Intl. J. River Basin Management Vol. 1, No. 1 (2003), pp. 33–40

Resilience strategies for flood risk management in the Netherlands

M. VIS, *Manager River Basin Management, WL| Delft Hydraulics, PO Box 177, 2600 MH Delft, The Netherlands.*
Telephone: +31 15 2858793; Telefax: +31 15 2858717; E-mail: Rinus.Vis@wldelft.nl

F. KLIJN, *Senior advisor/researcher on River Basin Management, WL| Delft Hydraulics, PO Box 177, 2600 MH Delft,*
The Netherlands

K.M. DE BRUIJN, *Researcher, Delft University of Technology, Faculty of Civil Engineering and Geosciences Delft, PO Box 5048,*
2600 GA Delft, The Netherlands

M. VAN BUUREN, *Senior Landscape Planner, Institute for Inland Water Management and Waste Water Treatment (RIZA),*
PO Box 17, 8200 AA Lelystad, The Netherlands

ABSTRACT

A comparison is made between the current flood risk management policy in the Netherlands, which is a resistance strategy aimed at the prevention of flooding along the lower Rhine River by raising the dikes, and two alternative resilience strategies that aim at minimising the consequences of these floods, but at the same time allow some flooding. The alternative strategies rely on detention in compartments and on discharge via "green rivers".

These strategies were evaluated on their financial impacts (costs and flood damage) and on their impacts on economy, ecology and landscape, as well as on flexibility. The tangible effects, such as costs and damage were calculated using mathematical models; experts awarded scores to the intangibles, such as landscape quality and ecology.

It is concluded that the initial costs of the resilience strategies are high whereas the gains, a reduction of the flood risk, will only be perceivable in the long term. On the other hand, the resilience strategies are more flexible and offer more opportunities for nature and landscape development.

Keywords: Fluvial flood risk management; resilience; Rhine River; hydraulic modelling; flood modelling; green river; detention.

Introduction

Floodplains and deltas are traditionally areas of special importance. They generally offer favourable conditions for human settlement and economic development. At the same time natural hazards threaten these areas and hazardous floods go hand in hand with economic and cultural development. Flood risks, defined as the probability of a flood multiplied by the damage [1], increase with economic development because potential damages increase. The heightening of dikes to protect the cultivated land even adds to the risk: the enhanced feeling of safety behind a massive dike invokes further investments thus adding to the value of property at risk. At the same time, with steadily increasing dike heights, the potential flood depths increase.

Such is the situation in the Netherlands. Traditionally, attempts to reduce the flood risks have focused on river training and the construction of embankments [2]. Such measures aim to reduce the flood hazard, i.e. the frequency of flooding. Flood risk management strategies based on this approach are called flood control strategies or "resistance strategies".

However, flood risk is a function of two factors: flood hazard on the one hand and the consequences of flooding on the other hand. Minimising the consequences of flooding, or learning to live with the floods, instead of reducing the flood hazard is another approach to lower flood risks. In this approach flooding is allowed in certain areas, while at the same time the adverse impact of flooding is minimised by adapting the land use. Such strategies are called "resilience strategies" [3]. They rely on risk management instead of on hazard control.

In this paper two alternative resilience strategies for the lower Rhine River are presented and compared with the current policy.

The current strategy for flood risk management in the Netherlands

More than half of the Netherlands needs, and has, artificial protection against flooding from the sea or the major rivers (Figure 1). In this area about 10 million people live and large industries have developed. Consequently, flood risk management is an important issue in the Netherlands. Before 1000 AD the flooding pattern was completely natural and floods were part of daily life. Later, people started to build dikes to protect relatively small areas, but already by 1400 AD an almost completely closed dike system

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Received and accepted on Dec 19, 2002. Open for discussion until May 31, 2003.

Figure 1 Flood prone areas in the Netherlands.

existed along the rivers [4]. Although dike bursts occurred regularly, the system was maintained and improved over the ages. Furthermore, mainly during the last 2 centuries, regulation and canalisation works changed the courses of the rivers and the river beds considerably. The rivers became more and more controlled and confined to a narrow corridor [2].

Before 1953, when a large flood from the North Sea killed 1800 people, dike heights were calculated on the basis of the maximum recorded water level. In practice this resulted in a raising of the dikes after each major flood. After 1953 a more scientific approach to establish safety levels was adopted. The desired safety level was defined as the acceptable probability of flooding, or, in simple terms, dike heights should exceed water levels related to a discharge with a certain occurrence probability [4]. After several years of debate one safety level was chosen for the whole area threatened by river floods: the discharge capacity of the rivers should allow a safe passage of a discharge with a probability of 1/1250 per year, the so-called "design discharge". Every five years this design discharge and the related design water levels are recalculated, using newly collected information on discharges and the river's morphology.

In 1993 and 1995 extreme high Rhine discharges occurred [5,6]. New calculations of the design discharge, taking into account these extreme events, showed an increase of the 1/1250 per year discharge from 15,000 m^3/s to 16,000 m^3/s at Lobith, where the Rhine River flows into the Netherlands. The design discharge is expected to continue to rise in the future as a result of climate change. Using the traditional approach to flood risk management this would imply a further raising of the dikes.

This resistance strategy has a number of disadvantages [3]. Firstly, one design discharge is applied for the whole area, implying that all land use types, e.g. cities, agricultural areas and nature reserves, have the same probability of flooding. Applying only one safety level also means that it is unknown which area will be flooded, once the design discharge is exceeded. Because all areas theoretically have the same probability of flooding, a large area must be evacuated.

Furthermore, little attention is given to the consequences of possible floods. As a result of economic development, the potential flood damage has increased dramatically since the 1950's. The resistance strategy creates a false sense of safety which explains why large investments are still being made in the area. As a consequence the economic value at risk of flooding still increases steadily, approximately doubling each 30 years.

Finally the current strategy causes an endless need for raising and improving the water defence structures, thus restricting the natural dynamics of a river system and spoiling landscape qualities such as cultural heritage and scenery.

A new approach to flood risk management: Resilience and living with floods

In recent years the above described strategy has become subject to debate. Alternative solutions have been explored and the concept of resilience has been introduced in flood risk management. The concept of resilience originates from ecology. In 1973 Holling [7] defined resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations and state variables". Pimm [8] used the following definition: "the speed with which a system disturbed from equilibrium recovers some proportion of its equilibrium'. More generally the term is used to describe a tendency to stability and resistance to perturbation. Its use is comparable to the use of the concept of sustainability, in the sense that everybody agrees that it is desirable, without agreeing on what is precisely meant by it.

Resilience has been defined as the ability of a system to persist if exposed to a perturbation by recovering after the response [9–11]. As such, resilience is the opposite of resistance, the ability of a system to persist if disturbed, without showing any reaction at all.

De Bruijn and Klijn [3] defined resilience in the context of flood risk management. Strategies for flood risk management in which resilience is used focus on reducing the impact of floods by "living with floods" instead of "fighting floods", as in the traditional strategy. Therefore, resilient flood risk management is flood risk management that aims at giving room to the floods but with concurrent impact minimalization. This implies that also the consequences of floods have to be taken into account and that safety standards must be differentiated on the basis of land use and spatial planning. The area as a whole is more resilient if the less valuable parts are flooded prior to the more valuable parts, which are being safeguarded longest.

A resilient flood risk management strategy also considers measures to reduce the impacts of flooding, such as the design of warning systems and evacuation plans and the application of spatial planning and building regulations. Resilience strategies may also include measures to accelerate the recovery after a flood, e.g. damage compensation regulations and insurances.

Two resilience strategies, “detention in compartments” and “green rivers”, have been elaborated for comparison with the current policy [12].

Detention in compartments

The central concept of this strategy is the controlled flooding of compartments of limited size, thus limiting the affected area and minimising the flood damage. It means designating areas along the river for temporary water storage and dividing the existing large continuous dike-rings (areas surrounded by a dike) into smaller compartments with different flood probabilities. The concept is schematically illustrated in Figure 2. At extremely high water levels compartments are flooded in a pre-determined order: the cascade. The number of compartments to be flooded depends on the flood peak’s height and duration. The most upstream located compartment is flooded first. This levels off the discharge peak, bringing about a lower flood level downstream. A compartment with a high probability of flooding would preferably be situated where the economic damage is limited, such as in agricultural or nature areas. Urban areas should be in compartments with a low probability of flooding.

Green rivers

This resilience strategy also relies on controlled flooding and decreasing the size of the flooded area. This is attained by increasing the river’s discharge capacity, either by enlarging the flood plain area and/or by adding “green rivers”. Green rivers are wide discharge compartments that have a high probability of flooding and are preferably located in areas where the economic damage resulting from flooding is limited. Green rivers are green – not blue – because they are dry most of the year. The probability of flooding is, of course, significantly increased compared to the current situation, and is almost the same as that in the floodplains: it varies from about once a year to about once every ten years.

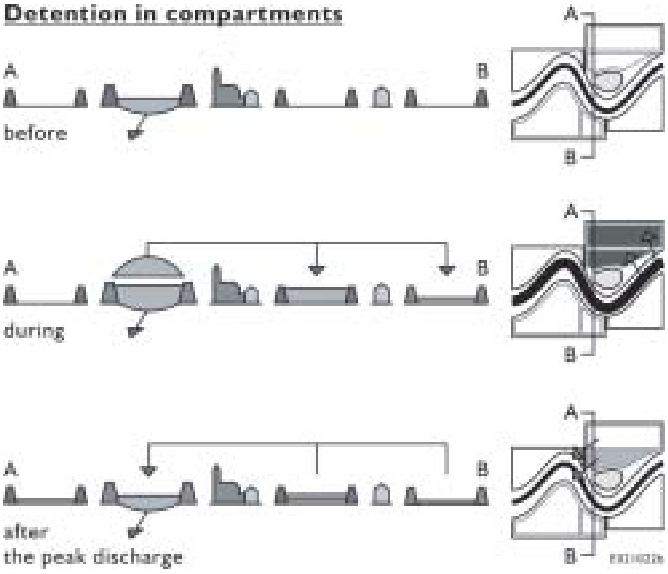

Figure 2 Schematic representation of the concept of detention in compartments.

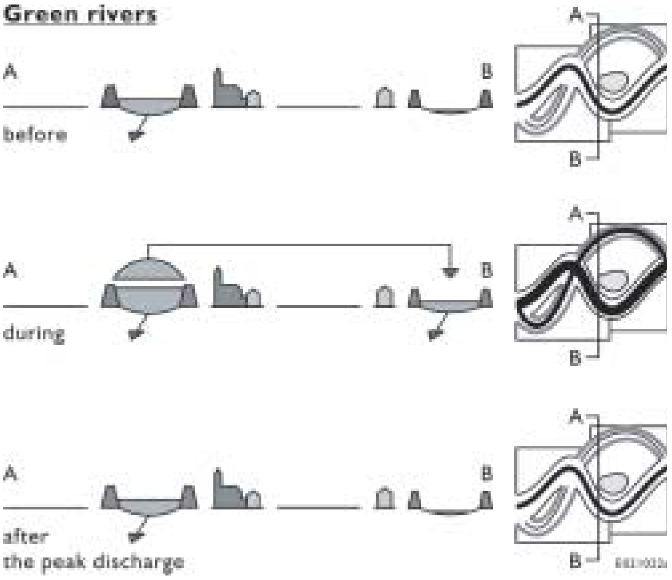

Figure 3 Schematic representation of the concept green rivers.

Green rivers not only provide extra discharge capacity, but because they cover a large area they also result in some peak attenuation. The concept is illustrated in Figure 3. Two alternatives for discharging extra Rhine water via green rivers have been designed: a northern route, along the River IJssel, and a western route. Former river valleys and backswamp areas, which in the past remained flooded for longest, are used for the green rivers as much as possible. The land use within the green rivers has to be adapted to the flooding regime: the more elevated parts will sometimes remain dry for years on end, whereas the lower parts will become wet and marshy.

Three variants of the green rivers strategy have been discerned: a spontaneous development variant, a biodiversity variant and a multifunctional variant. For the spontaneous development variant no structures other than those required for the hydraulic functioning of the green rivers (dikes and in- and outlets) are built and there is no active management of the area. Nature can develop without interference by man. The biodiversity variant implies active interference by man, e.g. by putting up low dikes or digging water courses, to steer the development of vegetation and habitat types that are poorly represented in the present river area. The multifunctional variant allows for other functions than nature in the green river: e.g. outdoor sports and activities and agriculture.

Assessment of damages resulting of flooding

The current policy

With a continuation of the current policy, dike failure may result in considerable damage. The procedure used in this study to assess this damage consists of 5 steps [13]:

- selection of representative flood waves and a breach development scenario;

- selection of likely dike breach locations and delineation of areas threatened by flooding with the aid of a digital terrain model;
- calculation of the effect of breaches on the river's discharge and thus on the water levels downstream with a one-dimensional hydraulic model;
- simulation of the flooding process with the two-dimensional hydraulic model; and
- calculation of the damage resulting from the flooding with a flood damage model.

In the model calculations the mean wave forms with a peak level of 16,000, 18,000 and 20,000 m^3/s as determined by Klopstra and Duits [14] have been used. Breach development depends on parameters such as flow velocity, dike structure, soil characteristics and wind and wave conditions. Since information on dike structure and other important parameters was not available, a breach width of 200 m, from the beginning to the end of the flood event, was assumed. The top of the breach is assumed to lower in three days from the initial level to the level of the adjacent flood plain.

Five different dike breach locations were selected (Figure 4). Because all dikes along the Rhine River are designed to withstand the same discharge, a peak exceeding this design discharge is most likely to cause problems upstream first. This explains why two "disaster scenarios" begin with an overtopping and a subsequent dike breach not far downstream of the point where the Rhine reaches the steadily widening, dike protected floodplain. Upstream of this point the river is laterally confined by the mountains of the Eiffel-Siebengebirge massif.

The selection of the dike breach locations is not based on probabilistic analysis of the risk of dike failure: the probability of flooding is based on the probability of the water exceeding the dike design load, while the conditional probability of failure given this load is assumed unity for the chosen breach scenario and zero for all other scenarios. This means that the exact location of the breach is not known. However, this is not important since the whole dike ring will flood independent of the exact location of the breach. The resulting damage is also, to a large extent, independent of the exact breach location.

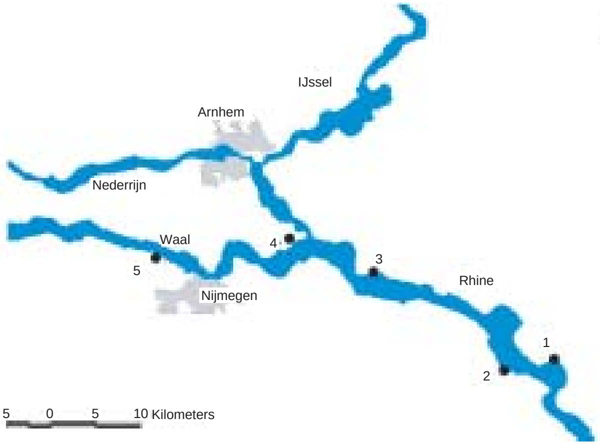

Figure 4 Dike breach locations for which flood simulations have been made (Source: De Bruijn, 2002).

The hydraulic simulations of the consequences of a dike breach have been carried out in two steps. The flow through the breach and the effects on the water levels downstream and upstream of the breach have been determined with the help of the one-dimensional hydraulic model SOBEK-River. This model is based upon the complete de Saint Venant Equations, thus including transient flow phenomena and backwater profiles [15,16]. The flooding process beyond the breach has been simulated with the flooding model Delft-FLS, a model that simulates unsteady hydrodynamic flow in two dimensions and calculates water levels and flow velocities in the flooded area. The model uses elevation data in a rectangular grid and is based on a robust finite difference scheme, able to tackle both subcritical and supercritical flow [17,18]. Elevation data were derived from the Actual Height Model of the Netherlands (AHN) of the Survey Department of the Netherlands Ministry of Public Works, Transport and Water Management. The accuracy of the elevation data is high: the standard deviation is 20 cm maximum, the systematic error is less than 10 cm. Geometrical input data such as dikes, roads, railroads, waterways, viaducts, culverts, etc. are imported from a GIS system. Figures 5 and 6 show the results of Delft FLS simulations of dike breaches at breach locations 1 and 4 (see Figure 4) respectively .

The damages resulting from the dike breaches have been determined with the Standard Damage Module developed by Vrisou van Eck *et al*. [19]. This model calculates both the direct and the indirect damage in the flooded area. Direct damage is damage caused by the water itself, while indirect damage is the damage caused by the impossibility to use the area or an object in the area. Examples of indirect damage are production losses (companies) and income losses (hotels, pubs, shops). Damage is calculated as:

$$S = \int_{i=0}^{i=m} \left(\int_{h=0}^{h=h\,\max} \alpha_i(h) * n_{id} S_{i\,\max} * dh \right) di$$

where S = the total damage [€], $\alpha_i(h)$ = damage factor of damage category i, depending on water depth (h) [-], h = water depth [m], $n_{id}(h)$ = number of units in category i with flooding

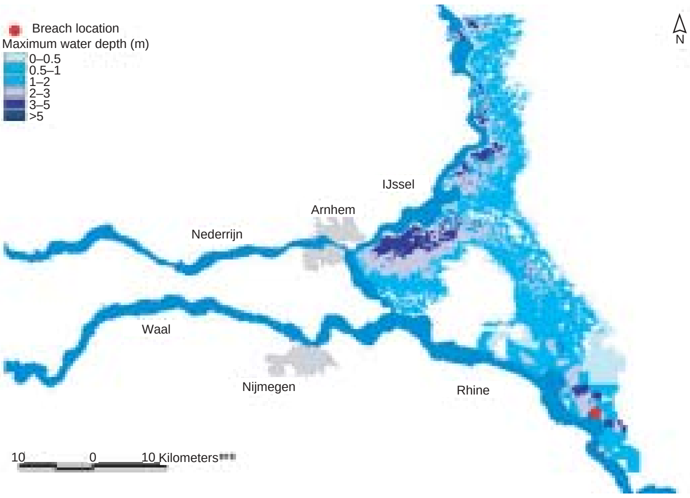

Figure 5 Maximum water depths caused by a peak discharge of 18,000 m^3/s and a breach near Rees (Source: De Bruijn, 2002).

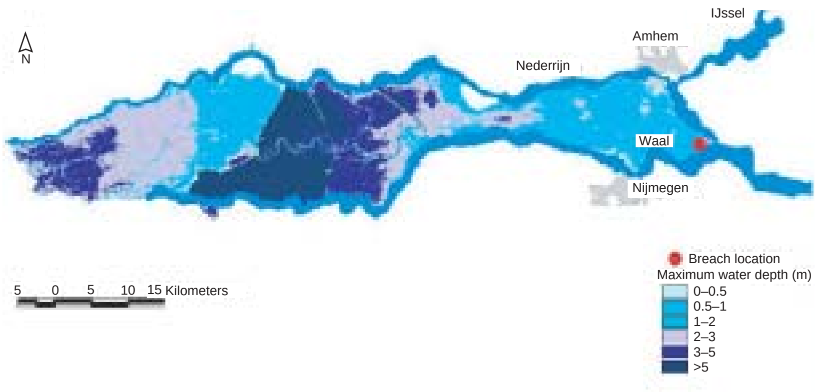

Figure 6 Maximum water depths caused by a peak discharge of 18,000 m^3/s and a breach upstream of Nijmegen.

depth h [-], $S_{i\,\max}$ = maximum damage per unit in category i [€], m = number of categories [-].

The damage factor of damage category i (α_i) is derived from the damage function of that category. The factor represents the influence of hydraulic conditions such as the flooding depth. These functions are taken from [20] and [21]. The total damage in an area is the sum of the damage in all categories. Examples of damage categories and their units are: agriculture (ha), houses (number), infrastructure (km length) and insurance companies or banks (number of employees). For detailed information reference is made to [19].

The economic value of the damage has been calculated by multiplying the probability of flooding of each dike-ring with the flood damage, taking into account an increase in the economic value at risk of 2% per year. This growth rate is an extrapolation of historic data on population growth and economic development. For conversion into a Present Value a discount rate of 0.04 over a timeless period has been used.

The modelling approach is schematically presented in Figure 7.

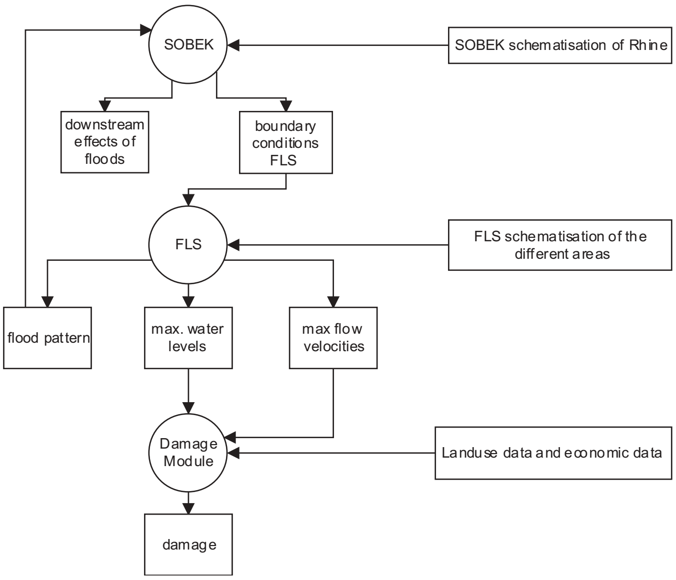

Figure 7 The modelling approach used for the calculation of flooding patterns, flood depths and flood damages.

Detention in compartments

Damage as a result of inundating detention compartments depends on the height of the flood peak that has to be accommodated. The higher the peak, the more compartments have to be flooded. It is assumed that 15,000 m^3/s can safely flow through the Netherlands. To hold back the excess discharge above this level up to 16,000 m^3/s (at Lobith) a detention capacity of 125 million m^3 is needed. When an excess flow up to 18,000 m^3/s has to be accommodated a detention capacity of about 700 million m^3 is needed and many more compartments must be flooded. For a discharge of up to 20,000 m^3/s a detention volume of 1,700 million m^3 is required.

Damage calculations with the Standard Damage Module are based on probabilities of flooding and the assumption that the compartments will be filled up to a level of one meter below the lowest dike level.

Green rivers

For the flood damage calculations a distinction is made between the variant with multifunctional development versus the variants with spontaneous development and the biodiversity optimisation. With spontaneous development and biodiversity optimisation there is no inhabitation nor are there agricultural activities within the green river. Flood damage is thus reduced to almost zero.

In the variant with multifunctional development inhabitation and farming is allowed to a certain level. In this case the flood damage depends on the extent of adaptation of the land use to the flooding regime. A rough estimate of the flood damage is based on the assumptions that:

- about half the green river area (340 million m^2) is used for agriculture;
- flooding occurs once in every 5 years; and
- flood damage on agricultural land amounts to € 0.11 per m^2 on average, a figure commonly applied in the Netherlands [22].

Assessment of other criteria

Next to the damage resulting from flooding a number of other criteria have been assessed to enable evaluation of the flood management strategies. They are costs, effects on and opportunities for economic development, flexibility, ecological effects and opportunities for nature development, and landscape quality.

Total costs of the various strategies have been calculated as the sum of all direct, financial, costs of measures needed for the implementation, operation and maintenance of the strategy. The annual costs have been converted to a Present Value.

Effects on and opportunities for economic development are related to changes in flood frequency and spatial planning in the areas that may be flooded. The resulting layout of the area may either impede or improve the opportunities for economic development. These effects have been assessed qualitatively by applying the so-called Delphi method by the multi-disciplinary project team comprising of hydrologists, engineers, geographers, landscape ecologists and economists. Each member of the team assigned scores on a set of sub-criteria for each strategy. Average score and the range in score were determined and discussed among the team members, after which a new round of assigning scores was held. This procedure was repeated until all team members were satisfied with the score they had assigned in the previous round.

The flexibility of a strategy can be defined as: "the ability to adjust quickly and without great efforts to changing circumstances as well as the ability to prevent future regrets" [23]. Measures taken and investments made are based on projections of developments and expectations of the future regarding the natural system, land use and social preferences. When actual developments differ from the projected ones, a strategy may have to be adapted. The flexibility of the various strategies has been assessed qualitatively by the project team.

Ecological effects and opportunities for nature development have also been assessed qualitatively by scoring on expected naturalness, (bio)diversity and connectivity. Criteria used for the assessment of landscape quality are preservation of abiotic natural heritage, preservation of cultural heritage and scenery.

Results

The results of the assessment are summarised in Table 1.

The initial costs of the resilience strategies are high, especially in the short term while the profit, decreased flood risk is only perceivable in the long term. The green rivers with nature development are particularly expensive (PV of 8 billion €), primarily because they require a lot of space and huge changes in land use. Continuation of the current strategy is least costly (PV is 0.9 billion €). The costs of detention in compartments and green rivers with multifunctional development are intermediate and have PVs of 1.6 and 3.0 billion € respectively.

The calculations showed that continuation of the current strategy may result in rare but enormous flood damage. A dike burst upstream of Nijmegen (Location 4 in Figure 4) and a subsequent flooding of the Betuwe area would result in a economic damage of up to 36 billion €. It is assumed that loss of human lives can be prevented by adequate early-warning-systems and evacuation procedures. Flooding as a result of a breach near Rees (location 1 in Figure 4) would result in an economic damage of about 10 billion €. The PV of the potential flood damage for the continuation of the current strategy is 0.5 billion €. The resilience strategies would result in a lower damage (0.3 billion € for retention in compartments and less than 0.1 billion € for the green river strategies).

Detention in compartments offers the possibility of reacting to future changes. Compared to the current strategy, this strategy is less likely to lead to measures or a particular arrangement of the river area which will be regretted in the future or which will have irreversible consequences for natural and cultural heritage.

In comparison with the current situation the green rivers provide excellent opportunities for the development of nature areas and attractive river landscapes. Detention in compartments offers only few extra opportunities for nature.

Conclusions

The currently applied strategy for flood management, based on dike-rings with equal safety levels, implies that discharges above the design discharge may cause flooding anywhere, in whatever dike-ring, and even at several locations at the same time. The course of events is consequently unpredictable. This form of "Russian Roulette" is undesirable.

The model calculations show that, depending on the location of a dike breach and the size of the flood wave, the direct flood damage may presently range from about 1.5 billion to 36 billion Euro. The present safety standards, which are relatively high, sustain the impression that the dike-rings are safe areas to live in, with the effect that there is no incentive to minimise the vulnerability to flooding by appropriate land use planning.

Table 1 Effect matrix with scores on criteria for the various strategies.

Strategy	PV* of costs	Flexibility	PV of flood damage	Economy	Ecology	Landscape
Continuation of current policy	0.9	4.1	0.5	5.0	4.5	4.4
Compartments	1.6	6.7	0.3	4.7	4.1	5.3
Green river						
a. spontaneous development	8.0	4.8	0.0	4.3	7.7	6.6
b. biodiversity optimisation	8.0	4.8	0.0	4.4	8.0	6.6
c. multifunctional development	3.0	4.7	0.1	5.7	6.7	6.7

* PV = Present Value in billion €.

Consequently, it is doubtless that the economic damage potential of the dike-rings may continue to rise.

The studied resilience strategies, detention in compartments and green rivers, are structural solutions for a comprehensive flood management scheme, and, in the long run, seem to have fewer disadvantages than the present flood protection strategy. These alternative strategies are based on the abandonment of the principle of applying one design discharge only and on the idea of splitting up (compartmentalisation) of dangerously large dike-rings where in case of flooding the damage would be very high. Both resilience strategies require that a large surface area which is now protected by dikes is occasionally "lent" to the river, in order to perform essential hydraulic functions: either as a detention area or in providing additional discharge capacity. This area is not permanently lost for human use, as it is only temporarily and/or incidentally needed for storage or discharge.

Both the strategies may be regarded as being *resilient*. In the detention alternative resilience is primarily achieved by "step-wise adding compartments" and thus a gradual increase of flood damage with increasing discharge. In the green rivers alternative, resilience is mainly achieved by keeping the water levels (i.e. the flood hazard), as well as the potential damage (i.e. the vulnerability) low.

Flood risk management based on resilience is a good alternative for the current policy of increasing resistance against flooding by raising the dikes. Resilience strategies are more flexible and offer more opportunities for nature and landscape development than the current policy. However, implementation requires enormous investments on the short-term whereas revenues will only become clear over relatively long time periods.

Data and predictive uncertainty in the modelling approach implies uncertainties in the results. A detailed uncertainty analysis has not taken place, since the results are not used in absolute terms, but basically to compare different strategies.

Acknowledgements

This paper is based on a research project of the Netherlands' Centre for River Studies (NCR). The research was financially supported by the EC through IRMA-SPONGE, and partly conducted in the context of Delft Cluster.

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