RESILIENCE STRATEGIES FOR FLOOD RISK MANAGEMENT UNDER UNCERTAINTIES

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ABSTRACT

Flood disasters are increasing in frequency and severity. Therefore, it seems that current flood risk management strategies need to be reconsidered. One of the most important issues in flood risk management is to find a way to cope with uncertainties. In this paper a new approach to flood risk management is proposed based on a systems approach. This system approach allows the definition of resilience and resistance strategies. This paper argues that resilience strategies are able to cope more adequately with uncertainties and lower the probability of flood disasters. In the paper the systems approach, resilience strategies and the way they cope with uncertainties is explained and illustrated with examples from the Netherlands.

1 INTRODUCTION

Despite centuries of experience with flood management, flood disasters become more frequent and increasing in severity (Takeuchi, 2002; Parker, 2000). Therefore, new strategies or new visions on old strategies must be studied to be able to cope with floods in the future.

Flood risk management involves dealing with uncertainties. It is uncertain whether, when and where floods will occur. Furthermore, there are uncertainties related to the strength of structures, the physical behaviour of river systems, the reaction of people and the consequences of floods. Despite all these uncertainties, flood risk managers must take decisions on how to improve flood risk management.

In this paper a systems approach is used to study flood risk management. This approach allows that resilience and resistance strategies can be defined, which include different approaches to cope with disturbances such as uncertain and variable flood waves. Resilience strategies are hypothesized to be able to cope with uncertainties more easily.

This paper first describes the systems approach. Secondly, the types of uncertainty that are important in flood risk management are discussed. Then resilience and resistance strategies and the way they cope with uncertainties is explained. Finally, flood risk management in the Netherlands and some research projects are discussed as examples of ways to increase resilience and to improve the way uncertainties are dealt with.

2 SYSTEMS APPROACH

Flood risk management is carried out within the wider context of sustainable development, meaning that environmental, social and economic processes must be considered. Sustainable development requires an efficient use of the area, equity for all social groups now and in the future, and no degradation of environmental resources. Furthermore, to be sustainable a system has to be able to cope with uncertain disturbances such as extreme discharges and discharge variability. How these extreme flood waves could be coped with is the main issue of flood risk management.

To improve flood risk management and to better integrate it in sustainable development, it is necessary to study the whole lowland river as one system, instead of studying one dike stretch or one polder area at the time. In this paper, a flood risk management system is defined as the lowland river stretch itself and the socio-economic and physical aspects of the whole area threatened by floods from the lowland river. The capability of this system to cope with uncertain variable flood waves is subject of research here. The society in the flood prone area is part of the system, because the impact floods have and the recovery from floods depends on society. Furthermore, the attitude towards risks, uncertainties, responsibilities and nature and thus the choice for a certain flood risk management strategy will be different for different societies. The socio-economic system in the area threatened by floods will be part of a larger socio-economic system. Therefore, if necessary, relations with a higher scale level will be considered as well.

The system's approach is a comprehensive approach that combines ideas of engineers and social science. Engineers' knowledge is required to quantify hazards and uncertainties, and to design structural measures. However, to determine the consequences of floods, to know from what kind of floods the system still can recover and how fast it will recover, social scientists' knowledge is required. Moreover, social science's input will contribute to the evaluation of flood impacts and impact of measures for different social groups and to the definition of priorities or goals for flood risk management.

3 UNCERTAINTIES

The management of systems as defined above involves dealing with many uncertainties. The importance of variability in rainfall and discharge is evident: if flood waves would always occur at the same time and with the same magnitude, they could be managed perfectly. However, nobody knows if, when and how frequent certain flood waves will occur. Even if the discharge probability function and waveform would be known, then still spatial variability in for example roughness and uncertainties on the behaviour of the river remain. Furthermore, the behaviour of the socio-economic system is uncertain.

Next to uncertainties in the current situation there are even larger uncertainties about trends and changes in the future. Climate change will have consequences on extreme discharge levels and frequency, the river system will change and society will develop, resulting in different land use patterns, norms and values.

The awareness of uncertainties and the need to incorporate uncertainties in flood risk management decisions has increased recently. Therefore, a lot of research on quantification of uncertainties and on how uncertainties are perceived and can be coped with is carried out (see for example Burn, 1999; Van Asselt & Rotmans, 2000; TAW, 2000; Vis *et al*., 2001; WL|Delft Hydraulics *et al*., 2003; Commissie Noodoverloopgebieden, 2002).

Some systems are able to cope with uncertainties better than others. To cope with changing systems flexibility is required (Klabbers *et al*., 1998; Vis *et al*., 2001). Flexible systems are easy to adapt and flexible strategies include measures that can be undone or can be implemented in phases in order to prevent regret. Flexibility in management requires evaluation and adaptation of goals and measures constantly. To cope with uncertainties due to lack of knowledge or due to variability in the current system resilience strategies are proposed, as is explained below.

4 RESILIENCE AND RESISTANCE

Flood risk management systems must be able to cope with uncertain flood waves and with other uncertainties. Two different ways to cope with flood waves can be defined: resilience and resistance strategies. 'Resilience' and 'resistance' as used in water management, are taken from the discipline ecology. Holling (1973) introduced the concept of resilience in the discussion on persistence and stability issues. Holling defined resilience as the ability of a system to maintain its integrity under disturbance. Since then resilience has been used in different ways. Generally, resilience is the system characteristic that determines whether a system can recover from disturbances, how fast it will recover, from what disturbances it still can recover and how severe the reaction to a disturbance will be (Holling, 1973; Gunderson, 1999; Carpenter & Cottingham, 1997; O'Neill *et al*., 1986; May, 1974; Jørgensen, 1992; DeAngelis, 1992; Ludwig *et al*., 1997). Resistance is defined as the characteristic to withstand disturbances by not reacting at all.

Figure 1 reveals reactions to different disturbances. The first disturbance results in a reaction of the system and a recovery from that reaction. The system can withstand the second much smaller disturbance. To cope with the first disturbance the system uses resilience, while for the second disturbance resistance is used. The reaction after the first disturbance can be described by the reaction amplitude (A) and the recovery rate (the angle α). The reaction amplitude is the severity of the reaction to the disturbance. The recovery rate, the angle α in figure 1, gives the rate with which a system recovers from a reaction to a disturbance

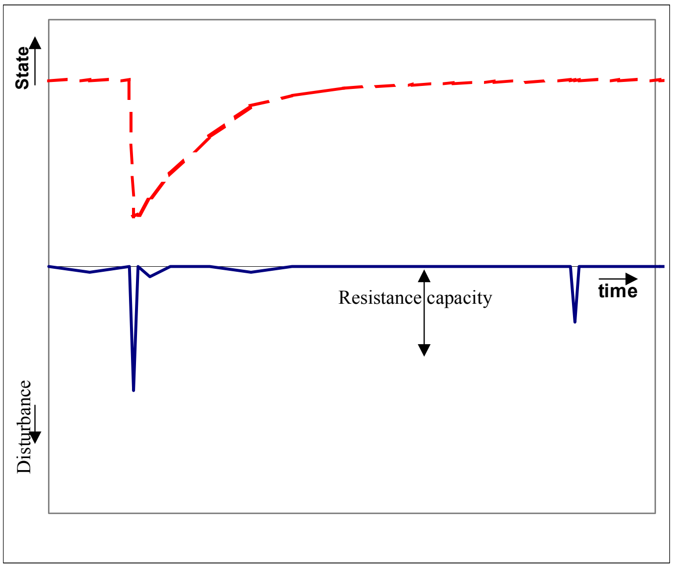

Figure 1. System behaviour as a reaction to one disturbance

Figure 2 presents the behaviour of the system to the whole regime of disturbances. From this graph a third important reaction aspect, graduality, can be deducted. Graduality describes the increase of the amplitude with increasing disturbances. The steeper the slope of the curve that represents the relationship between the reaction amplitude and the disturbance severity is, the less gradual the reaction. Systems with a high graduality behave as expected. A sudden discontinuity in the disturbance-reaction relationship may be unexpected and therefore dangerous.

Figure 2. The relationship between reaction amplitude and disturbance severity for a resilient and a resistant system and a system that has both system properties.

The resistance of a system determines which disturbances a system can withstand without reacting. If a reaction occurs, then this reaction and the following recovery can be described by the amplitude, graduality and recovery. These aspects together describe the resilience of the system. The resilience of a system is higher when the amplitude is lower and recovery rate is higher. Furthermore, resilience is higher when a system is capable of returning from a larger range of disturbances and when no sudden changes occur.

5 RESILIENCE AND RESISTANCE IN FLOOD RISK MANAGEMENT

By taking a systems' approach the system characteristics resilience and resistance of flood risk management systems can be studied. To describe the system's resilience the system itself, the disturbance for which resilience is required, the expected reaction and recovery from that reaction should be defined.

The system, as described above, is defined as the physical and socio-economic system in the whole lowland area threatened by floods, including the lowland river stretch. At the upper boundary of the flood risk management system, flood waves flow into the system and at the lower boundary they may continue their way to the sea. This flood waves can be considered as uncertain inputs or stress factors, or as the disturbances that are mentioned in the former section. The reaction from these flood waves consists of floods and flood impacts. The recovery after the reaction is obviously the return to the normal situation. This means that at least the economic, social and ecological development should be similar to the development before the flood or comparable to the development in areas that were not flooded. Damage has to be repaired, companies have reached there normal production level again and inhabitants have to overcome their emotions.

Summarizing, *resilience* against *flood waves* can be defined as *the ease with which the system recovers from floods*. In contrast, resistance against flood waves can be defined as the ability of the system to prevent any reaction to or impact from flood waves.

Because most lowland rivers are not natural but human influenced, people may choose how to influence the behaviour of the system. They may choose a certain strategy to cope with flood waves. Managers can choose to enhance the resilience or alternatively, the resistance of the system or both. Resilience strategies aim at a resilient reaction to the whole range of possible peak discharge waves. Floods may occur, but they should have low impacts, they should be easily recovered from and flood impacts should be related to the flood wave intensity. No sudden catastrophes should occur.

Alternatively, resistance strategies try to prevent floods caused by peak discharges below a certain threshold, often a ‘design’ discharge.

Differences between resilience and resistance strategies are:

1. **The measures that are used:**

   The measures used in a resilience strategy may differ for different parts of the system in order to maximise the resilience of the whole system. In certain parts of the area floods may have to be prevented, while in other less vulnerable areas, floods may be accepted but flood impact mitigating measures are advised. Measures can thus be structural or non-structural and changing the hazard or the vulnerability. Both types of measures increase the resilience of the system as a whole, because expected damages are lowered, recovery is enhanced and the reaction to peak discharges is more gradual.

   In contrast, in resistance strategies aim at flood prevention by structural measures.

2. **The range of discharges that is considered:**

   In resilience strategies the whole discharge regime is considered, while in a resistance strategy attention is focused on one threshold or one design discharge.

3. **The way uncertainties are incorporated and coped with:**

   The resistance strategy can deal with uncertainties by trying to assess them and include them in the flood probability or by over dimensioning dikes and other structures. Often, inhabitants are not aware of uncertainties and of the fact that they face a flood risk from discharges above the design discharge.

   In contrast, the resilience strategy is explicitly designed for dealing with uncertainty. The method acknowledges uncertainties and the fact that it is not possible to prevent all floods. Therefore, besides flood prevention measures also measures to limit the impacts and to enhance recovery are required. Furthermore, because resilience strategies consider the whole discharge regime and not only a certain design discharge or threshold, the occurrence and consequences of extreme discharges and floods is accounted for.

6 FLOOD RISK MANAGEMENT AND UNCERTAINTIES IN THE NETHERLANDS

As an example of flood risk management in relation with uncertainties, flood risk management as well as recent developments in the Netherlands are discussed. Flood risk management is very important to the Netherlands. One third of the Netherlands needs and has artificial protection against floods from the sea or the rivers (see figure 3).

Figure 3. The area in the Netherlands threatened by floods.

Flood risk management has a long history in the Netherlands. The first inhabitants of the Netherlands had no choice besides living with floods. Since 1000 AD, when the first dikes were constructed, the inhabitants try to prevent floods. Already in 1400 AD a closed system of dikes protected the areas along the rivers (Commissie Rivierdijken, 1977). After every dike breach, dikes were improved and raised, which reduced the frequency of dike breaches. In 1926 the last large river flood occurred. Currently, safety is based on a uniform design discharge for the whole area threatened by river floods. This design discharge is equal to the discharge with a probability of once in 1250 years. To establish the design height of dikes, water levels corresponding to this discharge are increased with 50 cm to account for uncertainties.

The uniform and high safety standard and the long absence of floods resulted in the belief that floods belong to the past and that the area is safe now. This feeling of safety and the attitude of ignorance towards the river changed in 1995, when an extreme discharge occurred on the Rhine River. A large area almost became flooded and 250000 inhabitants were evacuated from the low-lying polder areas along the river. This evacuation came by surprise and woke up many inhabitants who suddenly realized that they were living in a flood threatened area. After 1995 dike improvements were carried out faster than planned and research on long-term strategies was initiated.

The flood risk managers in the Netherlands have to cope with many uncertainties, such as:

1. Uncertainties in the design discharge:

- Since the range of measured discharges includes only 100 years, the height of the design discharge depends heavily on the used method. Therefore, the procedure to estimate this design discharge is part of the safety norm in the Netherlands. For the Lower Rhine River the Gumbel and the exponential distribution result in a design discharge with a probability of 1/1250 per year of almost 17000 m^3/s at the German-Dutch boarder, while other distribution types such as Log-Pierson result in 12000 m^3/s at the same location. Officially, the design discharge for the Lower Rhine River at Lobith is estimated as 16000 m3/s with a reliability interval of 13000 - 20000 m^3/s.
- Since the highest discharge ever recorded is 12600 m^3/s (in 1926), it is unknown whether it is physically possible that the design discharge of 16000 m^3/s ever occurs.

- Even if the discharge with a probability of 1/1250 per year is estimated accurately, this still does not mean that floods are prevented. Higher discharges may still occur.

2. Uncertainties in the behaviour of the river:

- The wave propagation is uncertain, the occurrence of river dunes, storm, or high roughness values is uncertain and as a result also the stage-discharge relationships at such extreme discharges are uncertain.
- The division of the discharge over different branches is uncertain (If 100 m^3/s extra is diverted into the smallest branch (IJssel) this may result in a difference of 20 cm in water level at this branch!).
- The dike strength and height is uncertain.

3. Uncertainties in the socio-economic system situation;

- Uncertainties on the behaviour of people in case of a flood.
- Uncertainties on evacuation efficiency, number of casualties;
- Uncertainties in the economic flood impacts;
- Uncertainties in the economic and social effects of flood management measures.

Furthermore, the Netherlands is changing. Climate change and changes in the socio-economic situation even add to the uncertainties. Extreme floods and droughts are expected to increase, while the rate and location of economic growth and land use changes also influence flood risk management.

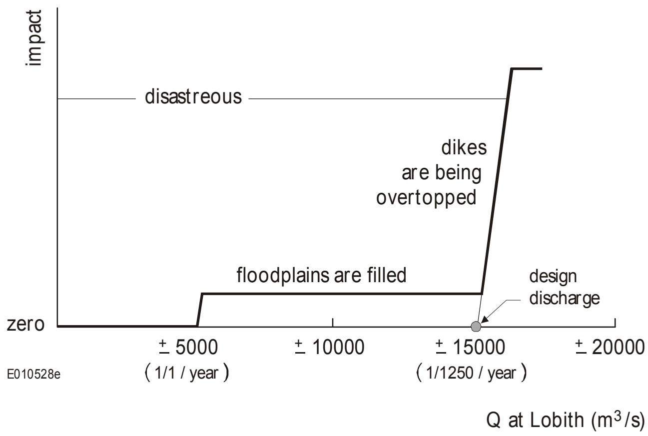

Figure 4. The impact-discharge relation of the Lower Rhine River in the Netherlands

In the current flood risk management the existence of these uncertainties are not very clear. The current river system of the Lower Rhine River consists of a main channel with small embankments, floodplains and large embankments that protect the surrounding flood plains where people and industries have settled. In the Rhine River flood waves with peak levels below about 5000 m3/s at Lobith do not result in any reaction (see figure 4). The system has resistance in the form of small embankments to cope with these flood waves. Flood waves with levels between about 5000 and 7000 m3/s at Lobith result in the flooding of the floodplains along the main channel. Flood waves between 7000 and 15000 m3/s do not increase flood impact any further. For this discharge range also resistance is used. Above 15000 m3/s floods will occur, but nobody knows where floods will occur, whether dike breaches will occur and what the consequences will be. No strategy is present to cope with such waves. The current strategy is thus mainly based on resistance.

The current strategy focuses on designing the river in order to create a discharge capacity equal to the design discharge. Uncertainties are incorporated only in the design requirements for the embankments. What happens when a discharge occurs above the design discharge was not studied, until recently. Furthermore, the advantages of flood prevention and creating the illusion of safety were not questioned.

However, this changed recently. In 2001 the design discharge with a probability of once in 1250 years was calculated again based on the latest measurements. This resulted in an increase of the design discharge from 15.000 to 16000 m3/s for the Rhine River and from 3650 to 3800 m^3/s for the Meuse River. Traditionally, this would lead to a further increase of dike heights. However, new solutions are being developed that aim at creating more room for the rivers (Min.VROM and V&W, 1997). Due to changes in the societal preferences, normative views and the available technology a new flood risk management strategy are needed and therefore alternatives are being studied (TAW, 2000; Vis *et al*., 2001; De Bruijn & Klijn, 2001; Min. V&W, 1998). Also uncertainties are subject of research nowadays (TAW, 2000, WL|Delft Hydraulics, 2001; Wl|Delft Hydraulics, 2003). This section describes the research programs ‘Floris’, ‘Emergency detention areas’, and ‘Living with floods’ in more detail.

In the research program Floris (FLOod Risks) the possibility to change from a design discharge based policy to a risk-based policy is studied (TAW, 2000). In the program the flood risks of all dike ring areas in the Netherlands are determined. Dike rings are areas surrounded by a closed ring of dikes or higher grounds. Not only probabilities of water levels in rivers are calculated, as is done in the official safety standard, but also flood probabilities and flood impacts. Uncertainties on dike strengths, and different failure mechanisms are incorporated in the calculations. The proposed change to a risk-based policy is only studied as on option for the far future. This risk-based policy is still focused on flood prevention and protection, because it proposes to improve protection in areas that face a high risk, not to lower the consequences of a flood in such areas. This policy will probably increase the resilience of the total system, because it will eventually lead to differentiation of the required discharge capacities and flood probabilities and thus to a more gradual and controlled response to floods. The most vulnerable areas will be protected in the best way, what will diminish the possibility of disasters.

Another important and heavily disputed policy is the research on emergency detention areas, which are areas that will be inundated when a discharge exceeding the design discharge occurs in order to protect areas with a high potential damage from flooding (Commissie Noodoverloopgebieden, 2002). The identification of emergency detention areas causes a lot of commotion in the Netherlands, partly because of miscommunication. If the emergency detention areas would function optimally, flood probabilities of vulnerable areas would be reduced resulting in lower flood risks of the total system. Furthermore, graduality would increase because extreme discharges would cause stepwise controlled inundation of less-vulnerable areas, instead of uncontrolled unexpected floods. Also recovery of the system would be higher because the inhabitants of the detention areas would be more prepared, essential infrastructure would be located in other areas, and damage would be compensated. The resilience of the total system will thus increase by this policy.

However, enormous uncertainties may reduce the effect of emergency detention areas. The efficiency of these areas depends on the quality of the forecasts, the storage volume of the areas, the operation of the inlet structures, the capability of the decision makers to actually decide for the inundation of the areas and the acceptance of the inhabitants. If the waveform and propagation are not forecasted well enough, or if the decision makers or managers fail to open the inlet at the correct time, the areas will become useless for influencing downstream flood risks. Furthermore, the dikes surrounding the detention area and the river dikes along other areas must be strong enough to prevent piping or failing by other mechanisms than overtopping, otherwise floods will occur anyway. Finally, emergency detention areas may influence the discharge division over the different Rhine branches, causing problems elsewhere. The inhabitants of the potential emergency detention areas are afraid that their living areas may suffer from a reduced economic growth, damage by floods, devaluation of their houses etc. This policy aiming at reducing uncertainties by developing emergency plans and identifying areas that will inundate first, evokes other uncertainties. If the areas are designed well with sufficient storage volume and strong dikes, this policy will be able to cope with uncertainties and increase resilience. However, whether the advantages and disadvantages of this policy outweigh the effects of doing nothing, and the advantages and disadvantages of alternatives such as dike heightening, should be considered as well.

To study in what direction flood risk management could develop in the far future, in addition to the current strategy of dike heightening, the following strategies have been explored:

- *River's land:* In this strategy the dikes along all river branches are removed except the most northern dike of the northern branch of the Rhine and the southern dike of the Meuse River. This will allow the rivers to flood large areas and eventually even to move its channels. The river is no longer adjusted to the land use, but instead the land use inside the area is adjusted to frequent floods (Vis *et al*., 2001).

- *Discharge through green rivers:* A strategy in which large corridors are used as bypasses during peak flows. In normal years a part of the areas is flooded in wintertime, in exceptional years the whole area is flooded and inundation depths are high. The water depths and inundated area increases gradually with increasing discharge (Vis *et al*., 2001).

- *Storage in compartments:* In this strategy high discharges are coped with by stepwise filling of compartments. At first the least valuable most upstream compartment is filled, then the one-but least upstream or valuable one, etc. This strategy assumes that in future, discharge waves can be forecasted precisely and that discharge division and inlet in areas can be managed adequately (Vis *et al*., 2001).

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7 CONCLUSIONS AND DISCUSSION

Flood disasters happen too often. Therefore, research on flood risk management strategies must continue. Concepts related to a systems approach as used in ecology can be applied to study flood risk management strategies in a comprehensive way. According to the system approach sustainability can be reached by either resilience or resistance strategies or a combination of both. Resilient flood risk management allows flooding, but tries to minimize the damage caused by these floods. Resistant flood risk management strategies focus on flood prevention only.

If a resistance strategy is chosen, then expected damage and risks will probably be low, but disasters may occur quite suddenly and unexpectedly due to floods above the design discharge. Besides, as has happened in the Netherlands, focussing on prevention of floods may confine all attention to the design of the river system, while the consequences of floods, emergency plans and alternatives to flood prevention are neglected. The inhabitants in the area may therefore get the illusion that floods will no longer occur.

Because in resilience strategies the whole discharge regime is studied, and a view on the impacts corresponding with certain flood waves is obtained, a more realistic overview can be presented. The variability and uncertainty of flood waves is included in flood risk management. Furthermore, a gradual reaction to increasing flood waves prevents unpleasant surprises and dangerous situations. By allowing controlled floods in less vulnerable areas the impacts of extreme flood waves may be reduced.

The choice for a certain direction or strategy for flood risk management in most ‘developed’ countries has already been made and might be hard to change. However, in developing countries, such as Cambodia, which are changing rapidly, options are more open. In these areas it may even be more useful to study flood risk management strategies and evaluating different alternatives. Sometimes it seems as if countries have to choose between economic development on the short term and safety on the long term with slow economic development. Building structures to control floods will quickly stimulate economy, but introduce the risk of failure of the structures and a large economic damage. The challenge for these areas is to find a strategy for flood risk management that fits in the socio-economic development process of the region, without creating very dangerous situations. This seems possible when a whole systems approach and long-term view are adapted.

This paper has explained the concept of resilience and has argued that in an uncertain world resilience strategies are more adequate. However, some questions remain to be answered such as: “Under what conditions are resilience strategies favourable?” or “What economic consequences have resilience strategies?” Further research is required in the future. The call from society to visualize and reduce uncertainties requires a rethinking of flood risk management. Resilience strategies on the long term must be able to cope with the uncertainties in a more clear and safe way.

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