Cost benefit analysis and flood damage mitigation in the Netherlands

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Aim of this paper is to investigate the application of cost benefit analysis methods in the decision-making on a desired flood protection strategy in the Netherlands. After a discussion of historical developments in flood protection in the Netherlands the method of cost benefit analysis is presented as a useful instrument in decision-making. In the second part of the paper the economic analysis of flood protection strategies is firstly approached from a theoretical point of view. Subsequently the economic analyses carried out in practice are described for two more practical cases, the study on "emergency retention areas" and the dike reinforcement program in the river system. It is concluded with some notions about a recent project, which aims at mapping the risk of flooding for the Netherlands. The paper shows that an economic analysis, when correctly applied, can provide important rational information in the decision-making process.

Key words: flood protection, flood damage, flood risk, cost benefit analysis, economic optimisation

1 Introduction and overview of developments in flood protection

1.1 Introduction

Large parts of the Netherlands lie below sea level and are threatened by river floods. The flood depths in some areas can therefore become higher than 7 meters. Without the protection of dunes, dikes and hydraulic structures more than half of the country would be almost permanently flooded as is shown in Figure 1. Therefore, flood protection has always received much attention. There is always the possibility of flooding. But how serious is this danger? It is difficult to say. Especially shortly after a (near) disaster the situation is perceived as unsafe. Dunes and water defences protect the country. Yet, there is no such thing as absolute safety against flooding. The question is which risks are acceptable and which ones are not. This is an ever-recurring socio-political consideration, which is fed by developments in the state of knowledge.

Figure 1: The Netherlands without flood protection (the dark area can be flooded due to influence from the sea)

In the last decade of the 20th century methods have been developed to determine the probability of flooding and its consequences. The outcomes of this research offer new insights and moreover new possibilities to carry out a cost benefit analysis for various flood protection strategies. The aim of this paper is to investigate the application of cost benefit analysis methods in decision-making on a desired flood protection strategy in the Netherlands.

The paper is structured as follows. The remainder of section 1 will give a short overview of history, and new developments in flood protection. Section 2 will describe the principles of cost benefit analysis and section 3 will show how the decision on an economically acceptable level of flood protection can be approached from a more theoretical point of view. Section will 4 analyse the application of methods for cost benefit analysis for two practical cases. The conclusions from this study are summarized in section 5.

1.2 History

Due to its location, the Netherlands is always threatened by floods. Life in the delta of the Rhine and Meuse involves risks, but has also enabled the Netherlands to develop into one of the main gates of Europe. In the past river floods provided fertile soil and clay for brickworks, but also negative effects occurred, such as the loss of goods and chattel and the danger of drowning. As welfare increased and population density grew, more and better protection systems were built to prevent flooding. Since the Middle Ages more and more dikes, quays and hydraulic structures have been constructed. Whether the protection against the water is sufficient, is an all-time question; one that is asked at this moment and one that will be asked constantly in the future.
Since the danger of flooding is difficult to determine in advance, politics and society usually adopted a reactive position until recently. An 'almost' flood should not repeat itself. Until 1953 dikes were constructed to withhold the highest known water level. In 1953 a flood from the North sea occurred in the south of the Netherlands, killing over 1800 people and causing the disruption of a large part of the Netherlands. This flood disaster resulted in major investments to improve the water defences, based on a more pro-active base. After the 1953 flood the Delta Committee was installed to investigate the possibilities for a new safety approach. Safety was not based on the highest occurred level anymore, but on a rough cost-benefit analysis. In an econometric analysis the optimal safety level was determined for the largest flood prone area, Central Holland. This work laid the foundations for the new safety approach, in which dikes are dimensioned based on a design water level with a certain probability of occurrence.
The Deltaworks, which were constructed to protect the Southwest part of the country against inundation from sea, were given priority over protection against river floods. After the completion of the Deltaworks, the strengthening of the river dikes began at full speed. As the last big river flood dated back to 1926, there was strong opposition from environmentalists who where against the strengthening programme. The strengthening of river dikes resulted in loss of ecological areas, landscape and sites of cultural value. In 1993 the Government and Parliament agreed upon a new approach, saving the landscape, nature areas and places of cultural value (see the Boertien-case in section 4 of this paper). The river floods in 1993 and 1995 once again drew attention to the risks of life in a delta; afterwards the water defences were reinforced at an accelerated rate. In 2001 most water defences were at strength, and in accordance with the safety standards referred to in the Water Defence Act. 53 So-called dike ring areas are distinguished, i.e. areas protected against floods by a series of water defences (dikes, dunes, hydraulic structures) and / or high grounds. The safety standards for these dike rings are based on the probability of exceedance of a design water level. Design and safety evaluation are based on these design water levels. For the coastal areas design water levels (see above) have been chosen with frequencies between 1 / 4000 [1 / year] and 1 / 10.000 [1 / year]. For the Dutch river area the safety standards were set between 1 / 1.250 [1 / year] and 1 / 2.000 [1 / year]. These safety standards for the various dike rings are shown in Figure 2.

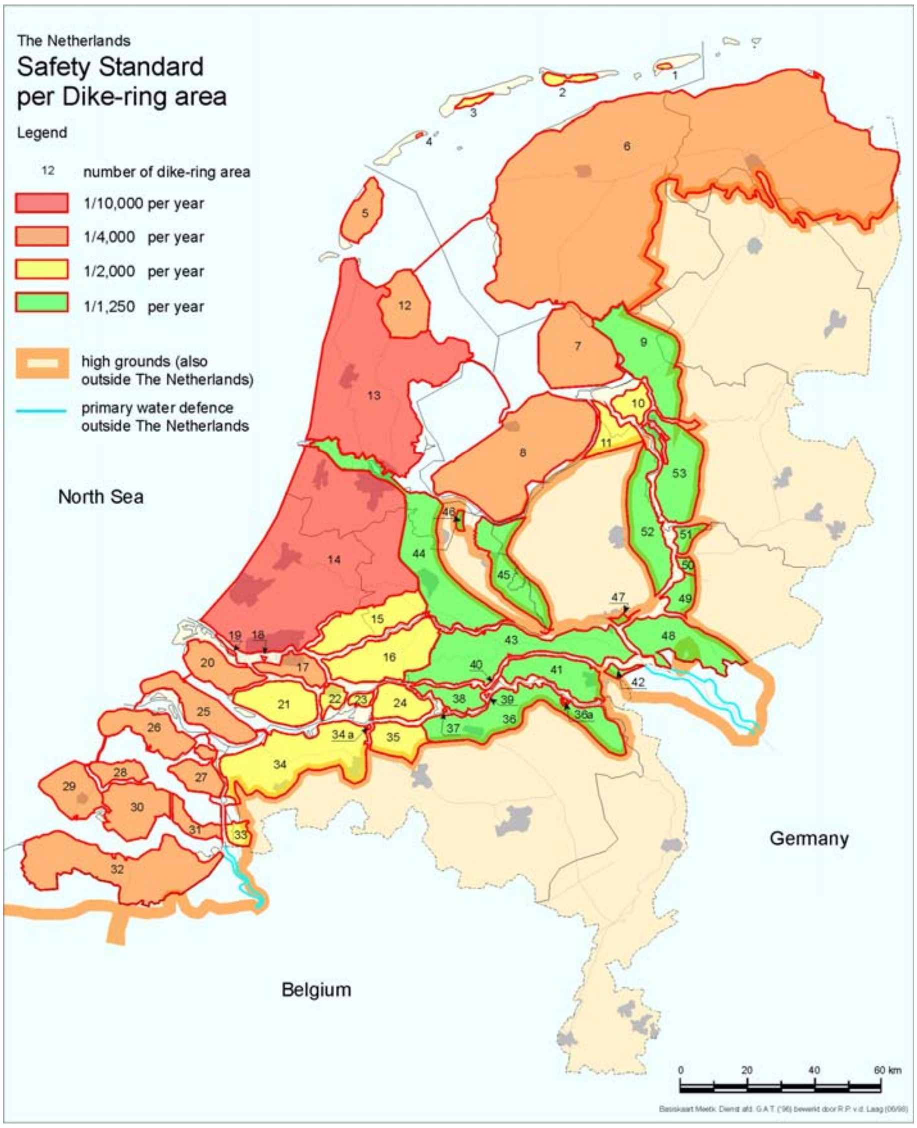

Figure 2: Overview of protection standards for dike rings given in the 'water defence act'

1.3 **Developments in coping with floods in the Netherlands**

While damage protection in the Netherlands traditionally aimed at reduction through improved dike construction, nowadays new political movement can be seen that searches for measures to prevent flooding *without* raising the dikes along the rivers. For example by giving the river more space. This 'Room for the Rivers' concept is a widespread in the Netherlands now as a possible alternative for dike strengthening. In the coming document of the national policy on spatial planning in the Netherlands it is expected that room for rivers will be described. An other 'hot item' are the so-called 'Emergency Retention Areas': Areas that can be inundated in a controlled way to prevent uncontrolled flooding of other areas. They will be used when a discharge occurs that exceeds the design discharge. These Emergency Retention Areas are, though controversial, a serious item in today's Dutch political discussion. Also more attention can be found for evacuation planning, early warning systems, insurance of flood damage and for the link with spatial planning. The expected developments of the rise of the sea level, higher river discharges and soil subsidence require a pro-active policy, in which the increase of the interests and investments to be protected will have to be taken into consideration. Knowledge of water and water defences is indispensable when considering the desired protection level against flooding. The Technical Advisory Committee for Water Defences has developed a method to determine the probabilities of flooding and has successfully tested its application for four dike ring areas (TAW, 2000). A dike ring area is a flood prone area protected by dikes, dunes, structures and / or higher grounds. Based on this study the Ministry of Public Transport, Public Works and Water Management carries out a project in which the probabilities of flooding are calculated for all 53 dike ring areas (definitive results 2005). The method to determine probabilities of flooding can be distinguished from the current "design water level" approach at three levels:

- The transition from an individual dike section to a dike ring approach: the strength of a dike ring (consisting of dikes, engineering structures and dunes) can be calculated as a whole. The method will considerably increase understanding of possible weak links in the protection system.
- Taking equal account of various failure mechanisms of a dike (ring). This is different from the current approach, in which the safety analysis of the dike dominated by the mechanism of overtopping and overflow of water.
- Taking into account, in a systematic and verifiable way, all uncertainties when calculating the probabilities of flooding. In the current approach uncertainties are for the greater part discounted afterwards by additional safety margins.

Knowing this probability of flooding gives the opportunity to use a risk-assessment (or cost benefit analysis) to determine if the current - or in future expected- flooding risks are acceptable. When evaluating the acceptability of the probability of flooding in an area the potential damage caused by floods and danger for the population are key-information. In the next years the Ministry wants to portray the damage as a result of a flood together with other parties involved. At that moment it will also be possible to calculate the costs and benefits of the entire range of measures. These measures might include research (inspection and testing, study and research), reinforcement and elevation of the water defences, ‘room for the rivers’, retention areas as well as restriction of flood consequences by means of spatial planning or technical and administrative measures.

2 Cost-benefit analysis

The basic principle of cost benefit analysis (CBA) requires that a project results in an increase of societal welfare, i.e. the societal benefits generated by the project should exceed the costs of it. Every effect of an investment project can be systemically estimated and, wherever possible, given a monetary value. In addition, the cost-benefit analysis gives an overview of distribution effects, alternatives and uncertainties, since an overall assessment by politicians and others requires complete information (Eijgenraam, 2000). This requires that all relevant effects, also the intangible effects, are taken into account. However, in the analysis of the costs and benefits of projects in practice, the analysis is often narrowed to the consideration of tangible monetary effects. An example is a study on the costs and benefits of six flood management projects (CPB, 2000).
In such a “limited” cost benefit analysis the economic benefits of an activity are compared with the costs of the activity. If the benefits are higher than the costs, the activity is attractive (it generates an increase in economic welfare). If the benefits are lower, the activity is not attractive. In flood management this means that the costs of measures for increasing the safety against flooding (for example dike strengthening of flood plain lowering) are compared with the decrease in expected flood damage. In the cost figure different types of costs have to be included: costs of investment (fixed and variable) and the costs of maintenance and management. The benefits include the reduction of damage costs, which are often subdivided in direct costs (repair of buildings and interior damage), costs of business interruption of companies in the flooded area, and indirect costs outside the flooded area (mainly due to business interruption. It has to be noted that companies outside the flooded area may also benefit of the flood due to transition effects. Also the potential economic growth due to improved flood defence should be taken into account in a full cost benefit analysis.
The cost benefit approach can be criticised because it necessitates quantification of all costs and benefits in monetary terms. However, in our opinion it is one of the essential parts of information, which is necessary for rational decision-making. Other elements can be added, in order to achieve a complete overview of all relevant aspects of the decision problem. Yet, there is no general accepted framework available where the relevant pieces of information are put together, and there are different ways of monetising the non-monetary impacts (for example contingent valuation by surveying the willingness to pay). Therefore it is investigated in the context of the flood management in the Netherlands how subjective attitude towards flood risks can be incorporated into a cost-benefit analysis. In a utility framework, see for example (French, 1988) non-monetary measurable impacts can be expressed in the utility function, which describes the usefulness of the

decision. The same can be done for the monetary impacts, so that all impacts can be summed up in one variable. An important notion is the attitude (of the people who might be a victim of a flood, or the decision maker) towards the costs and the flood damage reduction. There are three basic attitudes: the risk neutral (which is assumed in a cost-benefit analysis), the risk-prone attitude (where costs are valued lower and damage reductions are valued higher than they are) and the risk-averse attitude (where costs are valued higher and flood damage is valued lower). It turns out in the context of flood management that a risk-averse decision maker will choose higher protection levels than a risk-neutral of risk prone one (Voortman, 2002). However, a reliable method to quantify the risk aversion factor is in the context of events with ‘high impacts, low probabilities’, is not yet available. Summarizing this section it can be stated that despite the limitations, a cost benefit analysis still can provide significant rational information to the decision makers.

3 Economic optimisation and cost benefit analysis in theory

Firstly, the method of economic optimisation is presented as a framework for the derivation of an economically optimal level of risk in section 3.1. This method is closely related to the cost benefit analysis, as is shown in section 3.2. The elements to be included in both methods are discussed in section 3.3.

3.1 ***Economic optimisation***

The derivation of the (economically) acceptable level of risk can be formulated as an economic decision problem. According to the method of economic optimisation, the total costs in a system (C_{tot}) are determined by the sum of the expenditure for a safer system (I) and the expected value of the economic damage ($E(D)$). In the optimal economic situation the total costs in the system are minimised:

$$\min(C_{tot}) = \min(I + E(D))$$

The method of economic optimisation was originally applied by van Danzig (1956) to determine the optimal level of flood protection (i.e. dike height) for Central Holland (this polder forms the economic centre of the Netherlands). An exponentially distributed flooding probability (P_f) was assumed, which depends on the flood level h and the parameters A and B of the exponential distribution:

$$P_f = e^{-\frac{h-A}{B}}$$

The total investments in raising the dikes (I_{tot}) are determined by the initial costs (I_{h0}) and the variable costs (I_h). The dike is raised X, the difference between the new dike height (h) and the current dike height (h_0).

$$I_{tot} = I_{h0} + I_h \cdot X \qquad \text{and} \qquad X = h - h_0$$

In this study a more general formulation has been chosen between investments and flood protection level (denoted by flooding probability). Based on van Danzig a linear relation between the two has been adopted, but for more practical applications another relation can be chosen. The investment function is reformulated by substitution as a linear function of the negative logarithm of the flooding probability with parameters constant I_0 and steepness I' (By substitution with the equations presented above it can be shown that: $I_0 = I_{h0} + I_h(A\text{-}h_0)$ and $I'=I_h \bullet B$):

$$I_{tot} = I_0 + I' \cdot (-\ln(P_f))$$

The expected value of the economic damage can be calculated from the probability of flooding (P_f), the damage caused by the flood (D). The expected value has to be discounted with the so-called reduced interest rate (r'), which takes into account the interest rate (r) and the economic growth rate (g), for a very long time period considered, this can be written as:

$$E(D) = P_f \cdot D / r' \qquad r' = r - g$$

The total costs are the sum of investments and the expected value of the economic damage. The economic optimum is found by minimising the total costs. The derivative of the total costs and the flooding probability results in the economically optimal flooding probability ($P_{f,opt}$), from which the optimal dike height can be derived:

$$C_{tot} = I_0 + I' \cdot (-ln(P_f)) + P_f \cdot D / r'$$
$$dC_{tot} / dP_f = 0 \quad \Rightarrow \quad P_{f,opt} = I' \cdot r' / D$$

The relation between (decreasing) flooding probability and investments, risk and total costs is shown in Figure 3.

This analysis of the Delta Committee introduced the risk-based approach of flood defence, and was, as such, a major step. However, the proposed method proves to have some limitations. An improved approach has been proposed by Eijgenraam (2003). The main adjustments include the time dependent planning of dike improvements, and the modelling of the dependency between optimal protection level and economic growth. If these factors are taken into account, different outcomes will be generated.

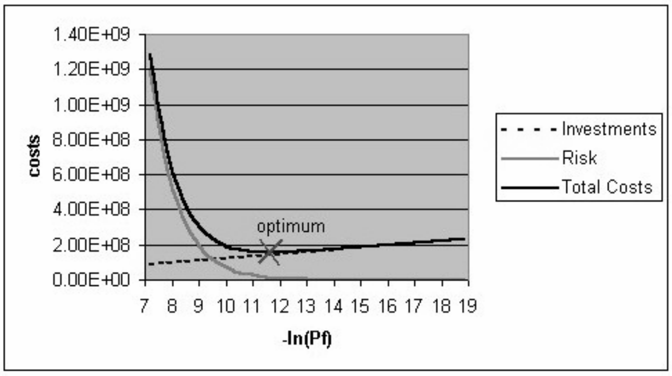

Figure 3: Relation between total costs and decreasing failure probability, for the example and corresponding variables analysed in (van Danzig, 1956):[I_0 = 3.9.10^7 (Dfl), I' = 0.33 . 10^6 (Dfl), D = 24.10^9 (Dfl), r' = 0.015 (/yr), 1 Euro = 2.2 Dfl]

3.2 *Cost benefit analysis*

The economic optimisation merely takes into account the cost side of the flood protection problem, and does not consider the potential economic benefits in the area due to improved flood protection. It has been shown by Voortman (2002) how economic benefits can be taken into account in the framework presented above. This shows that the economic optimisation as presented above is a special case of this full cost benefit analysis. A cost benefit analysis can be carried out to assess the profitability of a project, as has been described in section 2. In a simplified approach it should be checked that the costs in the initial situation should exceed the total costs after completion of the project. After determination of an economically optimal level of system protection, using the economic optimisation as presented in section 3.1, this cost benefit criterion should also be applied. Following the formulations given above the criterion can be written as follows:

$$I_0 + I' \cdot (-\ln(P_f)) < (P_{f,0} - P_f) \cdot D / r'$$

where:

$P_{f,0}$ - flooding probability in the initial situation

From the criterion shown above it can be seen that the cost effectiveness of a measure will depend on the ratio between investments and risk reduction. The most cost effective measure is the project for which the highest protection level is found (i.e. the smallest optimal failure probability) at lowest cost. Such rational information can be used in the decision making process. However, it should be noted that based on other values, such as ecological, social and political considerations, an alternative could be chosen that would not be the most favourable when merely economic aspects are considered.

3.3 *Elements in the CBA and economic optimisation*

In the formulation of the theoretical criteria for economic optimisation and CBA in sections 3.1 and 3.2 the same elements are included. These are the investments in raising the dikes or improving the flood defences in an alternative way, the flooding probability (P_f), and the benefits, in this case the prevented flood damage (D).

The investment costs in flood defence can include for example the construction costs of dikes and the maintenance costs. Also the decrease of agricultural production, and other limitations of economic growth of certain areas should be considered. See (CPB, 2000) for a more complete discussion of costs associated with flood defence projects. However, in general it can be stated that the required investments will be project specific and depend on the on the alternative solution chosen.

In recent years an advanced program for reliability analysis of ring dike systems has been under development: PC-RING. It implements reliability analysis of the elements in a ring dike system, considering all principal dike failure modes. The method is applied to calculate the probability of flooding for a dike ring, a further description is given by Steenbergen et al. (2004). This currently available method is based on the analysis of single dike rings. However, in practice the safety of one dike ring may depend on the safety of another dike-ring. A flood of one dike ring can for example lead to a reduction of the flooding probability of the dike-ring situated downstream. The main aspects of this so-called “system behaviour” are described by van Mierlo et al. (2003).

The damage that may be expected as the result of a flooding of one of the densely populated, highly economically developed areas in the Netherlands will undoubtedly be enormous. The extent of this damage depends on the nature of the flood, for example from sea or river, and the properties of the area, for example terrain height and land use. A method has been developed for estimation of the economic damage due to flooding (Vrisou van Eck et al, 2001). The procedure for damage estimation is schematically shown in Figure 4. Information on land use is combined with flood data (water depth). Stage-damage relations have been developed for different types of land use, which estimate (part of maximum) damage as a function of water depth. The result of the damage assessment is the total economic damage that can be expected, given that particular scenario.

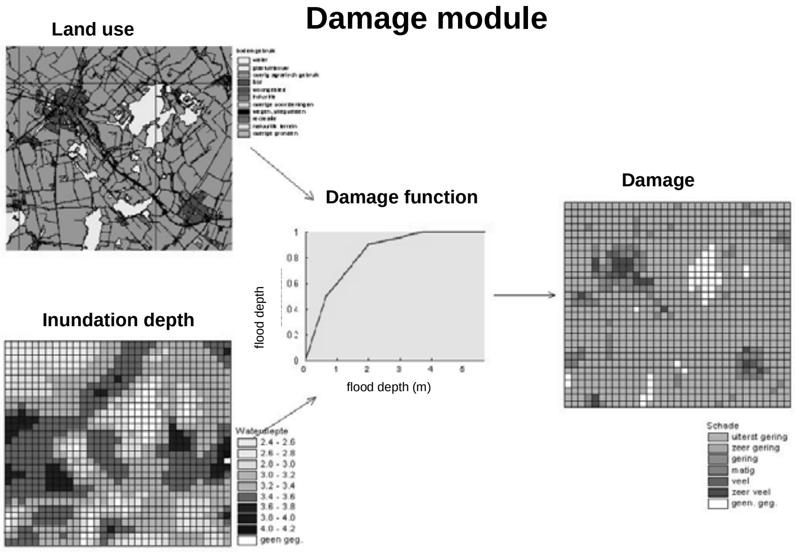

Figure 4: Principle of the method for assessment of economic damage

While the described method focuses mainly on estimation of the direct economic damage, ongoing research is carried out to gain more insight in the indirect effects of floods for the national economy. It is expected that neglecting of the indirect effects of floods will lead to an under-estimation of damage numbers. In the Netherlands for example the loss of gas-supply from the fields in the Northern part of the country due to flooding will result in an economic damage. Other examples could be the loss of the national airport of Schiphol or the Rotterdam harbour. However, when carrying out a complete cost benefit analysis, also other types of damage have to be included in the analysis. For example loss of life caused by floods. It is likely that floods in the Netherlands have inundation depths of more than 4 meters and it may even be 7 metres. The big flood of 1953 in South-West Netherlands caused 1800 victims. Another potential problem is the environmental damage due to pollution of all kind of chemical elements. The number of potential objects, which might cause the pollution, is enormous (chemical factories, stocks, oil tanks, etc.). Furthermore damage of Nature, Landscape and Ecological values may occur. Economic valuation of these “intangible” damage types is a difficult subject. Although some methods have been developed, which attribute an economic (monetary) value to loss of life, ecological damage, these are generally not taken into account in a cost benefit analysis. Yet, there is no general accepted framework available where the relevant pieces of information are put together, and there are different ways of valuing the non-monetary impacts.

4 The practice of cost-benefit analysis

Although theoretical concepts are nice and attractive, it is interesting to investigate the application of the theory in practice. Therefore two cases in the Dutch river-area are described. Both studies were carried out by a (different) advisory committee, which advised the Dutch government. The section is concluded with a short description of an actual project assessing the flood risks in the Netherlands (FLORIS)

4.1 ***1992: 'River dike reinforcement criteria testing commission'***

Reason of this project was the finding of the 1977 Commission (called the Becht commission), which recommended that river dikes be designed tot resist water levels that would be exceeded with an expected frequency of 1 / 1.250 [1 / year]. While dike improvements based on these standards were underway, protests grew against their harmful impacts on the landscape an natural and cultural values on and along the dikes. In response, the Minister of Transport, Public works and Water Management established the *'River dike reinforcement criteria testing commission' (*also called the Boertien Commission after its chairman) and contracted for the research. (Walker, 1994). Primary objective of the study was to identify policies that would provide a high level of safety, would not cost too much, and would preserve as much as possible of the existing landscape, natural, and cultural values (LNC values) along the rivers.

In the study it was stated that a flood protection policy is composed of two parts: a safety level, and a strategy for improving the dikes and / or reducing the water level of the rivers to provide the chosen level of safety. The minimum safety level considered was a level of 1 / 200 [1 / year] and the maximum level was the level of 1 / 1250 according to the Becht commission. The diverse consequences (or impacts) of the policies examined were estimated and were displayed in a scorecard. The scorecard which summarises the arguments of the committee is given in table 1.

The results show that the benefits through reduction of projected flood damage greatly exceed the financial costs of improving the dikes. The table shows that the return on the M€l 75 (=375-300) that it would cost tot build dikes to a safety level of 1 / 1250 instead of 1 / 200 is a present-value benefit of at least M€ 994. The commission recommended to maintain the safety-level in the river area on the level of 1 / 1250 [1 / year] and the government followed this line.

The score table shows that, if monetary costs and benefits are the only desiderata, even the 1 / 1250 safety level is lower than what a pure financial cost / benefit analysis would recommend. In the study no higher safety-levels were regarded. Apparently the decision makers considered a higher safety-level not acceptable from other than economic (LNC values) point of view. Our opinion is that it would have been better to take this extra step to complete the economic analysis. In this way the cost benefit approach is not used in an optimal way to support explicit and rational decision-making.

Table 1: *Investment cost and estimation of risk reduction for the alternatives analysed by the "Boertien Commission" (derived from table III in (Walker, 1994)*

Alternative	Investment costs (M€= 10^6 €)	Present Value of reduction in expected flood damage (M€) max	med	min
safety level 1/200	300	0	0	0
safety level 1/500	331	2872	1997	726
safety level 1/1250	375	4089	2809	994

4.2 2002: 'Committee Emergency Retention Areas'

Start of this project was the growing awareness in political regions that, even with the high safety levels in the Netherlands, absolute safety does not exist. The Minister of Transport, Public works and Water Management established the *'Committee Emergency Retention Areas'* (2002), which is also called the Luteyn Commission after its chairman. Objective of the committee was to advise about the attractiveness of a reservation of certain areas which can then be used as a storage basin to store access of water along the big rivers Rhine and Meuse. The committee was asked to advise about the usefulness, effectiveness and necessity of these storage basins, and if the idea is attractive, to choose (select) certain areas. The committee advised that it is indeed attractive to have these basins, and they proposed three areas, see Figure 5 for an overview.

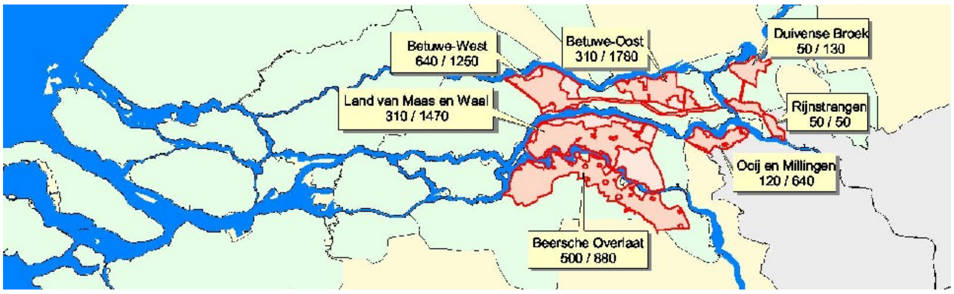

Figure 5: Proposed areas along the Rhine and Meuse for selection of an emergency retention area (Numbers indicate economic damage (in mln of Euros) with and without additional protective measures)

The basic argumentation of the committee is that controlled flooding is to be preferred above uncontrolled flooding, and that investments of more than an estimated one billion Euro are recommended. The scorecard which summarises the arguments of the committee is presented in table 2. This table can be found on page 32 in the report of the committee (Committee Emergency areas, 2002)

On the basis of table 2, the committee concluded that: "The committee has assessed that the total investment costs is about 1,25 10^9 €. But on the other hand, with a controlled flooding less people have to leave their homes, the societal disruption is smaller and the flood damage will be substantial lower. With other words, the benefits are far bigger than the costs” (page 33).

Table 2: Scorecard of the two alternatives as presented in the report of the Committee Emergency Areas, 2002

Alternative	Number of people to be evacuated	Flood Damage (10^9 €)	Investment costs (10^9 €)
Present situation (without emergency areas)	500,000	55	0
New situation (with 3 emergency areas)	35,000	0.7	1.25

However, if we apply the concepts as described in the sections above, we may conclude that the cost benefit analysis in the report cannot pass the test. The committee compares the total flood damage with the investments of the retention areas. In such a comparison, the present value of the economic risk has to be calculated (flood damage multiplied with the probability divided by the discount rate). Note that it is the opinion of the authors of this paper that the assumed flood damage in table 2 is unrealistically high: it assumes that all dike rings along the river will be flooded. In reality, however, if one the dike rings is flooded, the expected damage of the other dike rings will be lower, because the water levels in the river will drop after failure of one the water defences. Another observation is that in the calculations of the committee and in table 2 it is assumed that the emergency areas reduce the flooding probability downstream these areas completely. This, however, is not a valid argument, as is noted by the committee on page 22 (the flooding probability of these areas will be reduced to 1/4000). This part of the criticisms is also been remarked by the committee of water defence experts (Technical Advisory committee on Water defences). Applying the method as described above and in previous sections, table 3 is obtained. From the table it can be concluded that the costs of the emergency areas are (much) higher than in the current situation under the assumption of maximal damage. We also remark that the reduction of the flooding probability due to the impact of retention areas may be lower than is assumed in table 3 (see Kok et al, 2003).

Table 3: Scorecard of the alternatives using the theoretical concepts of section 4 and using more realistic assumptions

Alternative	**Investment costs (10^9 €)**	**Flood damage (10^9 €)**	**Present value flood damage (10^9 €)**	**Total costs (10^9 €)**
Current situation (maximal damage)	0	55	$\frac{55}{1250*0.04}=1.10$	1.1
Current situation (realistic damage)	0	15	$\frac{15}{1250*0.04}=0.3$	0.3
New situation (with 3 emergency areas)	1.25	0.7	$\frac{0,7}{1250*0.04}=0.014$	1.264

Discount rate:4%; flooding probability: 1/1250

Table 3 indicates that for case of realistic damage the creation of the emergency areas will lead to a reduction of present value of flood damage of 0.29 billion € a year, at a cost of 1.25 billion €. This difference between benefits (= risk reduction) and costs can be overcome by assuming non-monetary values of the three emergency areas. At the moment of writing this paper the government has not yet decided whether to adopt the commission's advise or not. If a decision would only be based on the cost-benefit analysis, the commission's advise would not be adopted. However, there are more values than the economic values, such as landscape, natural and cultural (LNC) values and social values. The final weighing of economic, cost-benefit aspects and other aspects is a political choice.

*4.3 **2001 – 2005: Project Floris, flood risks and safety in the Netherlands***

The FLORIS (Flood Risks and Safety in the Netherlands) project is initiated by the Directorate-General for Public Works and Water Management. In collaboration with the water boards and provinces, the initial aim of the project is to acquire a detailed picture of current safety from flooding in the Netherlands. To this end, the parties will work together to refine new research methods for determining the probabilities and risks of flooding.

A calculation will be made of the probabilities and consequences of flooding in the Netherlands. Together, the probability and consequence will constitute the risk of flooding. Based on the results of Floris, it will be possible to obtain the best survey of flooding to date in the Netherlands. This will provide insight into the probabilities of flooding and into the weakest links in the various dike ring areas. Based on this, rough estimates can be made of the costs of improvement. Furthermore, the Floris findings will provide an important basis in support of reconsidering socially desirable safety levels. Floris will also contribute to the decision-making process concerning measures to retain or increase safety, relative to costs and benefits. There should be complete insight into flooding safety in the Netherlands no later than 2005.

5 Conclusions

The aim of this paper is to investigate the application of cost benefit analysis methods in decision-making on a desired flood protection strategy in the Netherlands. The following conclusions and recommendations can be given:

The basic principle of cost benefit analysis indicates whether a project results in an increase of economic welfare, i.e. whether the benefits generated by the project exceeds the costs of it. An economic optimisation can be carried out to determine the optimal level of system. The information provided by the cost-benefit analysis and / or the economic optimisation should be considered as a technical advice to the decision- and policy- makers. In the decision making process it should be combined with other types of relevant information;

Analysis of two recent case studies shows that the theoretical cost benefit concepts are not fully applied in practice. In the two case studies the government asked an advise to an independent committee with respect to the level of investments in river flood management. In the first case study the committee compared the costs and benefits in a sound way, but the optimal level of protection is not determined. In the second case study the committee did not compare the costs and benefits correctly, and compared the investment costs directly with the flood damage. These shortcomings may have influenced the decision.

It is recommended to apply the concept of cost benefit analysis in decision problems with respect to flood damage mitigation more explicitly. Providing information to decision makers generated by these concept will increases the possibilities that the alternative is chosen which optimises the societal needs.

From an economic point of view decision makers may choose the flood protection strategy that achieves the largest risk reduction at lowest costs. The final decision on a desired flood protection level should not only consider economic aspects, but it should involve a comparison of all relevant alternatives. The economic optimisation and the cost benefit analysis can provide important rational information in this decision-making process.

Disclaimer

Any opinions expressed in this paper are those of the authors and do not necessarily reflect the position of the Dutch Ministry of Transport, Public Works and Water Management.

References

CPB, Centraal Plan Bureau, 2000, Ruimte voor water: kosten en baten van zes projecten en enige alternatieven, cpb werkdocument no.130

Danzig D. van, 1956, Economic decision problems for flood prevention, *Econometrica 24,* p. 276 – 287

Committee Emergency areas, 2002,Controlled flooding. Report of committee emergency areas. The Hague

Eijgenraam, C.J.J., Koopmans, C.C., Tang P.J.G., Verster, A.C.P., 2000, Evaluatie van infrastructuur projecten: Leidraad voor kosten-baten analyse, Sdu uitgevers Den Haag

Eijgenraam, C.J.J., 2003, Economische criteria voor de hoogte van dijken, cpb memorandum v/2003/I

French, S., 1988, Decision theory: an introduction to the mathematics of rationality, Chichester Horwood

Kok, M., Stijnen, J.W., Silva, W., 2003, Uncertainty analysis of river flood defence design in the Netherlands. in: *Proceedings of ESREL 2003*: Safety and Reliability – Bedford and Van Gelder (eds) Swets & Zeitlinger

Steenbergen, H.M.G.M., Lassing, B.L., Vrouwenvelder A.C.W.M, Waarts, P.H., 2004, Reliability analysis of flood defence systems, this issue

Mierlo, M.C.L.M. van, Vrouwenvelder, A.C.W.M., Calle E.O.F., Vrijling, J.K., Jonkman, S.N., Bruijn K.M. de, Weerts, A.H., 2003, Effects of river system behaviour on flood risk, Delft cluster report dc 1-211-1

Rijkswaterstaat, Road and Hydraulic Engineering Institute, 2003, Project Floris. Flood Risks and Safety in the Netherlands DWW-2003-009

TAW, Technical Advisory Committee on Water Defences, 2000, Towards a new safety approach. A calculation method for probabilities of flooding

Voortman H., 2003, Risk-based design of large-scale flood defence systems, Ph.D.-thesis Delft University of Technology, Delft University Press

Vrisou van Eck N.; Kok M.; Vrouwenvelder A.C.W.M., 2000, Standard method for Predicting Damage and Casualties as a Result of Floods, Lelystad: HKV Consultants and TNO Building and Construction Research

Walker, W., Abrahamse, A., Bolten, J., Kahan, J.P., Van de Riet, O., Kok, M., Braber, M. den, 1994, A Policy Analysis of Dutch River Dike Improvements: Trading off safety, cost and environmental impacts. *Operations Research* (42), 5, 823-836.