

## Keynote lecture: Flood defense in The Netherlands: a new era, a new approach

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**Abstract:** Intensive land use and far-reaching alterations to the fluvial hydrosystem, made feasible by technological developments in the past century, have reduced the hydromorphological resilience of the Rhine and Meuse river basins. Because the hydromorphodynamic processes could be controlled to a greater extent, residents of the riverine areas lost their sense of the natural dynamics of river systems, and further urbanization of areas prone to flooding took place without the potential dangers being recognized. It was particularly in the low-lying polders of The Netherlands that the potential damage from flooding increased tremendously over time. The Dutch Ministry of Transport, Public Works and Water Management is currently trying to achieve sustainable water and river management by developing and implementing a new approach to flood defense. In addition to the implementation of technological measures, the government aims to create more space for the rivers, combined with objectives from other policy areas, including the reconstruction of rural areas, development of the ecological infrastructure, surface mineral extraction, land use and other area-specific projects such as housing schemes.

This approach is not confined to The Netherlands: similar concepts have recently been introduced at various other locations in the Rhine and Meuse river basins. The new approach requires land-use changes and introduces new scientific research issues relating to land and water use, hydromorphology, river management and socio-economics. This paper discusses this new approach and related scientific developments.

**Keywords:** sustainable flood defense strategies, hydromorphology, habitat restoration, socio-economics, public-private enterprises.

### 1. INTRODUCTION

Located in the delta formed by the Rhine and Meuse rivers, The Netherlands has a long history of adapting the natural water and river systems to user functions such as housing, agriculture and shipping. Fig 1 provides an overview of the Rhine and Meuse river basins. The “everlasting fight” against floods in this small country, much of it situated well below sea level, is legendary. Large parts of The Netherlands are still subsiding, while the sea level is rising. Approximately 25% of the country is currently situated below mean sea level (by up to 6.7 m). Without the dikes and dunes along the coast, 65% of the most densely populated part of The Netherlands would be flooded every day. Huisman et al. (1998) presented a historic overview of geographic and hydrological aspects of The Netherlands and described the organizational and legislative developments of water management. Originally, the water boards, Netherlands oldest democratic institutions, took care of flood protection and land reclamation. However, the water boards tended to focus on regional interests, which frequently led to controversial management measures and sometimes to

dangerous situations. Since 1798, the overall responsibility and coordination of water management in The Netherlands has been a governmental task (Van de Ven 1976), and the Directorate-General of Public Works and Water Management (*Rijkswaterstaat*) was created to fulfill this task.



**Fig. 1** The Rhine and Meuse basins. For extensive data see Middelkoop and Van Haselen 1999.

The spectacular technological developments of the past century allowed far-reaching alterations to be introduced to the hydrosystem in the Rhine and Meuse river basins. In the short term, these alterations benefited agriculture, navigation, and flood protection. However, the large-scale reclamation of wetlands and the regulation and harnessing of rivulets reduced the hydromorphological resilience of both river basins. This meant that the water and sediment discharge patterns were affected in such a way that periods of high or low precipitation rates are now immediately reflected by extreme high or low water levels

in the river. The large-scale draining of agricultural land and the expanding urbanized areas, consisting almost completely of impervious materials, caused rapid run-off of rainwater and subsequent high water discharge peaks in the river. River regulation schemes and the diking of floodplains augmented this problem (Dister et al. 1990). For instance, the length of the river Meuse downstream of Grave has decreased by nearly 30 percent due to meander cut-offs (Middelkoop and van Haselen 1999). In addition, the morphological resilience of both river basins was affected by the large numbers of sluices, weirs, dams, groins and fortified riverbanks which impeded the replenishment of the bed load. In the Rhine, this has resulted in ongoing riverbed erosion at several locations (Anonymous 1993).

The above developments came about gradually. Technological innovations made it possible to alter the hydrosystem in favor of particular user functions and people started to lose their sense of the natural hydrodynamics of river systems and the related threat of flooding. Further urbanization of areas prone to flooding was undertaken without recognizing the potential danger. It was particularly in the delta, in the low-lying polders of The Netherlands, that potential flood damage increased tremendously in the course of time. After the near floods of 1993 and 1995, the countries along the rivers Rhine and Meuse realized that the traditional approach to land and water management had to be fundamentally changed, an awareness that was further raised by the high water discharges of 1998. Within the context of an international agreement, it was decided that considerable efforts would be made in the near future to restore the resilience of the Rhine and Meuse river basins (Anonymous 1995). Each country was to select the appropriate measures to restore the hydromorphological resilience of the relevant part of the river basin, from the perspective of the river basins as a whole. Up to now, the countries of the Rhine river basin have made considerable progress in selecting and implementing these measures (Anonymous 1998), and the countries of the Meuse river basin are expected to follow suit.

## **2. FLOOD DEFENSE STANDARDS IN THE NETHERLANDS: DESIGN WATER DISCHARGES AND DESIGN WATER LEVELS**

It took some time for people to recover from the anxiety caused by the floods of 1993 and 1995. In 1995, some 250,000 people were evacuated from their homes for some days due to the questionable stability of dikes that had been exposed to protracted flooding and had become saturated with water. The estimated economic damage to agriculture, industrial activities and private enterprises amounted to about 1 billion US dollars. Thereupon the Dutch government adopted a policy aimed at minimizing the potential damage, raising awareness among the public, improving international early-warning systems and developing measures to increase flood safety levels, preferably in an international context. The government immediately decided to initiate the so-called Major Rivers Delta Plan (Olsthoorn and Tol 2001), which stipulated that all river dikes had to be adapted to meet current standards. However, as a result of the near floods in 1993 and 1995, the design discharge in the river regions of The Netherlands will end up being higher than those used up to now as a basis for calculating dike heights (design water levels).

The design discharge is derived using a statistical analysis of discharge peaks that have occurred in the past (Silva et al. 2001). For example, measurements in the Rhine at Lobith (where it enters The Netherlands) have been taken since the year 1901. Firstly, a so-called homogenization of the flow measurements series is conducted. The Rhine catchment area has changed a great deal in the course of time, which has resulted in changes to the river's discharge characteristics: the same precipitation pattern in the catchment area now leads to a different flood wave at Lobith, in terms of height as well as shape, than was seen at the beginning of the 20th century. In order to derive the design discharge under the present circumstances, discharge peaks measured in the past have been corrected to accommodate

alterations in the catchment area that have occurred in the 20<sup>th</sup> century.

In terms of height, width and slope, dikes are designed to withstand the discharge of floodwater for a pre-determined length of time, based on specific technical guidelines. The design water level forms an important starting point, this being the water level that the dike must be able to hold back safely. This water level has a certain probability of occurring that corresponds to the level of protection chosen for the various dike regions. These levels of protection, which can be regarded as safety standards, are laid down in flood management legislation. Additionally, factors such as wind set-up and wave run-up are taken into consideration, for which a certain freeboard is maintained. This has resulted in the dike rings in the areas of the Rhine branches nearly all having a safety norm of 1/1250 per year. In other words, the probability that the river water will rise above the design water level must not be higher than 1/1250 in one year. In the western part of the country, safety norms are significantly higher, for instance 1/2000 up to 1/10000 in the “Central Netherlands” dike ring, a region including the cities of Amsterdam, The Hague and Rotterdam, and the area they enclose. This is associated with the greater economic interests and population densities, but also with the difficulty in predicting storms at sea, which carry a higher risk of victims, and with the fact that seawater is salty and thus causes greater damage in the event of flooding.

In 2001, the design water levels were reviewed within the context of the flood management legislation. For the Rhine branches, it was decided to increase the design discharge at Lobith from 15,000 to 16,000 m<sup>3</sup>/s. Without the implementation of further measures, this also means higher design water levels. If the design discharge at Lobith is known, then the design water levels on the Rhine branches can be calculated, using two-dimensional computer models simulating water discharge and water levels in the river. The design discharge is set at the upstream boundary of the model, i.e., at Lobith. The model then calculates the discharge across the three Rhine branches and the corresponding water levels.

### **3. ROOM FOR THE RIVERS**

In its Fourth Memorandum on Water Management, the Dutch government stated that engineering measures that are sustainable are preferred to meet the desired level of safety (Anonymous 1999). This means that measures should be devised and implemented which, despite the increased design discharge, prevent a new round of raising and reinforcing dikes. Thus, expanding the floodplain of a river by moving dikes further inland is preferred to raising the dikes. Taking the effects of climate change (increased rainfall and rising sea levels) into account, merely raising the dikes is pointless in the long term. Moreover, periodically reinforced and raised dikes may give local authorities and citizens a false sense of security, resulting in extensive private and public investments for structures inside the embanked areas. Therefore, the Dutch government has initiated a shift from “traditional” flood protection policies (i.e. merely dike raising and draining polders) towards creating increased water discharge capacity, i.e., creating more room for the river. Changing land-use functions and creating more room for the river is difficult but effectively anticipates future developments. Within this context, concrete management measures have been formulated, some of which had already been considered earlier, while others were new. With respect to the projects included in this plan, particular attention was given to increasing the water discharge capacity of the rivers and other goals within the framework of the Action Plan on Flood Defense for the Rhine (1998). Additional funding has been provided by the European Commission to implement these projects in the Rhine and Meuse basins. Moreover, studies carried out in The Netherlands during the period 1995-2002 have examined the options for increasing the water discharge capacity as well as the storage of

water (called “Meuse works” for the Meuse river; “Room for the Rhine Branches (RfR)” for the Rhine branches; “Integrated Exploration of the Lower River regions (IVB)” for the downstream sections of the Rhine branches and Meuse; and “Water Management in the Lake IJssel Region (WIN)” for the lake IJssel region). All of these studies have made it clear that water management can no longer be seen as a separate issue, unrelated to nature conservation policies and spatial planning. As the Dutch government puts it: “By opting for room for the river, possibilities elsewhere in the river regions will need to be found for a number of activities. Room for the river will not be able to exist without consequences for the public planning policy in the rural areas” (Anonymous 2000). The results of these studies are being used in some surveys at regional and national levels to determine the appropriate set of measures for each river section in The Netherlands. The Directorate-General for Public Works and Water Management bears the overall responsibility for selecting and implementing the appropriate flood defense measures along the Rhine branches and the river Meuse in The Netherlands. The decision-making process will take place within the context of the national Key Planning Decision procedure, which includes public participation in the decision-making process, and provides the legislation (including expropriation if necessary) required to implement the selected measures.

The Dutch government realizes that policies and management measures can only be successful with sufficient public support. Therefore, local and regional authorities as well as non-governmental agencies are involved in these studies. In the meantime, additional spatial planning policies and legislation have become operative (since 1995), protecting the (remaining) floodplain area against building and housing projects (Anonymous 2001).

#### **4. CLIMATE CHANGE AND A NEW APPROACH TO WATER MANAGEMENT IN THE 21<sup>ST</sup> CENTURY**

##### **4.1 Climate Change**

Future climate changes could influence precipitation levels to such a degree as to result in extreme discharges in the Rhine and Meuse. Under such circumstances, however, it can also be assumed that flooding and/or supplementary water storage measures along the upper Rhine would lead to an upper limit to the discharge in the downstream direction. Developments in the levels of precipitation in the central and northern sections of the Rhine and Meuse catchment areas in particular will influence the level of discharges in The Netherlands. An approximate analysis taking flooding along the Upper Rhine into consideration shows that, assuming a 4° C temperature increase in the next century (the highest estimate for the climate effect in 2001), a discharge increase at Lobith of 18,000 m<sup>3</sup>/s around 2100 cannot be ruled out (Silva et al. 2001). If floods and storage measures along the Upper Rhine are not taken into account, a 4°C temperature increase would mean a discharge at Lobith of more than 19,000 m<sup>3</sup>/s. One must also remember that the Lower Rhine imposes a limit on the amount of water that can reach The Netherlands: 17,500 to 18,000 m<sup>3</sup>/s, which is the estimated discharge rate at which flooding can occur along the Lower Rhine.

For the last 1000 years, sea water levels measured along the Dutch coast have become higher and higher. This is caused not only by the sea level rising in the absolute sense of the word, but also by the coastal areas subsiding. The combination of these two effects is called relative sea level rise, and it amounts to 20 cm per century. It is expected that this trend will continue in the near future.

Like river discharges, the consequences of climate change on sea level must also be taken into account. Various scenarios have been developed for this situation. The mid-range estimate of a 1°C increase in temperature around the year 2050 would cause a relative sea

level rise of 25 cm. The highest estimate of a 2°C increase corresponds to a sea level rise of 45 cm around 2050. The sea level rise in 2015, the year envisioned for achieving sustainable flood defense in The Netherlands, can be derived from these previous figures; the highest estimate will then be around 15 cm (Silva et al. 2001).

## 4.2 New Approach

For centuries, spatial planning in the low-lying Netherlands has been a matter of separating land and water and maintaining this separation. The Netherlands has benefited from this, considering the fact that two-thirds of the gross national product (around 2000 billion US dollars annually) is generated domestically (Anonymous 2000). However, climate changes are increasing the likelihood of floods and water-related problems. In addition, the population density continues to grow, as does the potential of the economy and, consequently, the vulnerability of the economy and society to flood disasters. These two undesirable developments add up in terms of safety, creating a growing risk with even greater consequences. As such, the safety risk is growing at an accelerated pace (safety risk = probability of flooding multiplied by flood damage). In 1999, the junior minister of Transport, Public Works and Water Management and the president of the Union of Water Boards established the Advisory Committee on Water Management in the 21<sup>st</sup> Century (Anonymous 2000). This Committee was charged with “developing recommendations for desirable changes to the water management policy in our country, focusing on the consequences of climate change, rising sea levels and land subsidence”. In 2001, this Committee produced some guidelines for future water management in The Netherlands. The Dutch government enacted these guidelines in the new approach to ensure safety and reduce water-related problems in the 21<sup>st</sup> century. They comprise:

- 1) Awareness; citizens are insufficiently aware of problems associated with water. The government will improve communication on the nature and scope of these risks and, in addition to its own efforts, will offer individuals the opportunity to contribute to risk reduction.
- 2) Three-step-strategy; the need for a new approach to ensure safety and reduce water-related problems founded on a number of underlying principles;
  - anticipating instead of responding;
  - not shifting water management problems to others, by following the three-step strategy (retaining, storing and draining) and not shifting administrative responsibilities to others;
  - allocating more space to water in addition to implementing technological measures.
- 3) More room for the river; in addition to implementing technological measures, allocating more space for the (occasional) storage of water is required. Wherever possible, this space must also serve other objectives that are compatible with water storage.
- 4) Spatial planning; the primary goal is maintaining the discharge capacity of the river by legislation preventing non-river-linked human activities in the floodplains and by adapting municipal zoning schemes. Furthermore, within the context of spatial planning, a “water test” must prevent the gradual decrease in the space allocated to water caused by land-use, infrastructure, housing and other projects. For the Rhine branches, a study has been conducted focusing on water storage areas or dike relocation based on a possible future design discharge of 18,000 m<sup>3</sup>/sec. Subsequently, a study has been initiated on the pros and cons of so-called “emergency storage polders” in order to cope with discharges even higher than 18,000 m<sup>3</sup>/s.

- 5) Knowledge; the new water management approach imposes new demands on the coordination and distribution of knowledge and on education relating to water and river management.
- 6) Responsibilities; the government, provincial authorities, water boards and municipal authorities are all responsible for ensuring safety and limiting water-related problems. Administrative agreements about the division of tasks and co-operation must ensure rapid and effective implementation of measures. A review has been conducted to assess the suitability of the relevant present legislation for a rapid implementation of “room for the river” projects and to see if this legislation needs to be adapted.
- 7) Investments; developments in terms of climatic change and land subsidence, as well as the new approach, require repeated additional investments in both the national and regional water management systems.
- 8) International co-operation; international co-operation on flood protection and water management must be intensified.

As regards the latter point, considerable efforts have been invested and clear results have been obtained. In particular, the co-operation within the International Commission on the Protection of the river Rhine and the political agreement on a mutual approach between the German NordRhein-Westphalen region and the Dutch province of Gelderland and the Directorate-General of Public Works and Water Management deserve to be mentioned here. This agreement was prolonged for another five years by the respective governments on 23 May 2002. Although the specific measures on both sides of the German-Dutch border may differ in character, (such as that the new dikes to be constructed in Germany are one meter higher than required by Dutch standards), the exchange of information, knowledge and views has led to an open and fruitful co-operation. Thus, a cross-border decision support system is under development and the respective dike design concepts and parameters are being compared and attuned. This co-operation has also led to a computer-assisted model for improved calamity management (Anonymous 2001a). Furthermore, a bilingual magazine is issued periodically to inform the public of the progress being made. During the successful cross-border conference in November 2001 in Nijmegen, The Netherlands (Smits et al. 2002), civilians, young people and scientists worked together in developing proposals for improved flood protection awareness.

In the context of the International Commission on the Protection of the Rhine river (ICBR) a so-called “Rhine Atlas” was published (Anonymous 1998). This is a collection of maps showing the potential damage that would result if a breach of the dikes should occur along the river Rhine. The purpose of this “atlas” is to increase the awareness of decision-makers involved in spatial planning, flood management and water management. The total amount of potential damage was found to add up to 100 billion US dollars for the entire catchment area of the river Rhine, including 80 billion US dollars for the Dutch section.

In the above list, point 2 (three-step-strategy) is of particular interest because it extends beyond the borders of The Netherlands and can be applied to small and large stream corridors, even to the level of entire river basins. In fact, other Rhine and Meuse riparian states have already adopted similar concepts. The innovative character of the new approach lies in the way this three-step strategy is implemented. In contrast to the traditional approach, which primarily involved engineering measures (such as dikes, sluices, weirs and dams), solutions are now preferably sought in restoring the natural hydromorphological processes of stream corridors, expanding the floodplains with previously reclaimed land and adapting user functions. The following section illustrates this new approach with some practical examples related to small rivulets (catchment area) and sections of the rivers Rhine and Meuse.

## **5. IMPLEMENTING THE THREE-STEP STRATEGY**

### **5.1 Catchments Area: Retaining Water by Restoring the Hydromorphodynamics of Rivulets**

Although water boards and river managers have acquired great expertise in regulating rivulets and rivers, they have little experience in reversing this process without increasing flood risks and adversely affecting the waterway (in terms of navigation). Recently, there have been attempts to restore the dynamic hydromorphology of small streams and rivulets at several locations in the catchment area of the Rhine and Meuse (Nijland and Cals 2001). Harnessing structures have been removed from the banks and in some cases wooden constructions or tree trunks have been deliberately placed in the stream to increase the hydromorphodynamics. While at first, these experiments merely aimed to improve biodiversity by restoring the morphological diversity of the hydrosystem, a morphologically diverse hydrosystem with riparian vegetation also retains water in the catchment area. Moreover, it provides better conditions for the replenishment of groundwater supplies and bed load, reducing riverbed erosion (In contrast to some river systems, the Rhine is a sediment-poor hydrosystem.). These advantages are lacking with the traditional methods of retaining water (by means of sluices and small dams). At present, numerous projects are being carried out in the Rhine and Meuse basins to stimulate the interaction between water flow and sediment (hydromorphological processes), with financial support from the European Union and various ministries of the Rhine and Meuse riparian countries.

### **5.2 Upstream Aand Midstream River Sections: Temporarily Storing Water and Delaying Run-Off**

In the midstream and lower parts of the river basin –especially in The Netherlands– discharges of inflowing rivulets river branches should be preferably fine-tuned in time and add up to the expected discharge of the main stream. In addition to water retainment in the upper parts of the river basin as described in the previous section, water should be stored temporarily in the rivulet systems themselves or, for instance, in medium-scale retention areas.

Another example of retention by habitat rehabilitation instead of building dams, but on a larger scale, is to be found along the so-called “Grensmaas”, the section of the river Meuse which forms part of the border between Belgium and The Netherlands (Leussen et al. 2000). This river section is being transformed into a natural riverbed, which functions as a natural retention area. Modified gravel extraction is used to widen the floodplains, and an attempt is made to restore the original hydromorphological processes. Navigation is limited to an existing shipping canal parallel to this river section. The “Grensmaas” project is a joint Dutch-Belgian undertaking.

In the lower parts of The Netherlands, polders allow people to live safely along the main rivers. As we have seen, water boards play an important role in water management and flood defense in these areas. Apart from dike surveillance and maintenance, water boards strive to create more room for water storage by pumping water from the polder into the river system. This strategy is used to cope with periods of heavy precipitation. Besides measures along the rivulets and mid-sized rivers, the respective catchment areas offer opportunities for retaining or temporarily storing water. These opportunities frequently have serious impacts on present zoning schemes for new housing activities or industrial estates. Municipal authorities have the final responsibility for these schemes, whereas regional or national governments have limited powers in this regard. Therefore, the water boards have intensified their communication with municipal and regional authorities to induce them to adapt physical plans. A so-called *water test* is being added to the present legislation to

examine the future effects of proposed zoning schemes in terms of water and flood management standards (Anonymous 2001).



**Fig. 2** Examples of experiments aimed at inducing hydromorphodynamics in formerly regulated streams. Top photograph; In order to stimulate the interaction between water flow and sediment, tree trunks are fixed in the bank of a rivulet ("Sandbach" Iffezheim, Germany) or wood debris is deliberately Left in a stream ("Geul", Maastricht, The Netherlands; next photograph). In both cases, the channel becomes shallower and wider, and the water discharge decelerates.

### 5.3 Increasing the Water Discharge Capacity of The Main Stream

Land reclamation has severely reduced the original floodplain areas of both Rhine (Havinga and Smits 2000) and Meuse (Van Leussen et al. 2000). At some locations, the riverbed has become extremely constricted due to urban developments (“hydraulic bottlenecks”). From this perspective, measures that increase the storage capacity of the riverbed are now preferred to raising dikes (Anonymous 2000).

Further downstream of the Rhine tributaries, proposed measures concentrate on creating more room for the river by moving dikes further inland (as happens, e.g., near the cities of Nijmegen and Arnhem), lowering floodplains and removing hydraulic obstacles from them. Van Alphen (2002) describes the study and decision process regarding the hydraulic bottleneck in the river Rhine near Nijmegen.

A number of possibilities can be identified for creating more room for the river –increasing the river’s cross section or water discharge capacity–, ranging from (a) moving dikes further inland, (b) constructing river bypasses, (c) lowering groins, (d) dredging the riverbed in sections of the river where sedimentation occurs, (e) removing obstacles such as non-flooding areas in the floodplain, summer embankments or ferry ramps, (f) lowering floodplains, for instance by digging secondary channels, frequently combined with land-use changes from agriculture to habitat restoration and recreation (Pruijssen 1999). Fig. 3 provides a schematic overview of the various types of measures, roughly ranked in order of decreasing efficiency.

Close co-operation with water boards, governmental agencies, municipal and regional authorities, institutes, universities, non-governmental bodies and interested civilians has yielded an inventory of large numbers of options for measures along the branches of the river Rhine in the Dutch part of the basin. These options have been screened and collected in a so-called “toolbox”, a user-friendly decision support system which enables the river manager to design combinations of measures along a river section to meet the desired increase in water discharge capacity. Apart from the net hydraulic effect of each combination of measures, the toolbox also estimates the total costs and environmental effects. This tool has proved to be very powerful, not only in planning measures but also in communicating with the people and authorities involved.

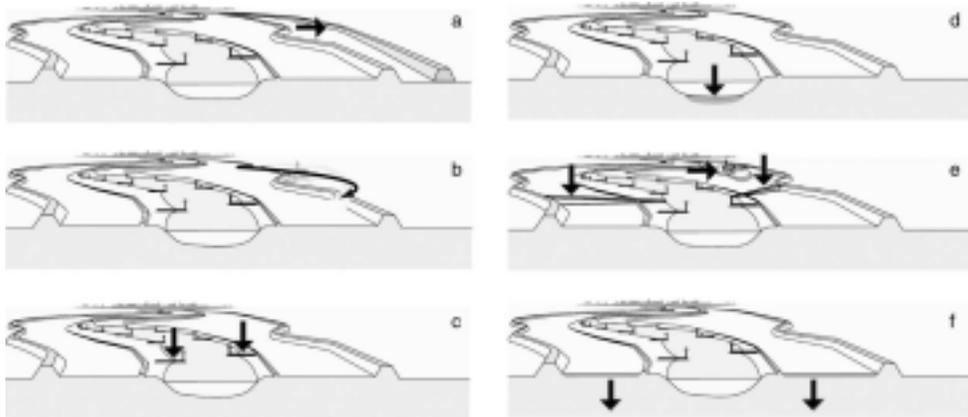
In parallel to the planning and design processes, quite a number of projects along the Rhine branches have been carried in recent years. The *Bakenhof* project –moving dikes further inland near Arnhem–, the reconstruction of the weir island near *Driel* and the replacement of the railway embankment near *Oosterbeek* will be addressed in the keynote speech of this conference.

For the next decade, the Dutch government has set aside about 3 billion US dollars for “room for the river” projects. Additional funds will be made available in due course for the construction of so-called emergency storage polders in the upper part of the Dutch section of the river Rhine and for long-term measures relating to design discharges of 18,000 m<sup>3</sup>/sec. Because high water discharges and near floods are erratic, it is crucial that the administrators make efforts to prevent flood awareness among the public from fading.

## 6. FOCAL POINTS FOR THE FUTURE

Following the high-water situations in 1993 and 1995, the international co-operation in flood defense has gained momentum. Public opinion, which was extremely critical of dike reinforcements in the preceding decade, changed totally into public support for a rapid dike reinforcement program. Local and regional authorities developed a renewed awareness of flood protection issues, which had almost disappeared after the last serious high discharge situation in 1926. The government is now using various means to stimulate awareness and

keep citizens alert, providing a basis for generating sufficient public support for the implementation of the new approach to flood defenses, land use and water management. In this respect, the government can probably learn from past experiences in major international projects (such as road and railway construction projects) which also involved changes in land use.



**Fig. 3** Overview of measures aimed at increasing water discharge capacity, roughly ranked in order of decreasing efficiency (a-f).

### 6.1 International Cooperation

Authorities of the Rhine and Meuse riparian states have become aware that sustainable flood defense can only be achieved when the entire catchment area is taken into consideration. The formulation of flood action programs for the Rhine and Meuse catchment areas was the direct result of the declarations of Arles and Strasbourg (Anonymous 1998), and was accomplished for the Rhine through the actions of the treaty participants in the International Commission for the Protection of the Rhine (ICBR). The “Rhine Action Program on Flood Defense” was approved at the 12th conference of Rhine Ministers, held in Rotterdam, The Netherlands (Noteboom 1998). It proved politically impossible to co-ordinate the formulation of an action plan within the the Commission for the Protection of the Meuse. Accordingly, a Flood Defense Task Force for the Meuse was established, whose function is similar to that of the International Committee for the Protection of the Rhine against Pollution (ICR). The “Meuse High Water Action Plan” was established by the Dutch and Belgian ministers in Namurs, Belgium, in 1998 (Anonymous 1998a). The European Union supported the implementation of these plans with the formulation of the INTERREG IIc program (IRMA) during 1997-2001. The objectives of the Rhine Action Plan on Flood Defense are: (a) reducing the damage risks by 10 % by the year 2005 and by 25% by the year 2020; (b) reducing extreme floods downstream caused by the regulated section of the upper Rhine, aiming at a reduction by 30 cm in 2005 and by 70 cm in 2020; (c) increasing public awareness of flood risks; and (d) improving the flood warning system.

The Meuse High Water Action plan is in all respects less ambitious and concrete than the plan for the Rhine, quantifying neither concrete objectives nor concrete measures. In addition, no estimate of the investment required is provided. Nevertheless, the plan does embrace a number of basic strategic principles that also form part of the plan for the Rhine: (a) increasing awareness and developing an approach to the risks, (b) employing the three-step-strategy approach of retaining, storing and draining water, (c) expanding space for the Meuse and its tributaries; and (d) improving the prediction and warning systems.

## **6.2 Funding**

It is unrealistic to assume that the governments of the Rhine and Meuse riparian countries will finance all the required measures and activities to achieve sustainable flood defense. Therefore, new economic incentives have to be found to facilitate these changes. For example, recreation in habitat rehabilitation areas may provide alternatives for the agricultural sector. In The Netherlands, agricultural production has become so efficient that this sector is suffering from over-production. Therefore, it is expected that a considerable area of the present farmland will become available for other spatial user functions within two decades (Anonymous 2001).

A particular focal point for the future is that of finding additional sources via public-private enterprises. At present some projects (e.g. the “Grensmaas” project) combine gravel and sand production with floodplain lowering and/or widening. The preliminary results demonstrate that public-private enterprises related to gravel and sand extraction are complex and difficult to put in to practice. More efforts by the government as well as private enterprises have to be made in the near future to improve this co-operation.

Another economic driving force can be found in the construction and selling of houses. In The Netherlands, living near riverbeds is becoming increasingly attractive because of habitat rehabilitation projects and recreational opportunities. Up to now, the Dutch government has been extremely cautious about housing projects near riverbeds, to prevent further reduction of floodplain areas by urban development. However, private enterprises have recently suggested some interesting ideas combining “adapted” urban planning with moving dikes further inland and the excavation of side channels. Finding a good balance between a sustainable flood defense strategy and the quality objectives of spatial planning will be a challenging task for the Dutch government in the present era.

## **6.3 Knowledge**

Last but not least, the knowledge infrastructure relating to water management and sustainable flood defense needs to be improved. The interaction between governmental institutions, universities and other educational institutions should be intensified. New insights must be more rapidly incorporated in educational programs, as must new scientific questions relating to this issue. In the near future, difficult choices will have to be made with respect to land use, if we wish to achieve sustainable flood protection. Without a proper understanding among citizens of the functioning of hydrosystems and what is required to restore the resilience of river basins, there will be insufficient support for “difficult” decisions (e.g. changing land use, moving dikes further inland, etc.). It is the government’s task to ensure proper education on this subject at schools, universities and among the general public. For instance, technical curricula should focus more on how to manage dynamic river systems without bridling the hydrosystem so much that it loses its resilience. In practice, this means that engineers should focus more on an understanding of hydromorphological processes and how to adapt various user functions to the natural dynamics of hydrosystems. Some suggestions for this have already been discussed by Smits et al. (2000). Non-technical curricula should focus on the public perception of risks, land-use changes and economic mechanisms and processes which can accelerate the implementation of the new approach to flood defense.

## **7. CONCLUDING REMARKS**

The high water discharges of the rivers Rhine and Meuse in 1993, 1995 and 1998 –the highest since 1926– caused a considerable change in governmental policy, public awareness and international co-operation in terms of flood protection and inland water management. A rapid dike reinforcement program was introduced; existing water discharge capacity was

protected by legislation, leading to a restrictive policy on land-use functions; the concept of “room for the river” and a corresponding program were developed, aiming at a long-term increase in the rivers’ water discharge capacity; international co-operation on measures, public awareness and early-warning systems was intensified; and a calamity approach using emergency storage polders was initiated. Flood protection measures between and outside the dikes are being anchored in physical planning and relevant policies. This new policy and flood protection approach have raised quite a number of new questions and issues on floods, water and land management, which will have to be answered and addressed in the near future. This will give rise to an extensive scientific agenda and will initiate global scientific co-operation aimed at dispersion and development of knowledge.

The need for innovation of flood defenses and water management in general appears to be widely accepted in The Netherlands. However, much more is required, as was recently stated by the junior minister for Transport, Public Works and Water Management: “It will demand creativity, energy, time and money. Protecting The Netherlands from floods will require repeated investments over a long period of time” (Anonymous 2000).

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