CHAPTER 230

FLOOD AND EROSION CONTROL IN THE CONTEXT OF SEA-LEVEL RISE

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ABSTRACT

Low-lying countries such as the Netherlands are very vulnerable to climatic changes, which are likely to cause an increase in sea-level rise. The most obvious threat is permanent inundation of unprotected low areas. However, such a 'final' situation will be preceded by a period of increasing episodic flooding and coastal erosion. Sea-level rise causes *safety* against flooding and erosion to reduce which should be accounted for in long-term coastal zone management plans. The question is to what extent such increases are tolerable and what can we do about it. This problem concerns the levels of safety which are desired, also in coastal areas which are already protected from flooding: is there a surplus of safety so that no intervention is required, or does the coastal defence system need to be adapted? The relevance of this question lies not perse in the threat of sea-level rise: the same question may be raised in the case of developing coastal areas, where economic values at stake increase: such developments cause a relative weakening of the flood defence system: the desired safety standards increase so that the existing defence system may not meet any longer the changed demand for flood protection and is to be adapted.

The above problem description was the background of a number of studies in the Netherlands to assess the impacts of a possible climatic change and to evaluate potential counter measures. A model has been developed for quick analysis of combinations of scenarios for climate change and potential counter measures. This paper describes the limitations of Cost Benefit Analysis as a tool for the appraisal of flood alleviation in view of the inaccuracies in investment costs and material flood damages.

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INTRODUCTION

The decision problem many coastal managers are facing concerns coastal protection. Intuitively, or explicitly by spelling out all possible advantages and disadvantages of possible protection options, the coastal manager puts the decision problem in a cost-benefit framework. In general, such a framework is not necessarily confined to monetary values only, also values in other units may play a role. Often a multi-criteria evaluation method is applied to evaluate all effects of the various options being compared.

However, the manager will tend to limit the amount of different units of expression in his decision framework, mostly he will try to monetize the effects in terms of benefits and costs, simply because he needs (monetary) budgets to implement any preferred policy. Therefore, the most appealing framework for the coastal manager is Cost-Benefit Analysis. Intangible effects and other, often external, effects which cannot be expressed in terms of money, are accounted for then as PM issues and are subject to, for example, environmental impact procedures. In this paper we point that there are practical problems when applying Cost-Benefit Analysis for the appraisal of flood protection and coastal defence systems, also in the case that only concrete monetized material benefits and costs are considered. These problems are due to the uncertainties in the various components, i.e. the various types of flood damages and cost estimates related to flood protection and erosion control.

FRAMEWORK OF ANALYSIS

When applying the method of Cost-Benefit Analysis (CBA), there are some issues which need to be addressed, viz.

- *valuation*: how to value the different measures and effects in monetary terms;
- *time*: how to account for future costs and benefits;
- *scale*: how to determine the scale the effects are to be looked at (accounting stance).

Suppose we know how to handle these issues, the decision to invest in coastal protection, as far as monetary effects is concerned, is not difficult if the costs C of a scheme and the benefits B differ significantly, i.e. if $C \ll B$ *or* $C \gg B$. If $B \approx C$ a closer inspection of the uncertainties in the cost and benefits is required.

When appraising a coastal defence system it is generally tried to maximize the net benefits Z over the analysis period:

$$Z = W - C_I - C_F \tag{1}$$

where W represents the income in the endangered area, C_I the investment cost and C_F the flood (or erosion) damages.

In most cases the costs and benefits are uncertain and unequally distributed over time. Figure 1 shows an example of two investments in flood defence between which the flood damage and benefits are constant, as determined by constant hydraulic forcing. Economic development or natural phenomena like sea-level rise may cause the cost and benefit streams to change over time.

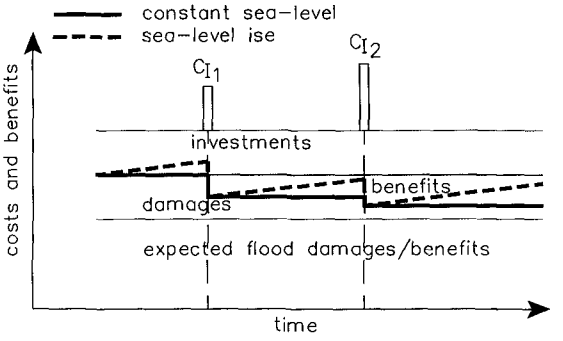

Figure 1 Costs and Benefits of flood protection

We suppose there is a number of K intervals, starting in the first year and with an investment C_{I_k} on the start of each interval K. Further each interval k ends on time p_k. The expected present value of the total investment cost $C_{I_{tot}}$ is written as

$$E\left\{C_{I\,tot}\right\} = \sum_{k=1}^{K} E\left\{C_{I\,k} \bullet \alpha^{p_{k-1}+1}\right\}$$

where $\alpha = \exp(-i)$ with i as the discounting factor.

In each investment interval flood and erosion damage may occur, and benefits due to flood protection. These damages and benefits are determined by the pattern of storm surges impacting on the structures, the structures itselves, and the topography and objects in the protected area. We need to capitalise these cost and benefit streams as follows in order to get the expected total damage to be put in the Cost-Benefit Analysis:

$$E\left\{C_{F_{tot}}\right\} = \sum_{k=1}^{K} \sum_{j=p_{k-1}+1}^{p_k} E\left\{C_{F_{k,j}}\right\} \alpha^j \tag{2}$$

and

$$E\left\{B_{tot}\right\} = \sum_{k=1}^{K} \sum_{j=p_{k-1}+1}^{p_k} E\left\{B_{k,j}\right\} \alpha^j \tag{3}$$

In principle, the expected benefits and costs can be compared now:

$$E\{B_{tot}\} < ? > E\{C_{I_{tot}}\} + E\{C_{F_{tot}}\}$$

Looking more in detail in the cost of flooding, we can schematize the cost of flood damage by

$$C_F = V \bullet F_p \bullet (1 + F_s) \tag{4}$$

where V represents the value of one or more flooded objects, and F_p and F_s damage factors, pertaining to primary and secundary (multiplier effects) flood damage.

The occurrence of flood damage is uncertain, depending on storm surge attacks, and the value of objects is often uncertain and can be estimated only from available statistical data on land-use and economics. Furthermore, the value of objects will change over time, due to development of activities in the flood-protected coastal zone. We suppose a growth factor of $(1+g)$. In order to project the time streams of costs and benefits in a reference year, we discount the benefits and costs, with a discounting factor i. Further the damage factors F_p and F_s are also uncertain variables. The expected value of the total flood discounted damage, in time interval k $[p_{k-1}+1, p_k]$ is written as:

$$E\{C_{F_{tot,k}}\} = E\left\{ \sum_{j=p_{k-1}+1}^{p_k} V_j \bullet \alpha^j \bullet F_{p_j}(1 + F_{s_j}) \right\} \tag{5}$$

where V_j, F_{p_j} and F_{s_j} are uncertain variables. Further $\alpha = e^{(-i+g)}$.

By definition, and taking continuous functions for the uncertain variables,

$$E\{C_{F_{tot\ k}}\} = \sum_{j=p_{k-1}+1}^{p_k} \int\int\int v_j \bullet \alpha^j \bullet f_{p_j}(1 + f_{s_j}) \bullet \prod(v_j, f_{p_j}, f_{s_j})\, dv_j\, df_{p_j}\, df_{s_j} \tag{6}$$

Supposing V_j, F_{p_j} and F_{s_j} are independent, we find

$$E\{C_{F_{tot_k}}\} = \sum_{j=p_{k-1}+1}^{p_k} \int\int\int v_j \bullet \alpha^j \bullet f_{p_j}(1 + f_{s_j}) \bullet \prod(v_j) \prod(f_{p_j}) \prod(f_{s_j})\, dv_j\, df_{p_j}\, df_{s_j} \tag{7}$$

which leads to

$$E\left\{C_{F_{tot_k}}\right\} = \sum_{j=p_{k-1}+1}^{p_k} E\{V_j\}\ \alpha^j\ E\{F_{p_j}\}\ E\{1+F_{s_j}\}$$
$$= \frac{\alpha}{(1-\alpha)}\left(\alpha^{p_{k-1}} - \alpha^{p_k}\right) E\{V_j\}\ E\{F_{p_j}\}\ E\{1+F_{s_j}\} \tag{8}$$

Similarly, the expected value of the total benefits incurred by the construction of a coastal protection system is written as

$$E\left\{B_{tot\ k}\right\} = E\{\sum_{j=p_{k-1}+1}^{p_k} B_j \alpha^j\}$$
$$\sum_{j=p_{k-1}+1}^{p_k} E\{B_j\}\ \alpha^j \tag{9}$$
$$= \frac{\alpha}{(1-\alpha)}\left(\alpha^{p_{k-1}} - \alpha^{p_k}\right) E\{B_j\}$$

The investments C_I are composed by the initial cost C_{IM} resulting from mobilisation and demobilisation, and the variable cost C'_{IV} depending on the "amount" of construction works, which is derived from the amount Q and the unit cost C_{IV}:

$$C_I = C_{IM} + Q \bullet C_{IV} \tag{10}$$

The expected value of the capitalized total construction cost is written as

$$E\left\{C_{I_{tot}}\right\} = \sum_{k=1}^{K} E\left\{C_{IM_k} + Q_k \bullet C_{IV_k}\right\} \alpha^{p_{k-1}+1} \tag{11}$$

Equations (9), (10) and (11) provide the framework for the evaluation of the difference between the benefits and costs resulting from coastal protection measures. The distributions of the various variables should be known to assess the reliability of the indicators, such as benefit-cost ratio, resulting from the CBA.

UNCERTAINTIES

Flood and erosion damages

The most violent case of coastal flooding in the Netherlands was the well-known February Storm Surge Flood in 1953. The impacts have been analysed in detail in governmental reports, consultancy reports and publications resulting in an idea about the uncertainty in flood damages. Further, in the case of riverine floodings, the Flood Hazard Research Institute in UK has collected a lot of material on flood damages [Penning-Rowsell & Chatterton, 1977]. Also in France systematic research

damages [Penning-Rowsell & Chatterton, 1977]. Also in France systematic research is being carried out in the field of flood appraisal, focusing on the effect of flood warning systems [Torterotot, 1993]. In the Netherlands recently a major project has been carried out to assess the consequences of the December 1993 floods of the Meuse River, and to analyse the best options for structural and non-structural measures [Delft Hydraulics, 1994].

From analysis of the published data on flood damages due to the 1953 storm surge flood [CBS, 1953; TNO, 1982; TNO, 1989] it becomes apparent that there is quite some uncertainty about the size of flood losses [Peerbolte, 1993], this is confirmed by studies for other countries [Penning-Rowsell & Chatterton, 1977; Torterotot, 1993; Klaus & Schmidtke, 1990]. We conclude that the alleged accuracy in the assessment of direct material flood losses, in comparison with the assessment of losses to immaterial values is often overemphasized; even in the former category accuracy is not expected to be less than 40%. We will illustrate this figure by looking at the various damages resulting from the 1953 flood in the Netherlands.

The 1953 storm surge flood in the South-West of the Netherlands killed 1835 people and caused substantial damages, between 5 and 8 billion Dutch guilders on the current price level. The number of damaged houses and farms amounted to about 55,000, spreaded in a flooded area of more than 200,000 ha. Figure 2 shows the flooded areas. In the following some damage categories are described.

The cost of rehabilitation of agricultural land amounted to about DFL 6000 per ha (present prices) and was fairly constant across the flooded areas which is very substantial, in some cases 30 to 50% of the land price. The most important component is the repair and cleaning of ditches, drainage provisions, etcetera. However, it depends very much on the scale of the inundation and the violence of the flood. More recent minor floods in the Netherlands did not result in such high levels of damage to agricultural land.

Other damages to agricultural objects concern greenhouses in horticulture, plants and orchards, cattle, inventories, products and stocks of raw materials. Comparing observed, often estimated damages, with the values of the concerned objects, we observe a large variability in damage factors which supports the hypothesis that no fixed, overall valid values exist (Figure 3). It is seen from the graph that damage to greenhouses and inventories (agricultural equipment, vehicles, tractors) varies between 10 and 20%, to plants and orchards between 20 and 40%, and to stocks of products and raw materials, between 40 and 80%, a very large variability. Finally, the damage resulting from drowned cattle amounts to about 20% of the stock present in the affected area.

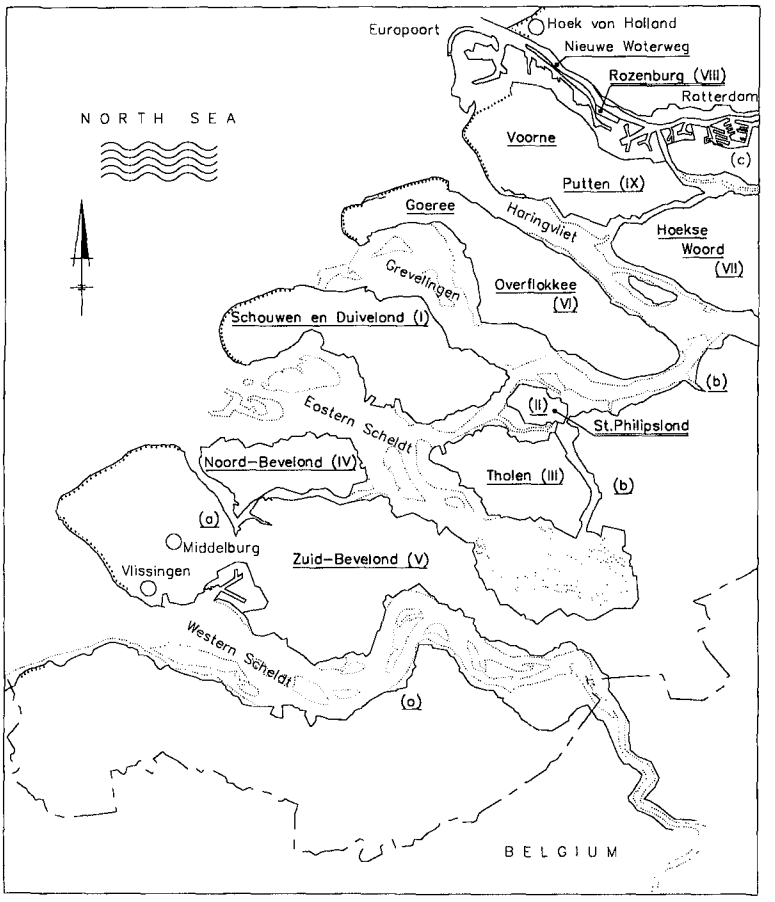

Figure 2 Areas flooded in 1953

Another picture is shown in the damages to the sector of industry, trade and banking, which is situated in the more populated areas. The core flooding areas which have been hit the most show damage factors for buildings and inventories of between 30 and 40%, and even up to 70% for stocks. The damage factors in the other core flooding areas and the surrounding areas are relatively constant with values between 10 and 20% for buildings and inventories, and between 20 and 40% for stocks (Figure 3).

The damage factor to motor vehicles amounts to about 10 or 20% of the replacement values, with the exception of some core flooding areas where the damage factors reach values of up to 40%.

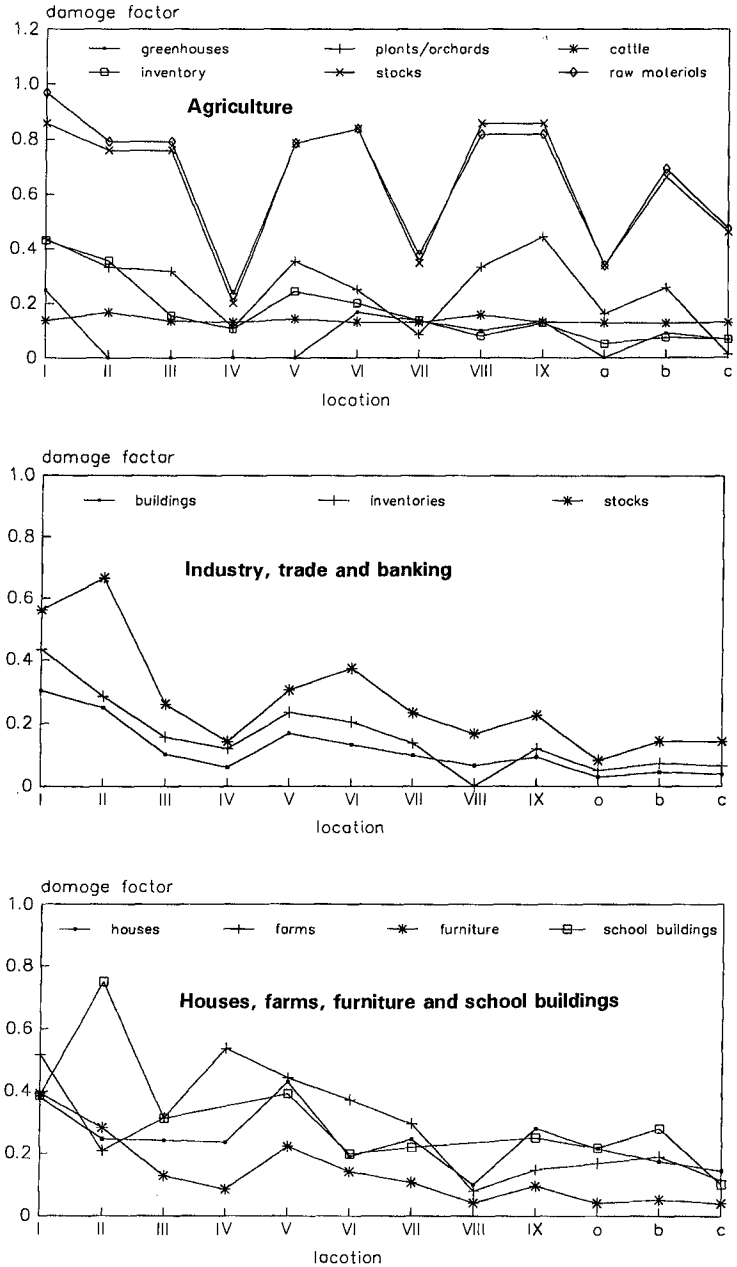

Figure 3 Damage factors in flooded areas

Damage to residential houses and farms, and the private belongings of the inhabitants, such as furniture, represents an important damage category. In addition, damage to public buildings such as schools will generally contribute substantially to the flood damage. The graph in Figure 3 shows that in the core flooding area the damage factor for houses and farms varies between 20 and 40%. Damages to furniture are more or less limited to 10%. Beyond the core area, in areas a, b and c, a damage factor of about 20% results.

The number of objects affected by the flooding is large, as mentioned earlier, so we may expect a fairly reliable result of the above survey. The crucial factor in the damage assessment has been the social survey; the structure and accuracy of this survey have eventually determined the accuracy of the resulting damage factors. Because of the large number of observations it is expected that the influence of subjectivity is averaged out and that there exists really a variability in resulting damage factors of the order as concluded above. The resulting figures give insight into this variability. Such variations can be explained by different factors such as i) inundation depth, ii) flow velocities, varying especially near a breach in the dike, iii) the time available to take preparatory measures and to evacuate, iv) the water quality and iv) the weather conditions [TNO, .1982].

THE INFLUENCE OF FLOODING DEPTH

Earlier analysis of the influence of the flood depth on the damage factor resulted in the graph shown on Figure 4. In the TNO report by Duiser [TNO, 1982] it is stressed that the scatter in data is wide, although the dependency of the damage factor on flood depth is obvious. From analysis of different damage categories it appears that furniture, buildings in industry, trade and banking and inventory in agriculture have, again roughly, the same damage factors as houses and farm buildings. Stocks and inventories in industry and trade tend to a somewhat higher damage factor. In Figure 4 the damage factor is plotted as a function of the different damage categories.

A later literature survey [TNO, 1989] has not resulted in new data on coastal flooding; all found studies considered concern riverine flooding. As regards flood damages to houses this study also confirms that a high variability in data exists.

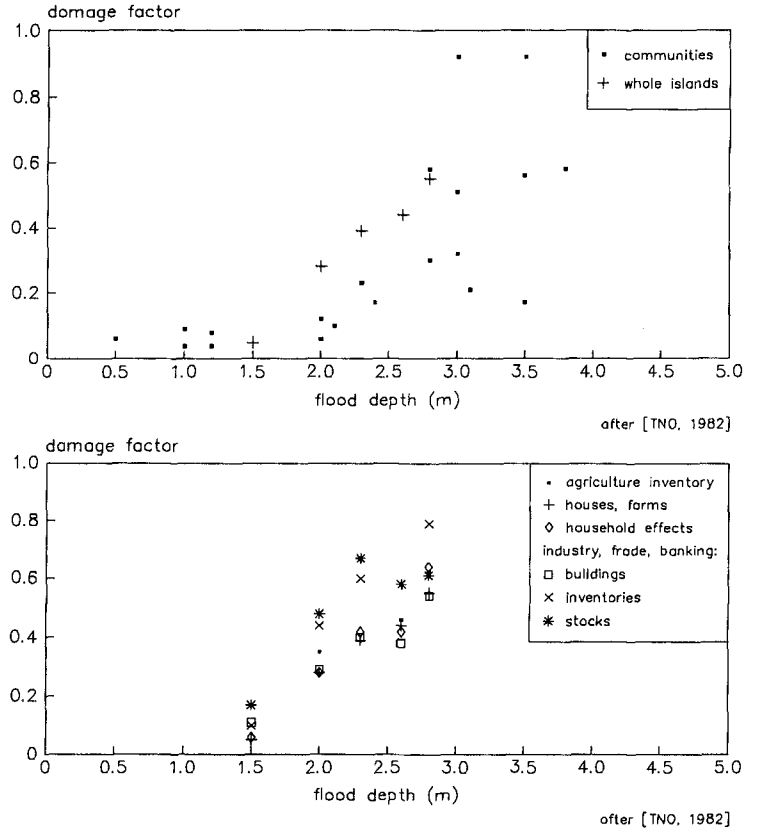

Figure 4 Damage-depth relationship

CONCLUSIONS ON FLOOD DAMAGES

Although major efforts have been undertaken to assess as precisely as possible the damages in real flood cases, a large variability in reported damage remains, partly due to a real variability in damages, for example caused by variations in flooding depth, duration and quality of buildings, but also partly due to differences in assessments. Whereas the 1953 damage data have been drawn from social surveys, focused on houses and household contents, the 1987-update of FHRC points to significant differences between perceived damages and real economic losses. Whilst the dependency on flooding depth may be obvious, as for example the work by TNO shows, a major scatter in data still exists, apparently because a lot of other parameters play a role in flood damages. For example, major influence on the variability

of damage factors is attributed to the effectivity of hazard warning systems and flood preparedness compared with physical parameters like flooding depth, flow velocities and flood duration.

Uncertainty in extreme water levels obviously adds to the uncertainty of flood damages. If the probability of exceedance of a certain design water level lies between $3*10^{-5}$ and $2*10^{-4}$, the resulting expected damages may vary by 100% if the damage factors are uncertain and range between 20 and 40 %, as has been shown above. So the strength of the flood protection system cannot be unambigously defined in a CBA framework, and we should have insight in the distributions of the relevant uncertain parameters.

SAFETY AND INVESTMENTS

Investments in dike-raising depend on a number of factors, which can be divided in two classes. First the required dimensions and strength of the dike are important factors. Secondly, the location of the dike determines the cost to a large extent. Dike sections in habitated areas are normally more complicated and hence costly to construct compared to dike sections in rural areas.

In the case of the Netherlands dike-raising is required when safety standards are no longer met. These standards are expressed in terms of water level exceedance probabilities as follows:

$$UF = 10^{-\frac{FB}{D}} \tag{12}$$

where UF represents the unsafety factor, determined by the decimating height D and the freeboard of the dike FB, being the difference between the actual crest level and the required level according to the safety standard. From analysis of the situation in the Netherlands it is concluded that the relative inaccuracy in UF may vary between 25 and 100% for dikes in coastal and deltaic areas, and even more than 100% in riverine areas Peerbolte, 1993].

Dike-raising p which is carried out as a response to a rise in sea-level of S_1, a rise in storm surge set-up of S_2 and increases S_3 in river discharges is related to these climate factors as follows [Peerbolte et al, 1991]:

$$p = \alpha S_1 + \beta S_2 + \gamma S_3 + 0.6\mu\,(S_1 + S_2 - \epsilon S_1) \tag{13}$$

The parameters α, β and γ reflect the propagation of sea-level changes and changes in river peak flow levels in the study area. Basically such parameters can be determined rather accurately. Wave run-up is accounted for by the parameter μ, and depends on the design wave and structural properties. Also this parameter is relative

accurate. The morphological response of the sea-bed is represented by ϵ. If ϵ is equal to 0 (i.e. the sea-bed does not raise due to sea-level rise), its accuracy is not important, compared to the other parameters because it does not contribute to the required dike-raising. If sufficient sediment is supplied and if there is no human interference, it is generally expected that the sea-bed follows sea-level rise. In that case ϵ is equal to 1 and only increase in storm surges may cause additional wave imacts leading to higher required dike-raising. In such cases the accuracy of ϵ is important: 20 to 40% of the accuracy in required dike-raising is due to the accuracy of ϵ. The fact that ϵ is an important parameter in coastal areas is illustrated by the reduction in required dike-raising: if ϵ is equal to 1, the required dike-raising is 25% less than in the case of $\epsilon = 0$, i.e. no sea-bed response to sea-level rise.

Finally we make a remark on the cost of dike-raising. From analysis by the Dutch Public Works Department it is concluded that the estimates of the cost of dike-raising vary between 10 and 40%. Figure 5 shows the total cost of dike-raising of all primary dikes (3400 km) in the Netherlands.

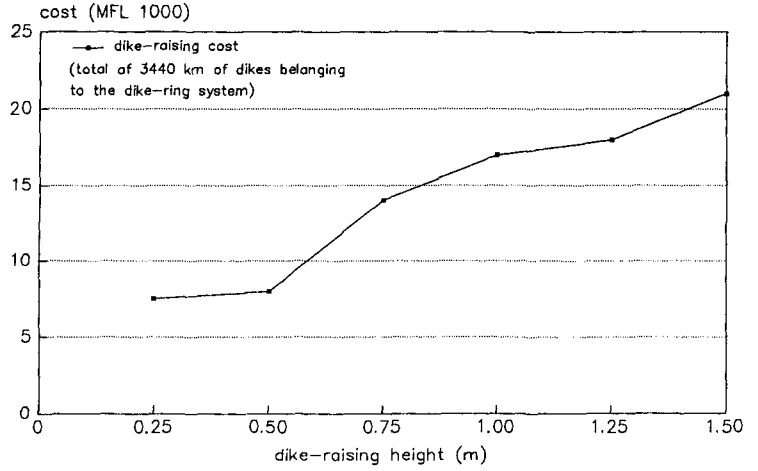

Figure 5 Cost vs. dike-raising of 3440 km primary flood dikes

THE NETHERLANDS

The studies carried out so far have produced the computational models to evaluate the costs and benefits of flood protection and erosion control in a deterministic way. These models relates investments to flood protection measures on the one hand, and the expected flood damages to the protection level on the other hand, and provide the information to optimize the investments in dike-raising (Figure 6). Full description of the various underlying models can be found in [Peerbolte, 1993].

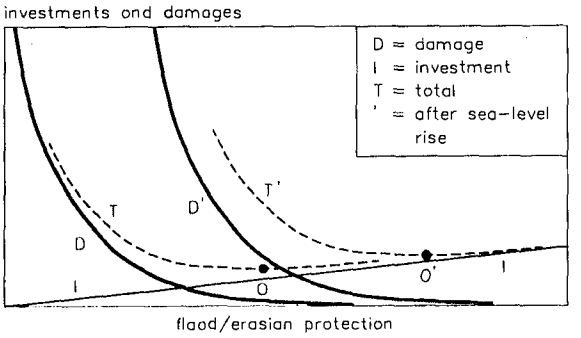

Figure 6 Principle of the shift in the optimal level of protection

Two aspects can be considered when evaluating these models: a) the cost of flood protection and coastal defence related to the protected tangible and intangible values, and b) the point of time at which the current dike-raising strategy, based on a rise of sea-level of 0.2m per century, should be reconsidered in order to maintain the present safety standards. As far as the cost of flood protection related to protected values is considered, in the Netherlands the benefits from flood protection obviously by far outweigh the necessary investments to maintain the established safety levels (see Figure 7). The optimal investment level (Figure 6) would be obtained if the dikes are raised with at least 1 metre [Peerbolte, 1993].

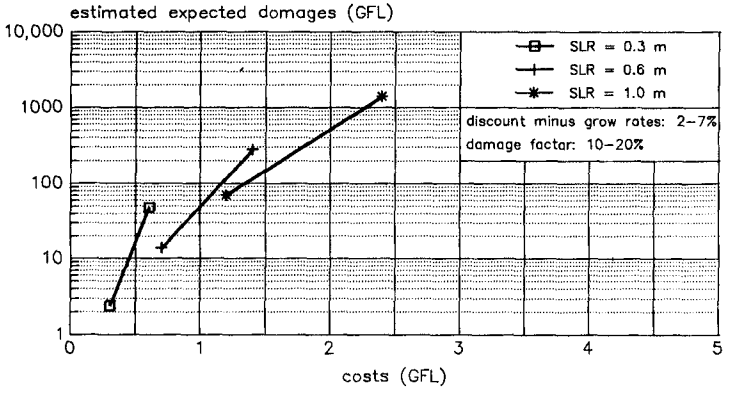

Figure 7 Estimated benefits and costs for different sea-level rise scenarios

As far as point b) is concerned, the conclusion is that it seems to be justified to reconsider this dike-raising strategy after 30 to 40 years, and to intensify dike-raising if the data point to a higher rate of sea-level rise. If, within this period of time a more serious scenario is seen to be inevitable, there is still time to switch to a dike-raising strategy matching these new predictions. This follows from computations of the unsafety factor and dike-raising cost, and the sensitivity thereof, for a number of sea-level rise scenarios. However, it should be kept in mind that the constraint on the system consisted of prescribed safety levels in terms of water level exceedance frequencies. These standard safety levels have been based on economic analysis by Van Dantzig [Delta Committee, 1962].

The above conclusions are based on modelling the different natural subsystems in the Netherlands, i.e. the coastal system, the estuarine systems in the North (Wadden Sea) and the South (Delta area), the lower and upper river systems, and the flood protected land itself, the analysis concentrated on the cost of dike-raising given a set of climate scenarios. The main conclusion regarding dike-raising is that there is no reason now to anticipate more severe scenarios than the present value of 0.2 m sea-level rise. With this scenario an average additional cost of roughly MFL 60 per year may be expected after about 60 years from now.

Vrijling has presented the formulation of a probabilistic optimization model on the basis of the problem definition by Van Dantzig whereby risk is defined as the product of uncertain flood levels and deterministic economic damages [Vrijling, 1993]. The above main conclusion regarding dike-raising is confirmed by the results of this probabilistic approach by Vrijlink.

DISCUSSION

One of the arguments against CBA is that this method cannot account for intangible values like human life and distress. The present study shows that also uncertainties in the "concrete" material damages form an important drawback for a practical application of CBA in flood defence appraisal. The assessment of these damages involves a great deal of uncertainty. It is therefore recommended to estimate the distributions of the various uncertain economic parameters as well, such as the parameters related to construction cost and protected values, in order to be able to apply a more comprehensive probabilistic model than a model with only water levels as stochastic variable. It may even be considered to apply only the values protected as guiding parameter, without including a damage factor, and to choose (political choice) a fraction of the established values for investment in flood alleviation schemes.

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