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Resilience and flood risk management

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Abstract

Since flood disasters still occur and even increase in frequency and severity, flood risk management must be reconsidered. This paper describes a new way of looking at flood risk management by applying a systems approach. This approach may result in flood risk management that is better suited to the socio-economic context in which this flood risk management occurs. The systems approach allows the definition of resilience and resistance strategies for flood risk management. Resistance strategies aim at flood prevention, while resilience strategies aim at minimising flood impacts and enhancing the recovery from those impacts. A resilience strategy is supposed to be able to better cope with uncertainties than a resistance strategy. To enable the evaluation of resilience and resistance strategies under different conditions the concepts of resilience and resistance must first be sufficiently understood. This paper discusses the meaning of resilience and resistance and applies the concepts to flood risk management systems. This discussion is exemplified by The Netherlands' flood risk management.

Keywords: Floods; Flood risks; The Netherlands; Resilience; Systems approach; Uncertainties

1. Introduction

Floods are natural phenomena for lowland rivers that always have occurred and will always continue to occur in the future. However, there may be a lot that more knowledge, research, adequate strategies and decision-makers can do to prevent them from becoming disasters. Flood disasters are human problems with underlying natural but also social, economic and political causes. It seems that flood disasters become more frequent and increase in severity, despite centuries of experience with flood management (Parker, 2000; Takeuchi, 2002). Although it is not sure whether this increase in frequency and severity may be blamed on climate change, population growth or unsustainable development, this increase in flood disasters does show that flood risk management needs continuous attention. New strategies or new visions on old strategies must be studied and evaluated to better cope with floods in the future.

Within the context of sustainable development, which aims at an efficient use of an area whilst maintaining equity between generations and within the current generation, flood risk management aims at coping with uncertain and variable discharge waves (De Bruijn, 2003). The actual concretisation of how these waves can be coped with differs by area. Traditionally, flood risk management of lowland rivers focuses on flood prevention. Attention has mainly been confined to determining discharge probabilities and constructing defensive structures to protect the land against floods. However, flood risks consist of two elements: the hazard, in the form of peak discharges, and the consequences, the resulting damage and social disruption. The traditional strategies in developed countries, focusing mainly on the hazard by aiming at flood prevention, can be considered resistance strategies. In contrast, resilience strategies focus more on living with floods instead of preventing them. Such strategies rely on a flexible response to floods and a rapid recovery from them (De Bruijn & Klijn, 2001; Vis *et al.*, 2001). The terms "resilience" and "resistance" relate to a systems approach to flood risk management.

To enable the study of resilience and resistance strategies for flood risk management, first the concepts of resilience and resistance must be sufficiently understood and adequately defined. Although there are some definitions of resilience in the context of water management, clear definitions for flood risk management do not exist yet. Hashimoto *et al.* (1982) and ASCE & UNESCO (1998) define resilience as the speed of recovery from an unsatisfactory condition. Resilience is then equal to the probability that a satisfactory state value will follow an unsatisfactory state value in the next time step. This definition is based on statistics derived from measurements of the water system (the discharge, water levels, etc). Damage caused by water shortage or excessive water is not explicitly incorporated in this definition. For flood risk management this approach is not comprehensive enough. The system cannot be limited to the water system only, for the consequences of floods need attention as well. Since these potential consequences influence the choice of a certain strategy for flood risk management, the consequences of floods must be incorporated into the definition of the flood risk management system. Because floods are rare and data of flood damage are usually incomplete, it is very difficult or entirely impossible to derive flood impacts and flood recovery from recorded data. Therefore, other indicators for resilience may be required. Before starting a search for such indicators, the resilience concept must be sufficiently understood.

This paper explains and discusses resilience as a characteristic of flood risk management systems. This requires that a systems approach is adopted. Because flood risk management systems are partly anthropogenic systems, different management strategies can be chosen. Two different types of strategies can be distinguished: resilience and resistance strategies that both cope with peak discharges in a different way. The identification of these two strategies creates the possibility to study, evaluate and compare the strategies in order to identify under which circumstances which strategy is to be preferred or which combination of the two strategies is preferred. This may prevent the automatic association of flood risk management with flood control. The two different management strategies are discussed.

This paper starts by discussing the resilience and resistance concepts as developed by system ecologists. Then, the concepts are applied to flood risk management by adopting a systems approach. Finally, flood risk management in The Netherlands is described and discussed as an example.

2. The concepts of resilience and resistance

Resilience is a frequently used concept. It is usually associated with the recovery or return from a bad situation to the better original situation. Companies that almost go bankrupt but recover are called resilient and patients in hospitals that recover quickly are called resilient as well. In water management policy in The Netherlands resilience is associated with ideas such as water conservation, creating space for natural processes, allowing natural processes to cause variability or reducing the control over a system (Min V&W, 1998; Remmelzwaal & Vroon, 2000; Klijn & Marchand, 2000). Resilient water systems are believed to be able to cope more easily with disturbances such as pollution and extreme events. However, what resilience exactly means is often unclear.

The use of the resilience concept in water management is derived from ecology, where a systems approach is very popular. The central question in system ecology addressed in the 1970s and 1980s was how to explain the apparent stability or persistence of complex ecosystems. In this context, Holling (1973) introduced the concept of 'resilient systems'. Holling states that the most essential feature of ecosystems is that they recover from disturbances. This recovery means that the principal characteristics of the system are restored, not that the exact same situation returns.

Nowadays, two different definitions of resilience are used in ecology. These definitions can be best understood by having a look at system reactions to disturbances. The reaction of any system in apparent equilibrium to a disturbance may be one of the following:

1. The system does not react at all.
2. The system reacts but soon returns to the equilibrium situation.
3. The system reacts and turns into another stable situation.
4. The system comes into an oscillating instable situation.

In the first case, no reaction is visible. In the second situation the system reacts, but the system state stays in the domain of attraction of the equilibrium. The domain of attraction of an equilibrium is the collection of all initial states from which the system tends towards equilibrium as time progresses. The system in the second case will therefore return to the equilibrium state. In the third case the disturbance causes the system to flip suddenly and unexpectedly to another equilibrium situation. An example of this situation is a shallow lake that is disturbed by a huge inflow of nutrients. It turns from a state with a high number of game fish, effective grazing upon phytoplankton and low incidences of algal blooms into a "pathological" state in which there are few game fish, less grazing, no macrophytes and extensive and frequent algal blooms. This transition is rapid and is not easily reversed. Both situations are stable in a certain domain. In the fourth case the system does not become stable anymore.

The above example of a static system is relatively simple. In reality, however, systems are seldom static, but instead develop and change continuously. If a developing system is disturbed, the same four types of reaction apply, but the system does not return to the previous state, but to a similar pattern of development or the system develops as it would have developed if no disturbance had occurred.

Against this background, resilience can be defined in two ways:

1. Resilience is the ability of a system to maintain its most important processes and characteristics when subjected to disturbances. Resilience is then measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behaviour. A system with a small domain of attraction that can change dramatically by small disturbances is considered not resilient (Coller, 1997). This definition has been used to describe the dynamics of a variety of ecosystems, including freshwater lakes (Carpenter & Cottingham, 1997), forests (Ludwig *et al.*, 1978), etc (Gunderson, 1999). It is based on the idea that, in resilient systems, no sudden changes or collapse should occur.

2. Resilience is the ability of a system to return to an earlier equilibrium or development pattern after a perturbation. This definition is based on the assumption that systems operate at or near a global equilibrium (Clapham, 1973; May, 1974; Pimm, 1984; O'Neill *et al.*, 1976; Jørgensen, 1992; Begon *et al.*, 1996; Pérez-España & Arreguín-Sánchez, 1999). The users of this definition measure resilience as the return time of a system (O'Neill, 1976; Kwa & Ringelberg, 1984; Pérez-España & Arreguín-Sánchez, 1999). O'Neill (1976) adds that, to measure resilience, both the time needed to return to equilibrium and the movement of the system after a disturbance should be measured. He includes the amplitude of the reaction by quantifying resilience as the sum of the squared deviations of the equilibrium. In this definition resilience and resistance are both considered as characteristics that make a system become persistent or sustainable. A resilient system reacts on a disturbance and then recovers; a resistant system does not show any reaction at all (see Figure 1). A tree species could, for example, survive fires by having fire-resistant bark (exhibiting resistance), or alternatively it could burn down and regenerate from seeds with fire-induced germination (exhibiting resilience). In very dynamic environments, such as coasts and natural floodplains, resilient species dominate, whereas in stable environments, such as rainforests and coral reefs, more resistant species will be found.

Holling (1973) calls 'resilience' as in the second definition above 'stability', while Begon *et al.* (1996) define stability as the result of a combination of resilience and/or resistance. Resilience is then one of the two prime characteristics which may make a system stable.

In this paper we use elements of both definitions. We define resilience as the ease with which a system recovers from a disruption. However, we also take into account the graduality of the reaction to increasing disturbances, as in the definition of Holling. Resilience is defined here as a system characteristic depending on system properties. Since these properties change in time, the resilience of the system also changes in time. If the system changes radically and does not return easily, as in the example of the lakes mentioned above, its resilience is considered to be low. If the system recovers fast, the system is considered resilient. If a system does not react at all, it is considered resistant.

The main features of system reaction are represented in Figure 2 as the behaviour of one hypothetical state variable reacting to sudden disturbances with negligible duration. The system in Figure 2 has sufficient resistance to cope with small disturbances without any reaction, whereas it has enough resilience to recover from larger disturbances. The reaction amplitude (A) and the recovery rate (the angle α) together describe the reaction to disturbances. The reaction amplitude is the severity of the reaction to the disturbance. The recovery rate is the speed with which the system recovers from its reaction to a disturbance.

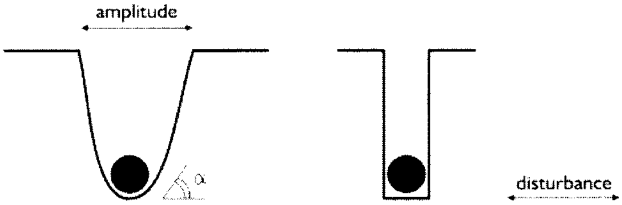

Fig. 1. Representation of a resilient and a resistant system according to the second definition. The ball in the resilient system can move a little uphill when pushed but will automatically return to the centre. The ball in the resistant system cannot move. If the ball in one of the two systems is pushed so hard that it goes over the edge of the system, then return is not certain. (Source: Knaapen *et al.*, 1999.)

In order to understand the behaviour of a system its reaction to the whole regime of disturbances should be studied. Figure 3 shows the reaction amplitudes given the whole range of disturbances. From this figure a third reaction aspect, the graduality of the reaction increase with increasing disturbances, can be derived. The steeper and less uniform the slope of the curve that represents the relationship between the disturbance intensity and the corresponding impact is, the less gradual the reaction.

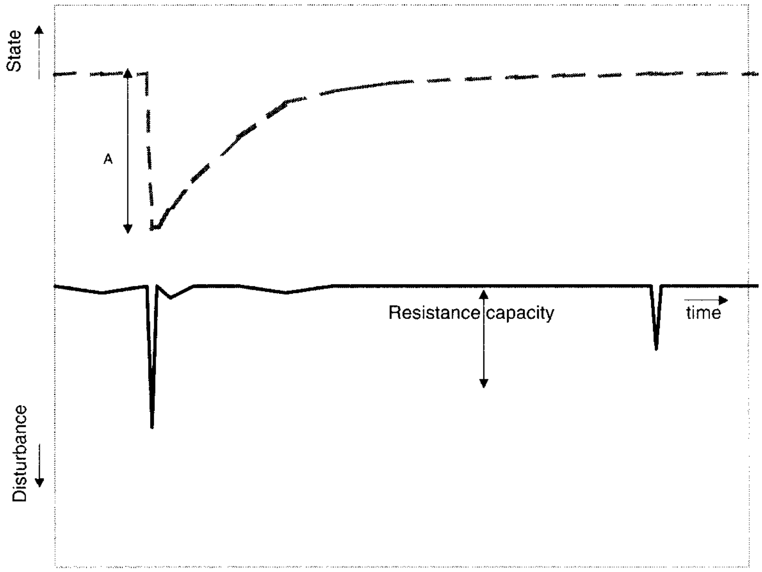

Fig. 2. The system in the figure has resistance to cope with small disturbances; therefore, no reaction to these disturbances is visible. To cope with larger disturbances, the system in this figure has resilience. The degree of resilience depends on the reaction amplitude (*A*) and the recovery rate (*a*).

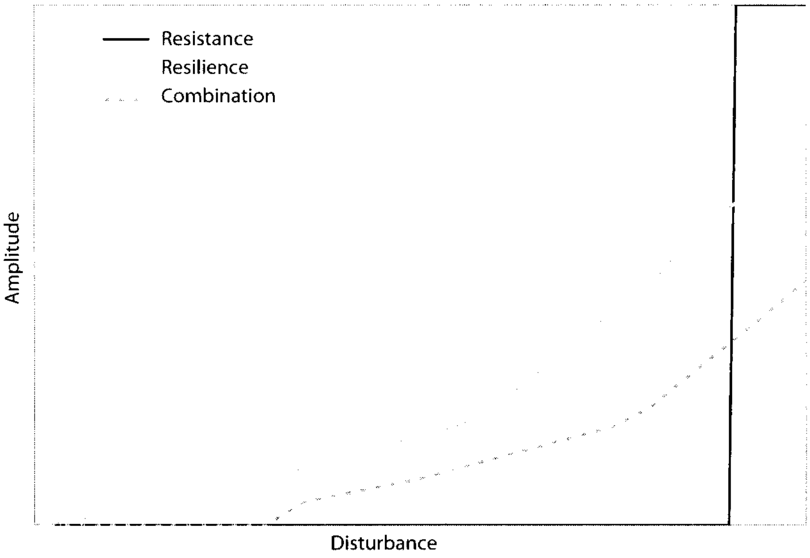

Fig. 3. The relationship between reaction amplitude and disturbance severity for a resilient and a resistant system and a system that has both system characteristics.

Instinctively, a gradual response that is proportionate to the disturbance is expected. A sudden discontinuity in the disturbance–response relationship is usually unexpected and thus may be undesirable. Such an unexpected behaviour occurs, for example, when a lake changes from a clear water state to a nutrient-rich, muddy equilibrium state.

In conclusion: a system's reaction to a disturbance depends on its resistance and resilience. The resistance of a system determines which disturbances a system can withstand without reacting; its resilience determines the response to and recovery from more intense disturbances. The system's reactions can be described by the amplitude of the reaction to disturbances, by the recovery rates and by the graduality of the reactions to increasing disturbances.

3. Resilience and resistance in the context of flood risk management

3.1. Flood risk management systems

In order to be able to apply the systems characteristics resilience and resistance, first the system that flood risk management focuses on has to be defined. Then the disturbance for which resilience is required, the potential reaction of the system on this disturbance and the recovery from the reaction have to be described.

In this paper a flood risk management system (see Figure 4) is defined geographically as the combination of the lowland river stretch and the adjacent flood-prone area. The upper boundary of the system is where the river becomes a lowland river and the lower boundary is where the sea influence on the river becomes dominant. Discharge waves from the upper river enter this system as an outside force. Conceptually, the system comprises both the socio-economic and physical aspects of the area. Flood risk management copes with this system and is not considered part of the system.

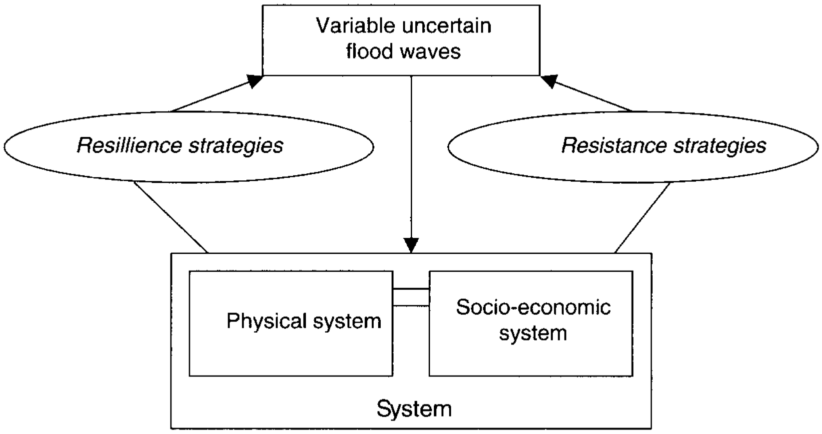

Fig. 4. A flood risk management system consists of the river and flood-prone area and incorporates both the physical and socio-economic characteristics. This system is subjected to discharge waves. To cope with these discharge waves, the system needs resilience or resistance or a combination of both characteristics.

For practical reasons, the flood risk management system is geographically limited to the area threatened by floods. However, the socio-economic situation of this area strongly relies on a larger socio-economic context at a regional, national or even global scale. Therefore, although the area threatened by floods is the focal system, relationships with other areas must be taken into account when these other areas suffer indirect flood impacts or influence recovery.

3.2. Resilience and resistance of flood risk management systems

The disturbances for which a flood risk management system needs resilience or resistance are discharge waves, generated upstream in the catchment area, i.e. outside the focal system. These waves may cause a reaction in the form of floods, resulting in casualties, damage and/or social and economic disruption. After this disruption the system may recover to a situation in which the most important system properties are restored and in which developments continue.

Summarising, the resilience of flood risk management systems for lowland rivers can be defined as the ease with which the system, consisting of the socio-economic and physical aspects of the flood-prone area and the river, recovers from floods. In contrast, the resistance of these systems can be defined as its ability to let discharge waves pass without causing floods. In other words, in resilient flood risk management systems floods may occur, but their impacts will be easily recovered from. In resistant systems discharge waves will not result in floods.

The three most important characteristics of reaction – amplitude, graduality and recovery rate – can also be applied to flood risk management systems. The first aspect, amplitude or severity of the reaction, is equal to the economic, social, psychological and ecological impact of floods. It depends on:

1. hydraulic parameters that are related to the event or the hazard, such as the maximum water depth, stream velocity, area flooded, duration of floods and sediment carried;
2. socio-economic parameters that determine the corresponding damage, such as the land use and the preparedness to floods;
3. ecological parameters, such as the types of ecosystems, the presence of refugee locations and the connectivity with other ecosystems.

The second aspect, the graduality of the reaction, relates to the increase of flood impact with increasing discharge waves. The graduality depends on the same parameters as the reaction amplitude, but is also strongly dependent on the relief of the area and the flood defence infrastructure of dikes, outlets, weirs, bypasses, detention areas, etc, and their operational management.

The third aspect, recovery rate, indicates how fast a system returns to its former state or former development pattern or to a development pattern comparable to systems that were not disturbed. It is not necessary that exactly the same state is achieved, as long as the most important characteristics return. After all, people may try to improve their situation during the recovery process, which may result in a system that is better prepared for new floods or with better living conditions. The duration of the recovery period depends on the severity of the damage itself and the context in which the flood damage occurs. Because the severity of the reaction is already described by the amplitude aspect, we should try to describe recovery rate independent from the severity of the flood damage itself. Important factors that determine recovery are, for example, the duration of the floods, the possibility of finding funds for recovery, the ability to earn an income during and after a flood, the spreading of effects to other areas, management and corruption in an area, health and equity, etc. A sound assessment of recovery requires the co-operation of social scientists and engineers.

3.3. Resilience and resistance strategies

Most lowland rivers are influenced by the presence of people. Since people have influence on these rivers and on the corresponding flood risk management systems, they may, to a certain extent, determine its behaviour. They may decide on a certain flood risk management strategy. Decision-makers may choose to enhance either the resilience or the resistance of the system, or both. Resilience strategies for flood risk management can be defined as strategies that allow floods, but aim at minimizing the flood impacts, maximizing the graduality of the increase of flood impacts with increasing discharges and maximizing the recovery rates for all possible discharge waves. In contrast, resistance strategies can be defined as strategies that prevent floods from events smaller than a certain threshold (usually a design discharge). In resilience strategies the whole discharge regime is considered, while in a resistance strategy attention is focused on one design discharge.

The two strategies apply different measures, although the same measures may be used in both resilience and resistance strategies. The measures used in a resilience strategy may change the hazard or the vulnerability for specific areas. They comprise both structural and non-structural measures. Decreasing the protection of natural areas, or increasing that of cities, changes the hazard for those areas, while raising the consciousness of inhabitants, changing land use or flood-proofing houses change the vulnerability of the area. Both types of measures may increase the resilience of the system as a whole as, when expected damages are lowered, recovery is enhanced and the reaction to discharge waves is more gradual. In resistance strategies, in contrast, flood protection by means of structural measures dominates.

Another important difference between the two strategies is how they cope with uncertainties. In flood risk management many uncertainties have to be dealt with. First of all, the probability of discharges is very uncertain. Second, these discharges have to be translated into water levels for each river section. Stage-discharge relationships for extreme discharges are again very uncertain, because the extremes are so rare that they cannot be easily verified. Besides, in such extreme situations the discharge division over different river branches may also add to the uncertainties. Then there are questions of dike stability, wind effects, ice dams, effects of shipping accidents, etc, that all influence flood probabilities. And, when a flood occurs, neither the flood pattern nor the behaviour of the people is certain.

The resistance strategy can deal with part of these uncertainties by assessing them and including them in the flood probability or by just over-dimensioning the dikes and other structures. In such a case, the inhabitants are usually unaware of the uncertainties and of the fact that they face a small flood risk from discharges above the design discharge or due to other uncertainties. In contrast, the resilience strategy is designed explicitly to deal with uncertainty. It relies on the notion that floods cannot be entirely prevented and argues that therefore measures to limit the impacts and to enhance recovery are also required. Resilience strategies are expressly designed for the whole possible discharge range and not only for a certain design discharge; the possibility that extreme discharges may occur is regarded as self-evident.

4. The Netherlands as an example

To illustrate the need to reconsider flood risk management and the possible advantages of resilience strategies The Netherlands' flood risk management is discussed here. One third of The Netherlands is artificially protected against floods from the sea and the major rivers (see Figure 5). This area is densely populated and the potential damage is enormous. To prevent floods from the major rivers (Rhine, Meuse and Vecht Rivers) dikes have been built and raised to a level that secures a safe passage of a design discharge with a probability of 1/1250 per year.

The Netherlands' flood risk management strategy primarily relies on flood prevention. Therefore, little attention is paid to the consequences of floods. The potential damage in the flood-prone area has steadily increased with economic development and will continue to grow. The alternative states of the flood risk management system therefore vary between either no flood or, alternatively, a catastrophe. Along the diked rivers in The Netherlands a small flood is virtually unthinkable.

In 1993 and 1995 extreme discharges occurred, followed by raising the design discharge. Traditionally, this would result in a further heightening of the dikes. However, The Netherlands' river management policy nowadays gives preference to creating room for the rivers before further heightening dikes (Min.VROM and V&W, 1997). This is a first step towards a change of policy, which takes into account changes in the societal preferences and views on flood risks and technological flood protection, such as:

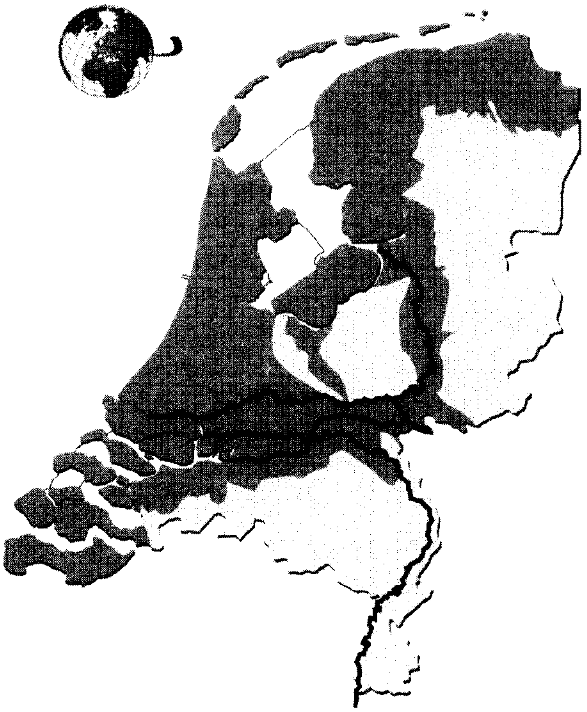

Fig. 5. The flood-prone area (dark-grey) in The Netherlands.

- The continuous improvement of infrastructure in the past decades has affected much of the natural value of the Rhine region and its scenic beauty.
- In some areas flooding brings not only benefits for nature but also socio-economic benefits.
- The more the infrastructure is improved, the greater the impact of occasional floods. The notion that more frequent non-catastrophic damage may be preferable over rare catastrophic damage is growing in popularity.

Beyond this recent change in policy, it also gradually becomes clear that the traditional strategy of flood protection has, next to its obvious advantages, also some important disadvantages. Since the current strategy is based on *one* design discharge for the whole area threatened by the main rivers in The Netherlands, it is uncertain which area will be flooded first when the design discharge is exceeded. Furthermore, it means that all areas along the river have the same level of protection, independent of the potential damage to the areas. This is economically not sensible. Nowadays, the possibilities of making accurate flood forecasts, and to spread flood warnings throughout The Netherlands, have adequately improved. Also the possibility to anticipate peak flows by operating a detention area has grown. Since floods and their impacts can be better controlled now, flood prevention under all circumstances is no longer necessary. De Bruijn & Klijn (2001) provide more detailed information on the advantages and disadvantages and the meaning of resilient strategies for The Netherlands.

Next to the current strategy consisting of dike heightening to create sufficient discharge capacity for the design discharge, alternative strategies are now being studied. In these studies different time scales are distinguished, which determine the type of measures taken into account, ranging from short-term measures (to be realised within approximately 10 years), long-term measures (within about 50 years) and entirely new comprehensive strategies for the far future (within 100–300 years).

For the short-term, taking the design discharge as a safety standard is not disputed. Only measures that increase the discharge capacity to comply with the new 1/1250 per year design discharge of 16,000 m^3/s, instead of the former 15,000 m^3/s, are being considered, such as dike heightening, lowering the floodplains, removing obstacles from the floodplains, dike relocations and bypass channels. Sometimes these measures are combined with proposals to change the discharge division over the different river branches to limit the measures to one or two branches instead of all three. All measures still fit within the main approach of flood prevention and will increase the resistance of the system.

For the long term, the adoption of one single design discharge for the whole river area is being disputed. Research on the possibility of changing from a design discharge policy to a risk-based policy is being carried out (Jorissen, 1997; TAW, 2000). This risk-based policy is still focused on flood prevention, because it proposes to improve protection in areas that face a high risk, but does not consider lowering the consequences of floods by spatial planning yet. This policy may increase the resilience of the total system, because it may eventually lead to a differentiation of protection levels and related flood probabilities and thus to a more gradual response to floods. It is likely that the most vulnerable areas will be best protected, thus diminishing the possibility of disasters. In this context measures that have a large impact on spatial planning are also considered, such as detention areas which can be inundated to prevent flooding elsewhere.

For the far future strategies are being studied which abandon the one design discharge as the basis and which allow the flooding of large areas where land use is adapted to higher flood frequencies. Climate change is a very important issue in these studies. Examples of such strategies are:

- Compartmentalisation. In this strategy a normal peak discharge is kept in the river, but if discharges of 1/500 per year to 1/20,000 per year probability occur, compartments are inundated in a pre-fixed order. At first the least valuable, most upstream compartment is used to protect the downstream compartments from flooding, then the last-but-one upstream or valuable one, etc (Vis *et al.*, 2001; Klijn *et al.*, 2003).
- Green rivers. A strategy in which large corridors are used as bypasses during peak flows. In normal years a part of the area floods in wintertime, while in exceptional years the whole area is flooded and inundation depths are high. The water depths and inundated area increases gradually with the increasing discharge from Germany (Vis *et al.*, 2001; Klijn *et al.*, 2003).
- Rivers' land. Removing all dikes except the outer dikes bordering the comprehensive alluvial plain of the Rhine and Meuse rivers. This will allow the river to flood large areas and eventually even to form new channels. The river is no longer adjusted to the land use, but instead the land use in the alluvial plain is fully adjusted to the frequent floods (Vis *et al.*, 2001).

These resilience strategies for the far future lower flood impacts, increase the graduality of response and thus reduce the possibility that sudden disasters occur, and increase the recovery rate since floods are less unexpected and will occur only in the less vulnerable areas. However, these strategies are expensive to implement as they require that land use be changed over vast areas.

For the short term The Netherlands' water managers mainly put their trust in maintaining or increasing the resistance. Not much change to the current strategy is expected. The usual flood control measures are proposed and the design discharge remains the basis for decision-making. However, resilience may increase in the longer term. Changing the discharge distribution over the different branches and paying more attention to bypasses and detention areas may already introduce some graduality because flood probabilities are being further differentiated. Whether the true resilience strategies have any chance of being implemented will remain a question until after intensive and lengthy public debate.

5. Conclusions

This paper explains that, by adopting a systems approach, flood risk management can be better focused towards contributing to sustainable development. The flood risk management system consists of the lowland river stretch and the adjacent flood-prone area and includes both the socio-economic subsystem and the physical subsystem. The upstream boundary of this system is where the river changes from an upland river into a lowland river and the downstream boundary where the sea influence becomes dominant.

This flood risk management system has a certain degree of resilience and resistance to cope with discharge waves. The resistance of the system determines which discharge waves can pass through the river without causing floods, while the resilience of the system determines the ability to recover from floods. The smaller its reaction to floods, the faster the recovery from this reaction, and the more gradual the reactions increase with increasing discharge waves, the larger is the resilience of the system.

Flood risk managers can choose between different strategies to improve the ability of the flood risk management system to cope with discharge waves. They can increase the resilience or, alternatively, the resistance of the system. Resistance strategies aim at flood prevention and focus on designing the river in such a way that a certain design discharge can be dealt with. Resilience strategies aim at maximizing the resilience for the whole discharge regime with all the uncertainties related to it. In resilience strategies, floods are allowed to occur in less vulnerable parts. This type of strategy uses both non-structural and structural measures, while resistance strategies mainly apply structural measures. Uncertainties are difficult to manage in the resistance strategy, while they lie at the basis of resilience strategies.

The systems approach and the concepts of resilience and resistance are new for flood risk management in the way that they focus on the balance between the socio-economic situation, the physical situation and climatic variability. It is a comprehensive approach which uses ideas from the discussion on structural versus non-structural measures, from vulnerability theories of social scientists and from systems theories of ecologists. The approach incorporates the main issue of flood risk management: it must add to the sustainable development of a region.

In developing countries that are changing rapidly, the choice between resilience and resistance strategies can still be made. This paper discusses the concepts of resilience and resistance also to raise the consciousness among flood risk managers to the fact that they do have a choice and do not automatically have to build dikes and embankments, as is often advised by consulting engineers.

This paper argues that using a systems approach and defining resilience and resistance strategies may result in more comprehensive flood risk management strategies that are better suited for the specific socio-economic context of a particular area. In future, further research will focus on questions such as under what conditions resilience strategies are favourable and what economic consequences they have.

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