Kind, J. (2011), Cost-Benefit Analysis Water Safety 21st century (In Dutch), Deltares report 1204144-006-ZWS-0012, Delft. There is a presentation available in English: Eijgenraam & Kind (2011).

4.2 Is one efficient standard design possible?

Since a chain is as strong as its weakest link, a test standard can be uniform for the part of a ring dike bordering the same water system. However, this uniformity does not apply to a design standard. One reason is that actions to prevent flooding not always have the same effect along a ring dike. An example is the removal of a bottleneck in a riverbed. This has a specific location. Further, the effect of widening the bottleneck is far from equal along the river. The lowering of the water level is largest directly upstream of the widening. Further upstream the lowering effect diminishes until it peters out. But directly downstream of the widening, the water level becomes even higher. Moreover, such an action can have its own obvious optimal size, which does not need to have any relation at all to the size that results out of some general calculation on safety.

Therefore, no general method or value can be given for the most efficient (optimal) size of a specific action at a specific location. In other words, the numbers S^+ or Pplus are too specific and cannot be applied as a general guideline for all possible types of designs. The consequence can even be that a combination of separate actions, which each are big on their own, only succeeds in bringing the highest probability of flooding along the ring dike just under the maximum as defined by the test standard. So, the conclusion on design standards is that the optimal size of each action has to be chosen on its own merits.

However, if the size of an upgrade can be chosen freely and there are no major construction work involved, but mostly regular dikes, then the experience in the Netherlands shows that efficient designs result in flood probabilities which are a factor 3 to 5 smaller than the test standard. In Figure 5 this is roughly the difference between Pmidden and Pplus at the same moment in time. For a longer discussion on design standards see Eijgenraam (2007).

4.3 Simple formula for a test standard for flood control[5]

The formula for the optimal probability of flooding is actually a combination of two formulas. Formula 1 defines an optimal level for expected loss that can be considered as a sort of summary of the optimizing CBA. Formula 2 is based on the usual definition of risk used in the water domain: risk = probability of flooding times loss by flooding.

On average the expected loss (risk) should be equal to the yearly costs of an optimal investment. First in words:

Formula 1: $$Middle\ expected\ \ loss = yearly\ costs\ of\ \ a\ standard\ \ investment\,.$$

The annual costs are the sum of the interest paid on the investment plus the extra maintenance costs of the upgrade. To find the middle of the probability interval we apply the definition of expected loss (probability times effect) to the previous equation:

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5 For the theory behind the original concept of the middle probability of flooding see Eijgenraam (2006) pp56-61. The definition given here is the most recent one and differs only slightly from the original definition.

Formula 2:

$$Middle\ probability\ of\ flooding_t = \frac{middle\ expected\ loss}{loss\ by\ flooding_t}$$

$$= \frac{yearly\ costs\ of\ a\ standard\ investment}{loss\ by\ flooding_{\mathrm{t}}}.$$

Or in words:
The middle probability of flooding in a year is the yearly costs of a certain standard investment divided by the potential loss by flooding in that year.

This formulation is all we need to know to understand the most important implications of the solution of the cost-benefit analysis. As said before, it is very important that the figure used for the loss by flooding encompasses all welfare losses, material losses with a market price like houses, factories or crops on the fields, but also unpriced losses like pollution of the soil and immaterial losses like the loss of human lives. Every type of welfare loss should be taken into account.

In mathematical terms a first way to write the first formula is:

Formula 1 $$S_{j+1}^{middle} = \delta \, {}^{1}\!/_{\theta} \, k_{j+1}(u)\, l,$$

Legend:

S	*expected loss per year (million Euro/year),*
δ	*discount rate (δ > 0) (1/year)*
1/θ	*investment size that diminishes the flood probability by a factor e (= 2,72…) (m)*
k(u)	*average investment costs per metre heightening per km dike (million euro/m/km)*
u	*optimal investment size (m)*
j+1	*number of the next action*
l	*length of the dike (km).*

It turns out that the average expected loss per year depends only on the average costs of protection per meter. Average costs are far less dependent on the nature of the preferred action at a specific time and location than the ratio of fixed and variable costs. If we have different actions with different size effects on the costs of these actions, but with roughly the same unit costs for an optimal investment size, the middle optimal expected loss will also be roughly the same. A second nice property of formula 1 is that we do not have to worry too much about the precision of the figure for the average investment costs k(u). Theoretically one should take the optimal value for u that comes out of the complete model. However, experience has shown that the average costs k(u) are not too different for values of u that are not far from their optimal value. Instead, one can calculate the unit costs for the size of an upgrade that seems most efficient purely from a civil engineering point of view.

To find the middle of the probability interval we apply the definition of expected loss to the outcome of Formula 1:

Formula 2
$$P_t^{middle} = \frac{S_{j+1}^{middle}}{V_t} = \frac{\delta \, {}^{1}\!/_{\theta} \, k_{j+1}(u)\, l}{V_t},$$

Legend:

P^{middle}	*optimal flood standard (1/year)*
V_t	*loss by flooding (million Euro).*

To give the reader more grip on what the formula means some numerical examples are presented in Chapter 5. Here we only demonstrate the calculation by using some figures which will be explained in Chapter 5.

Suppose the discount rate is 8%, a heightening by 0.5 m brings the flood probability down by a factor e, the costs of an efficient upgrade are 20 million yuan/m/km if the length of the dike is 100 km. Then S^{middle} becomes: 0.08 * 0.5 * 20 * 100 = 80 million yuan/year. Suppose that the total welfare loss by flooding in this area is evaluated at 80,000 million yuan, then P^{middle} is 80 / 80,000 = 1/1000 year, or a recurrence interval of 1000 years.

Formula 1 is cast in a form that is suitable for water defences like ring dikes. This is applicable along the coast and along the downstream parts of rivers, like the situation in the Netherlands, which covers only the last 100-150 km of the big rivers. In China not all types of water defences fit easily in this format. Therefore, we give the same formula in a second format[6]. This format can for instance be applied in a small valley, where building a dam with a reservoir is a much more efficient way of flood control than building dikes. Suppose we have an action A which lowers the flood probability for an area by a factor y. The total investment costs of this action A(y) is I(A(y)). Then we can put formula 1 in the following format:

Formula 3
$$S_{j+1}^{middle} = \delta \, {}^{I(A(y))}\!/_{\ln y},$$

and hence:

Formula 4
$$P_t^{middle} = \frac{S_{j+1}^{middle}}{V_t} = \frac{\delta \, {}^{I(A(y))}\!/_{\ln y}}{V_t}.$$

Of course, here the potential loss by flooding (V) corresponds to the area protected by measure A, for instance the valley protected by the reservoir.

[6] Formula (3) was developed during the writing of this report.

4.4 Is the result understandable and explainable?[7]

Although the definition of the middle probability of flooding is not that difficult to understand, it can be handy to have an approximation. To be helpful to explain the differences in the model outcomes between ring-dike areas to the general public this approximation should only contain the very basic notions without using monetary figures. The first notion is that in the investment costs in the numerator the largest difference between ring-dike areas is the length of the dike, not the cost of an upgrade per kilometer. The second notion is that in the loss by flooding in the denominator the largest difference between ring-dike areas is the number of people, not the value of the damage per person. This leads to:

Formula 5 $$Approx_E\left(P_{a,t}^{middle}\right) = constant_t \frac{l_a}{N_{a,t}},$$

Legend:

N_t *population*

a *ring-dike indicator.*

The coefficient can be estimated by regression analysis, explaining the real $P^{middle}_{(a,t)}$ by the length of the dike and the number of people. This approximation works well only if the coefficient turns out to be roughly the same for a group of similar ring dikes. Figure 6 gives an example for about twenty ring-dike areas along the Rhine in the Netherlands. The numbers refer to the different ring-dike areas. The two horizontal lines indicate the present legal safety standards in these two areas along the big rivers, with return periods of 2000 and 1250 years. In the next section we will discuss the CBA approach to derive legal safety standards and the usefulness of the concept ‘middle probability of flooding’, with reference to Figure 6.

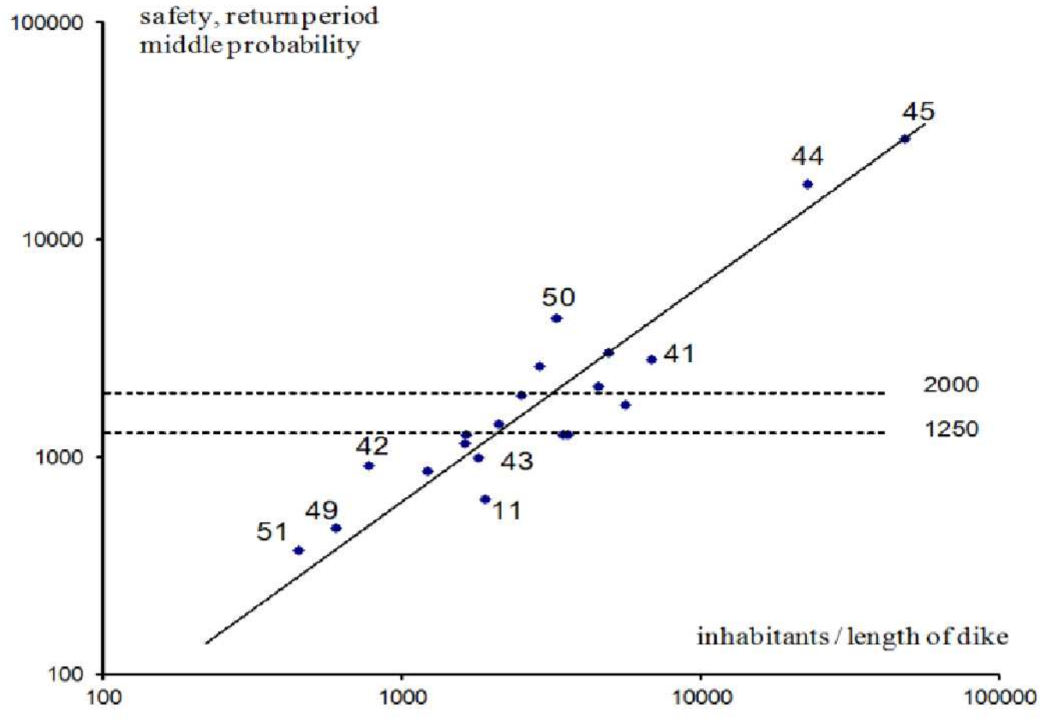

Figure 6 Comparison of optimal return periods and the ratio inhabitants / length of the dike

7 See Eijgenraam (2006), Chapter 4.5, based on the figures in Chapter 4.4.

4.5 Two common opinions in the discussion of standards

In the Netherlands two opinions concerning the new legal standards are often voiced:

- More differentiation of the standards between different areas seems *efficient*
- Base new standards on *Cost Benefit Analysis*.

When talking about more differentiation most people only think of the potential loss by flooding: more people/value => more safety (both between areas and in time). Nice examples are the dike rings 49, 50 and 51 (Figure 6). They lie next to each other along one side of a branch of the Rhine River and envisage therefore the same type of threats. Nevertheless, 49 and 51 come out as dike rings with the lowest optimal flood probability, while 50 is among the ones with the highest safety level. The size of these dike rings is comparable; their largest difference is the estimated loss by flooding. 49 and 51 are agricultural areas, while 50 is the central city between them with many amenities. Indeed it is the loss by flooding that makes the difference. A lot of people have the feeling that this type of difference is appropriate.

Still, both ideas on *efficiency* do raise questions on *equity*. This can be explained by pointing to two consequences of using Cost Benefit-Analysis:

- Costs matter as much as benefits
- The outcome of the CBA is roughly similar to distributing the same amount of money to every inhabitant of a ring dike, irrespective of the situation of that ring dike.

Nice examples for differences in costs are the dike rings 43 and 45. They lie opposite to each other along the same branch of the Rhine River. Both have 300,000 inhabitants and the potential losses by flooding are equal indeed. Both have an elongate rectangular shape. 45 borders to the river with the short side with 6 km dike. 43, in contrast, are almost surrounded by branches of the Rhine, so it has 180 km of dikes. In Figure 6 ring dike 45 gets the highest safety level because the costs are so small, while 43 gets a safety level that is a factor 30 lower than that of 45. Not all people appreciate the differentiation of standards because the costs are different.

Conclusion is that to some extent CBA leads to equality in input, but not to equality in output.

4.6 Efficiency versus equity

The practical and political consequence of the thoughts in the previous section for establishing acceptable flood standards is that CBA is an important source of information indeed, yet not a sufficient one. Personal and societal risk should also be taken into consideration. Therefore the Vice Minister indicated that he wants to base the new legal standards on the outcomes of the CBA, but with a maximum level for personal risk. There should be no location where the probability of dieing due to flooding would exceed 10^{-5}, or 1/100,000.

Since the discussion on the figures of the new legal standards has started recently it is not clear if the figures for societal risk (the probability that more than a certain number of people will die in one flood) will play a role. The loss of lives is also accounted for in the CBA. However, it is possible that in urban areas with many houses and people and less other capital goods the CBA outcome would be considered to be too low.

5 Examples of standards for different situations

5.1 Purpose of this section

The purpose of this section is to give the reader some feeling for the outcomes of formula 2:

Formula 2 $$P_t^{middle} = \frac{S_{j+1}^{middle}}{V_t} = \frac{\delta \, {}^{1}\!/_{\theta} \, k_{j+1}(u)\, l}{V_t}.$$

However, the reader should be warned not to take these examples as the full story, feel free to use the figures most applicable to the situation at hand. While the formula itself indeed is the best formula for the most efficient protection level, the values for the variables are strongly dependent on the local situation. They can differ a lot and can give quite different outcomes. In the recent CBA in the Netherlands the outcomes lie between 1/300 and 1/250,000 (see Eijgenraam & Kind, (2011). Since in China the density of the population probably differs more between regions than in the Netherlands, with much higher density figures in the flood plains than in the Netherlands, the real figures in China may be even more diverse. These differences are further enlarged by the huge differences in average GDP per person per province, ranging in 2010 from 13,000 yuan in Guizhou to 76,000 yuan in Shanghai, which almost is a factor 6.

So, even if the reader gets the impression that the flood safety standards calculated hereafter are on the high side, for instance because their recurrence intervals are much longer than existing standards, and some are really high indeed, the reader should be aware of the fact that these standards still represent the most efficient solution of the flood problem at hand. This means, that acting according to these standards in the long run results in the lowest possible welfare losses, of course, on the assumption that the figures used for the variables are correct.

5.2 Data

Cost information for China.

Table 1 Information on investment costs

Description	**Investment costs**
Dikes	**Heightening of 0.5m per km**
Sea dikes grade 1	30 million yuan
Sea dikes grade 2	7 - 8 million yuan

Description	**Investment costs**
River main dike grade 1	10 million yuan
River main dike grade 2	5 - 6 million yuan
Reservoirs	
Large >100 million m^3	300 million yuan, depending on size
Medium 10 - 100 million m^3	20 – 40 million yuan
Small I 1 - 10 million m^3	4.5 million yuan
Small II 10,000 – 100,000 m^3	2 million yuan

For the discount rate we start with δ = 0.08 /year (see UoB, 2011) e.g. Table 5.12. In this source estimates for GDP growth can also be found (See UoB, 2011: Table 3.10 GDP annual growth rates Yellow River Basin Medium estimates: to 2020 8%; 2021-2030 6.5%). High and low estimates differ 0.5%-point from the medium estimates. In discussion with Dr. Jiang the annual growth rate in the examples is set at 7%.

In the short time available to make this report it was not possible to make real estimates for the potential loss by flooding in regions in China. Therefore, a short cut has been made using figures that were readily available. The formula for the short cut used is:

Formula 6 $$V_t = GDP_0\, f\, N_0 \exp(\gamma t).$$

Legend:

V_t	*loss by flooding (million yuan)*
GDP_0	*GDP (gross domestic or regional product) per person (yuan/year/person) in 2010*
f	*factor to change GDP per person in loss by flooding per person (year)*
N_0	*population in 2010*
γ	*annual growth rate of GDP*
t	*number of years after 2010.*

Material wealth per person that will be lost during a flood, is estimated by multiplying GDP per person with a capital/output ratio. A reasonable number for a capital/output ratio is 3, maybe ranging from 2.5 to 4. This figure for the direct material loss will be multiplied by a factor 2 to cover the indirect and not-priced material losses and the non-material losses, like the loss of human lives, hardship resulting from evacuation, the loss of personal belongings which cannot be repaid or pollution of the soil caused by a flooding. This is roughly the same factor which was estimated and used in the recent CBA in the Netherlands. Since already GDP per person differs a lot, it does not make much sense also to vary f in the examples, so f = 6 in all examples.

Population and GDP or GRP figures come from China Statistical Yearbook 2011 (NBRC, 2011). All figures refer to 2010. For instance, in 2010 the population density in China as a whole was about 140 persons per km^2. Average GDP per person was 30,000 yuan (NBRC 2011 Table 2-1), but in Shanghai it was 76,000 yuan per person (NBRC 2011 Table 2-15).

Water related figures come from China Water Statistical Yearbook for 2010 (MWR, 2011), especially from part 2 Control of Rivers (MWR, 2011, Table 2-9).

5.3 Cases 1-6: Variation of damage costs

In the first six cases the numerator with the investment costs is held constant, only the damage in the denominator will be changed. For the numerator the following values are used:

- δ = 0.08 /year
- $1/\theta$ = 0.5 m
- k(u) = 10 million yuan/m/km
- l = 100 km.

These values reflect a relative flat area, but not close to the sea, with a river main dike grade 2. The investment costs in the numerator are then 40 million yuan/year.

If we consider this dike as a circle around an area, the surface of the area would be 800 km^2. In combination with the average population density for the whole of China this would lead to more than 100,000 people in this area. This is, however, an extremely low estimate for the number of people in a flood plain.

Case 1 thus describes an area, which has low population density and a quite low estimate of GDP per person: 100,000 people (N_0 = 10) with an average income of 10,000 yuan per person (GDP_0 = 1). This implies a total loss by flooding of 6000 million yuan. The middle probability of flooding is then: 40/6000 = 1/150years. In the table P^{middle} is given not as a probability but as a recurrence interval of 150 years. Suppose the annual rate of growth of the total damage is equal to the rate of economic growth and that this rate is estimated to be 7% per year till 2025. Then P^{middle} in 2025 would be 1/429 year. In all cases the figures for the recurrence intervals have been rounded off to 3 significant digits.

The characteristics of other case model areas are summarised in Table 2 and results in Table 3.

Table 2 Key model characteristics

Case	Characterisation of model area
1	A relatively flat rural area
2	Rural area adjacent to Grade IV Town or Grade III Medium-sized City
3	Grade II Important City with national average GDP and average economic growth
4	Grade II Important City with high average GDP and average economic growth
5	Grade II Important City with very high GDP but slightly lower economic growth
6	Grade I Very Important City with dike only along one side

Table 3 Cases 1-6 Variation of the damage by flooding, in combination with low investment costs

Case	**Investment** 10^4 **yuan**	**GDP_0** 10^4 **yuan**	**Population** 10^4 N_0	**Economic growth (γ) %**	**P^{middle} 2010 years**	**P^{middle} 2025 years**
1	4000	1	10	7%	150	429
2	4000	2	20	7%	600	1720
3	4000	3	100	7%	4,500	12,900
4	4000	5	100	7%	7,500	21,400
5	4000	5	100	6%	7,500	18,400
6	4000	5	1000	6%	75,000	184,000

In Case 2 the population density has been increased to 2 times the national average. Case 2 represents the surroundings of a Grade IV Ordinary City or Town and Grade III Medium-sized Cities, see for this classification PR China (1994). In China the legal recurrence interval on this boundary was set in 1994 at 50 years.

Case 3 describes a Grade II Important City, with income reaching national average.

It is likely that in this type of city the wealth per person is much higher than in a low density rural area. Therefore, in Case 4 the GDP per person has been increased to 50,000 yuan per person.

Since this already is an important city with a high density and high wealth, it is possible that the growth rate will be lower, say 6% till 2025, which lowers P^{middle} in 2025 as shown by Case 5.

It is also possible that the dike is only on one side of the area. Then it is possible that much more people will be affected by a flooding. This is Case 6 with a Grade I Very Important City. The efficient standard of 1/75,000 is not only higher than the present standard in China of (better than) 1/200 per year, but looks incredibly high indeed. However, keep in mind that Case 6 describes a city of 10 million people, and that on a yearly basis the costs of protection of this city would be not more than 40 million yuan or 4 yuan per person per year, which is really 'nothing' compared to the city income of 50,000 yuan per person per year. Remember that all the figures for the costs components in Table 3 were chosen on the low side.

5.4 Cases 7-11: Variation of investment costs

In the next cases (Table 4) the costs are varied. The costs of damages in the denominator are held the same as in Case 4, with a rate of economic growth of 7% per year till 2025. Since the cost figures in Table 3 were chosen on the low side, in most cases the cost examples in Table 5 must be table 4are chosen higher.

Table 4 Key characteristics of case 7-11 with case 4 as reference

Case	Characterisation of model area
4	Grade II Important City along river with high average GDP and average economic growth
7	Grade II Important City along river with high discount rate = High inflation
8	Grade II Important City along river with higher investment costs (sluices and pumping stations)
9	Grade II Important City along river with grade 1 dyke
10	Grade II Important City along river
11	Grade II Important City on the coast with Grade 1 sea dike

Table 5 Cases 7-11, Variation of the investment costs with damage costs as in Case 4.

Case	Discount Rate (δ) %	Investment (1/θ) m	Unit cost per m k(u) 10^4 yuan	L Length km	V_0 Losses 10^8 yuan	P^{middle} 2010 years	P^{middle} 2025 years
4	8%	0,5	1000	100	3,000	7,500	21,400
7	12%	0,5	1000	100	3,000	5,000	14,300
8	12%	0,5	2000	100	3,000	2,500	7,140
9	12%	0,25	2000	100	3,000	5,000	14,300
10	12%	1	2000	100	3,000	1,250	3,570
11	12%	1	6000	100	3,000	417	1,190

Compared with the rate of growth the real discount rate in Case 4 is low, since the Ramsey Rule states that a stable macro-economic growth is only possible, if the discount rate is higher than the rate of growth: $\delta > \gamma$[8] .

In Case 7 the rate of discount is set at 12% to foster efficiency in investing. Further, it is possible that 10 million yuan/m/km is a reasonable figure for a 'green dike'; however, a dike section of 100 km encompasses also constructions like sluices and pumping stations.

In Case 8 the average the costs are twice as much. Another possibility is a river main dike grade 1. In both cases costs are 20 million yuan/m/km.

The heightening which corresponds to a lowering of the flood probability by a factor *e* can vary a lot between regions. It is small in regions not too far from the sea where the level of a river doesn't differ that much from the sea level. On the other hand, it can be quite high at the coast (storm surges) or along upstream sections of rivers. Cases 9 and 10 sketch lower and higher values for 1/θ, but still along rivers.

[8] See for the Ramsey Rule any good handbook on macro-economics.

Case 11 is a sketch of a situation along the coast where a sea dike grade I is needed, because heavy storms are possible.

All these examples show that efficient flood standards not only depend on the damage that will occur when there will be a flooding, but also on the costs that are necessary to prevent a flooding to occur.

5.5 Cases 12-15: Examples of flood standards for reservoirs

In Chapter 3.2 a second format for the flood standard is the combination of the formulas (4) and (6):

$$P_t^{middle} = \frac{S_{j+1}^{middle}}{V_t} = \frac{\delta \, {}^{I(A(y))}\!\big/_{\ln y}}{GDP_0 \, f \, N_0 \exp(\gamma t)}.$$

This format can be used for flood protection measures like reservoirs. Here the difficulty in defining examples lies in making a reasonable assumption of the relative change in the flood probability (*y*) by completing an efficient protection project (A). What an efficient size would be, is completely determined by local circumstances. In case of a reservoir in a valley, it will depend on the location where a dam can be constructed efficiently depending on the soil (also on the slopes), the width of the valley at some place and the capacity of the reservoir that will be the result. Since we have no information at all we assume a flood probability of y = 10 for all cases below. Also we fix the discount rate δ = 12% per year, f = 6 and the growth rate γ = 7%.

Table 6 Key characteristics of case 12-15 for protection by reservoirs

Case	Characterisation of model area
12	Small rural area protected by 1 simple and relatively cheap medium sized reservoir
13	Large rural area protected by 5 simple and relatively cheap medium sized reservoirs
14	Urban population of 1 million people protected by 1 large reservoir
15	Urban population of 1 million people protected by 10 large reservoirs

Table 7 Case 12-15: Examples for reservoirs.

Case	I (A(10)) Investment 10^4 yuan	Reservoirs No	Income GDP_0 10^4 yuan	Population 10^4 N_0	P^{middle} 2010 years	P^{middle} 2025 years
12	2000	1	2	20	23,000	65,800
13	2000	5	2	20	4,600	13,200
14	30000	1	5	100	19,200	54,800
15	50000	10	5	100	1,150	3,290

For the damage costs we used Case 2 for the Cases 12 and 13, and then Case 4 for the Cases 14 and 15.

In Case 12 we suppose one relatively cheap medium sized reservoir would do the job, which results in very high protection levels indeed.

In Case 13 we suppose that 5 of these constructions are necessary to achieve the overall effect of a factor 10.

In the Cases 14 and 15 there is a city of 1 million people in the flood plain of the valley, so the valley cannot be a small one. Therefore, we assume in Case 14 one big reservoir and in Case 15 ten very big reservoirs are needed to get a factor 10. Nevertheless, the overall impression of the outcomes in Table 7 is that building reservoirs may be indeed a very efficient way of providing protection against flooding. Constructing dams seems cheap since the costs of a medium sized reservoir are the same as the costs of an upgrade of only 2 to 4 km river main dike grade 1, see Table 1.

5.6 Cases 16-17: Examples of flood standards based on statistical figures

In this section we try to give some examples for flood standards loosely based on real Chinese statistical figures for provinces. Provinces are much larger areas than dike rings. So we do not pretend that these examples really can be used as such. More that they bear hopefully a bit better resemblance to real life situations than the theoretical examples given before. Nevertheless, one very important figure is still completely missing: the influence of a dike heightening on the flood probability or the expected loss ($1/\theta$). This lack of crucial information severely limits the significance of the following calculations.

Table 8 Key characteristics of case 16-17

Case	Characterisation of model area
16	Shanghai protected by 200 km grade 1 sea dikes, 400 km grade 2 sea dikes and 500 km grade 2 river dikes
17	Actual renovation of 27/35 km Yangtze River dyke in Hunan Province

First, Case 16 with some figures related to Shanghai. The number of people in the protected area is 7 million, which are supposed to have the average GDP per person of Shanghai which is 76,000 yuan in 2010. There are 3700 km of dikes which all comply with the standards. 1100 km of them are grade 1 and grade 2 sea and river dikes. Here we need to make some assumptions. The present situation is: 200 km of Huangpu sea/river dikes grade 1 with a recurrence interval of 1000 years, 400 km of sea dikes grade 2, and 500 km of Yangtze river dikes grade 2. Upgrades of both the 400 km sea dike grade 2 and the 500 km river dike grade 2 would cost the same amount of money as an upgrade of 100 km sea dikes grade 1. So, in the calculation we use 400 km with average costs of 60 million yuan/m/km. This can be on the low side, since there will also be quite expensive constructions. Further, the 2600 km river dikes with a lower grade than grade 2 are supposed to cost 4 million yuan/m/km, which is equivalent to 180 km with a cost price of 60 yuan/m/km.[9] We choose δ = 8%; f = 6 and γ = 0.07 till 2025. What we really do not know, is how a heightening affects the flood probability ($1/\theta$). We just take some number, $1/\theta$ = 0.5 m. Here we can make another mistake, since it is possible that a real improvement in the overall standard can only be achieved by changing for instance the sea dikes grade 2 into sea dikes grade 1.

Nevertheless, we get in Case 16 outcomes that do seem to be within a reasonable range. A recurrence interval in 2010 that is roughly a factor 10 longer than the 1994 standard of >200 year seems reasonable, if only compared to the increase in GDP in this period, see Chapter 2.3. Intuitively speaking, these figures seem even at the lower side of a reasonable band for recurrence intervals for such an important city. They certainly reflect the high costs of protecting a city at the mouth of such a big river and near the sea with the regular occurrence of typhoons.

Table 9 Cases 16-17 More realistic examples.

Case	$1/\theta$	Unit costs k(u) yuan	Length of Dike km	GDP_0 (10^4 yuan)	Population 10^4 N_0	P_{middle} 2010 years	P_{middle} 2025 years
16	0.5	60	580	7.6	700	2300	6550
17	0.5	12	11	2.5	16	4550	13,000

Case 17 is a completely different one since it refers to only 27 km of dike in Hunan, which protects 160 thousand people. In 2010 the average GDP in Hunan was 25,000 yuan. The total damage by flooding is very small indeed compared to the previous example. Here we split the dikes in 3 km with costs of 12 million yuan/m/km and 24 km where an upgrade costs 4 million yuan/m/km corresponding to 8 km with a cost price of 12 million yuan/m/km. Since the costs are even smaller than the damage compared to Case 16, the estimate of an efficient flood standard is higher. But also here, there is no indication at all for the real value of the parameter $1/\theta$. So these two cases cannot even be compared since the real value of $1/\theta$ can differ a lot between these very different areas.

Concluding remarks

Nevertheless, these examples clearly show that for the value of efficient flood standards not only damage matters, but costs too. Whether one wants to give costs that much weight, is a political decision. As said already in Chapter 2.2, besides efficiency there are other important considerations as well like equality of people or the possible size of a flood as such. Maybe it is possible to evacuate 160 thousand people in time in a situation where the flood prone area is a relatively small stretch along a river and where it is easy to transport the people only a few kilometres uphill. On the other hand, it can be practically impossible to evacuate say 10 million people from a wide, flat flood plain, especially near the sea where the warning time always will be short.

[9] Such a non-homogeneous case, probably with different values for $1/\theta$ per dike section too, asks for a suitable approach, which is described in Brekelmans et al. (2012).

6 Conclusions on flood security

1. The expected loss, not the probability of flooding is the pivotal variable in making decisions about the safety of flood prone areas. So legal safety standards for the probability of flooding should be derived from standards for expected loss.

2. The Middle Probability of Flooding is an excellent numerical basis for an efficient standard for testing the safety of the whole ring dike. This means that acting according to these standards in the long run results in the lowest welfare losses that are possible.

3. There are other important considerations rather than efficiency in establishing a legal flood standard, like guaranteeing a minimum safety level or taking possibilities for evacuation into account. In the end to set flood standards is a political decision, not the outcome of a calculation alone.

4. The numerical value of the middle probability of flooding is hardly influenced by climate change. However, climate change will influence the frequency of the upgrades to comply with the test standard.

5. General rules for the size of good designs cannot be given, see Eijgenraam (2007). In practice efficient designs can easily result in a probability of flooding which is 3 to 5 times lower than the flood standard.

6. In China there are no maps available that indicate the legal standards for different areas, or are there maps indicating actual flood risks.

7. The standards for flood control that exist in China date back to 1994. Since that year real GDP in China has increased by a factor 5.3. Efficient flood standards expressed as recurrence intervals are proportional to the potential damage by flooding. All other things equal and given the 1994 standards by 2010 the recurrence intervals should have been increased by factors ranging probably between, say 3 for low density rural areas to maybe even 9 for big cities.

8. To calculate efficient flood standards for areas in China is useful. Even if it does not directly lead to a revision of the legal standards they can be used to give upgrades the right size or to reserve enough space for broadening riverbeds to prevent bottlenecks to occur in the future, especially in fast urbanizing areas.

9 To calculate the middle probability of flooding figures are needed on the costs of efficient improvements, on the effect that these improvements have on the probability of flooding, and on the potential damage by flooding. In China probably a lot of this information is already available somewhere, but needs to be brought together and organized in the way as indicated by the formulas.

10 Consider the revision of the flood standards in China since they date back to 1994.

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Appendix 1

Appendix 1 1994 Flood Control Standards of China

On June 2nd, 1994, the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) and the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) jointly issued one of the national standards - *Standard for Flood Control*, making regulations on protection objects such as urban areas, rural areas, industrial and mining enterprises, communication and transportation facilities, water conservancy and hydroelectric power projects, power facilities, communication facilities, cultural relics and historic sites and tourist facilities, and on the articles in *Standard for Flood Control* concerning the prevention and control of storm flood, snowmelt flood and rain-on-snow mixed flood.

According to *Standard for Flood Control*, cities shall be classified into four grades according to their importance of social and economic status and their non-agricultural population. The standard for flood control of the four grades is defined as follows.

Table 10 Grades and Standard for Flood Control of the Cities

Grade	**Importance**	**Non agricultural Population** 10^4	**Standard for Flood Control as Recurrence Interval** years
I	Very Important Cities	≥150	≥200
II	Important Cities	150～50	200～100
III	Medium-sized Cities	50～20	100～50
IV	Ordinary Cities and Towns	≤20	50～20

All the protection areas which mainly consist of towns and counties (Rural Protection Areas) shall be classified into four grades against their population and agricultural area. The standard for flood control of the four grades is defined as follows.

Table 11 Grades and Standard for Flood Control of Rural Protection Areas

Grade	**Population of the Protection Area** 10^4	**Agricultural areas within the Protection Area** (10^4 *mu*)	**Standard for Flood Control as Recurrence Interval** year
I	≥150	≥300	100～50
II	150～50	300～100	50～30
III	50～20	100～30	30～20
IV	≤20	≤30	20～10

All the industrial and mining enterprises such as metallurgical businesses, coal businesses, petroleum businesses, chemical engineering businesses, forestry, building material businesses, machinery businesses, light manufacturing businesses, textile businesses and commercial businesses shall be classified into four grades against their sizes. The standard for flood control of the four grades is defined as follows.

Grades and Standard for Flood Control of Industrial and Mining Enterprises

Grade	Sizes of Industrial and Mining Enterprises	Standard for Flood Control as Recurrence Interval year
I	King-sized	200～100
II	Large-sized	100～50
III	Medium-sized	50～20
IV	Small-sized	20～10

Appendix 2

Appendix 2 Mathematical model for the optimization of flood protection strategy

Flood Probability

$$P_t = 1 - F_t(H_t) = P_0\, e^{\alpha\eta t}\, e^{-\alpha(H_t - H_0)} \qquad for\ H_t \geq H_0.$$

With
- P exceedance probability in year t (1/year),
- F exponential distribution function of extreme water levels,
- α parameter exponential distribution F (1/m),
- η structural increase of the water level (m/year),
- H height of the dike (m).

There is an effect of climate change on the flood probability.

Loss by flooding

$$V_t = V_0\, e^{\gamma t}\, e^{\zeta(H_t - H_0)} e^{\varepsilon\eta t}.$$

With
- V_t average loss by flooding in year t (million Euro),
- γ rate of growth of wealth in the ring dike (per unit per year),
- ζ increase of loss per m dike heightening (1/m),
- ε increase of loss per m water level (1/m).

There is an effect of economic growth on the loss by flooding, an effect of climate change on the loss by flooding and, only along rivers, an effect of dike heightening on the loss by flooding.

Expected loss (risk)

$$S_t = P_t V_t = S_o \, e^{\beta t} \, e^{-\theta h_t},$$

Where $\beta = \alpha\eta + \gamma + \varepsilon\eta,$

$$\theta = \alpha - \zeta > 0,$$

$$h_t = H_t - H_0.$$

With St expected loss at time t (million euros/year).

Investment costs

$$\begin{aligned} I(u_j, h_{j-1}, t_j) &= J(u_j) e^{\lambda h_{j-1}} = D(u_j) \, e^{\lambda h_j} && for \quad u_j > 0, \\ &= 0 && for \quad u = 0, \end{aligned}$$

With I investment costs (million Euro),

u heightening dike (m),

Where $\lim_{u \downarrow 0} I_j = I_j^F > 0,$

$$I'_u > 0 \qquad for \quad u > 0.$$

As an example:

$$D(u_j) = c + bu_j, \qquad c > 0, \quad b + \lambda > 0, \quad b\lambda \geq 0.$$

The investment cost function is discontinuous in $u_j = 0$ and non-convex because of the fixed costs. The linear specification of D has been used in the CBA for the project Room for the Rivers (see for a summary Eijgenraam (2006) Chapters 4.2 - 4.5) and for the CBA to establish new legal safety standards for flood protection 'Water Safety 21st century', see Eijgenraam & Kind (2011).

Objective function, state and control variables

$$\min_{U(u,t)} \left\{ \int_0^{\infty} S(h,t)\, e^{-\delta t}\, dt + \sum_{j=0}^{\infty} I(u_j, h_{j-1})\, e^{-\delta t} \right\},$$

With

$$\Delta h_t = \begin{array}{ll} u_0 \geq 0 & t = t_0 = 0, \\ u_j > 0 & t = t_j > 0, \\ 0 & t \neq t_j > 0. \end{array}$$

Also

$$h_t = h_{j-1} = \sum_{k=0}^{j-1} u_k \qquad for \quad t \in \left[t_{j-1}, t_j \right) \quad j \geq 1.$$

Solution

This non-convex optimization model can still be solved analytically and has under some conditions on the specification of the function *D* only one solution. This unique solution is periodical, i.e., $u_j = u$ for all $j > 0$. See for part of the proof of the necessary conditions Eijgenraam (2006) pp. 49-54. The proof on the sufficient conditions in Eijgenraam (2006) is not correct. The complete proofs are only written down in the draft PhD thesis of Eijgenraam which is not publicly available yet. A paper on the solution of the flood problem for a ring dike with different dike sections (Brekelmans et al. (2012) has been accepted for publication in *Operations Research*. Further a paper is under review for possible publication in *Management Science*.