Water International

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rwin20

Flood Defense in The Netherlands

Hein T.C. van Stokkom [a] , Antonius J.M. Smits [b] & Rob S.E.W. Leuven [c]

[a] Ministry of Transport, Public Works and Water Management, Arnhem, The Netherlands

[b] Radboud University Nijmegen and Erasmus University of Rotterdam, Netherlands

[c] Institute for Wetland and Water Research, Radboud University Nijmegen, The Netherlands

Available online: 22 Jan 2009

To cite this article: Hein T.C. van Stokkom, Antonius J.M. Smits & Rob S.E.W. Leuven (2005): Flood Defense in The Netherlands, Water International, 30:1, 76-87

To link to this article: http://dx.doi.org/10.1080/02508060508691839

International Water Resources Association
Water International, Volume 30, Number 1, Pages 76–87, March 2005

Flood Defense in The Netherlands

A New Era, a New Approach

Hein T.C. van Stokkom, *Ministry of Transport, Public Works and Water Management, Arnhem, The Netherlands,* **Antonius J.M. Smits**, *Radboud University Nijmegen and Erasmus University of Rotterdam, The Netherlands, and* **Rob S.E.W. Leuven**, *Institute for Wetland and Water Research, Radboud University Nijmegen, The Netherlands*

Abstract*: Intensive land use and far-reaching regulation of the fluvial hydrosystem 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 high water discharges of the rivers Rhine and Meuse in 1993, 1995, and 1998 caused a considerable change in governmental policy, public awareness, and international cooperation in terms of flood protection and inland water management. The Dutch government 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 restructuring 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*

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. Figure 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 percent 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 percent 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 sometimes led to controversial management measures regarding public interest on national level. Since 1798, the overall responsibility and coordination of water management in the Netherlands has been a task of the national government (Van de Ven, 1976), and the Directorate-General of Public Works and Water Management was created to fulfill this task.

The spectacular technological developments of the past century allowed far-reaching alterations to be introduced to the hydrosystem in the Rhine and Meuse river

Figure 1. The Rhine and Meuse basins with surface areas of 185,000 km^2 and 36,000 km^2, respectively. The source-mouth lengths of the rivers Rhine and Meuse are 1,320 and 935 km, respectively. For extensive data on hydrology, water quality and land use see Middelkoop and Van Haselen (1999)

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 embanking of floodplains augmented this problem (Dister et al., 1990). For instance, the length of the river Meuse downstream of Grave, the Netherlands 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. 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 Secretary of State 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, 2000a).

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, 1998a), and the countries of the Meuse river basin are expected to follow soon.

Flood Defense Standards: 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 US$ 1 billion. As a result, the Dutch government adopted a policy aimed at minimizing the potential damage, raising public awareness, 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 Delta Plan for Large Rivers (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, Figure 1) have been taken since the year 1901. First, 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 20th 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: 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 set forth 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 1/1,250 per year. In other words, the probability that the river water will rise above the design water level must not be higher than 1/1,250 in one year. In the western part of the country, safety norms are significantly higher, for instance 1/2,000 up to 1/10,000 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^3/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 (Silva et al., 2001). The design discharge is set at the upstream boundary of the model at Lobith. The model then calculates the discharge across the three Rhine branches and the corresponding water levels.

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 (Figure 2). Taking the effects of climate change

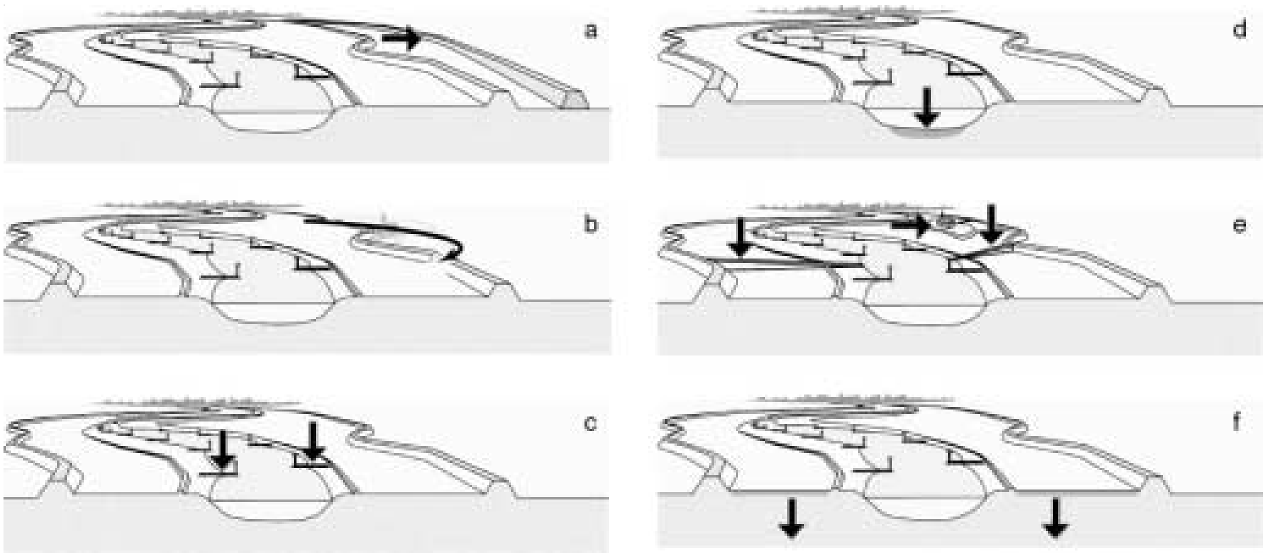

Figure 2. Overview of measures aimed at increasing water discharge capacity, roughly ranked in order of decreasing efficiency: (a) moving dikes further inland, (b) constructing river bypasses, (c) lowering groins, (d) dredging the riverbed in sections of the river where sedimentation occurs, (e) removing obstacles such as non-flooding areas in the floodplain, summer embankments or ferry ramps, (f) lowering floodplains, for instance by digging side channels, frequently combined with land-use changes from agriculture to habitat restoration and recreation

Table 1. Evaluation of flood defense projects executed within the framework of the INTERREG Rhine Meuse Activities (IRMA) program (Van Rooij and Van Wezel, 2003)

Project	*Transnational cooperation*	*Effect on water discharge*	*Effects on landscape quality*	*Public participation*	*Degree of innovation*
Rhine River					
Restoration of river confluences Kinzig and Schutter (G)	+	+	++	+	+
Restoration of Rhine meanders and floodplains along the Rhine river section Kunheim and Marckolsheim (F)	+	+	++	0	++
Infiltration of rainwater in urban area of Neuenberg am Rhein (G)	0	0*	+	++	0
Realization and management of retention areas along the Rems River (G)	+	+	+	++	+
Infiltration of rainwater in rural area of Massenbachhausen (G)	+	+	+	+	++
Dike relocation Worms-Bürgerweide (G)	++	++	++	+	+
Realization of retention areas along the Alzette River (L)	+	+	++	0	+
Floodplain rehabilitation (Klompenwaard) with construction of side channels (NL)	+	++	++	+	+
River dike relocation, creation of side channel and floodplain lowering location Bakenhof along Nederrijn River (NL)[1]	+	+	++	+	+
Adaptation of railway abutment in floodplain at Rosandepolder along Nederrijn River (NL)[1]	+	++	0	++	++
Meuse River					
Demonstration projects focused on widening of floodplains along the Meuse (border B-NL)	++	+	+	+	++
Reconstruction of weirs and dredging of river bed of the Haute Meuse (B)	++	+	0	0	+
Slow down of rainwater run-off by reforestation and revitalization of rivulets in the Ruhr River catchment (G)	++	++	+	++	+

B: Belgium; F: France; G: Germany; L: Luxembourg NL: The Netherlands; 1: see also Table 2; *: requires up scaling

(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 in the hinterland. 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 (Anonymous, 1998a). The INTERREG Rhine Meuse Activities (IRMA) program of the European Commission has provided additional funding to implement these projects (Table 1; Van Rooij and Van Wezel, 2003).

Studies carried out in the Netherlands during the period 1995 to 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" [RVR]" 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) (Anonymous, 2000b; 2000c; Van Leussen et al., 2000; Silva et al., 2001). All of these studies have made it clear that water management can no longer been 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, 2000a). 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, 2001a).

Climate Change and a New Approach to Water Management in the 21st Century

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 2100), a discharge increase at Lobith of 18,000 m^3/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^3/s. However, 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^3/s, which is the estimated discharge rate at which flooding can occur along the Lower Rhine (Silva et al., 2001).

For the last 1,000 years, sea water levels measured along the Dutch coast have become higher and higher. This is not solely caused by the sea level rise, but also by subsiding coastal areas. 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).

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 US$ 2 trillion annually) is generated domestically (Anonymous, 2000a). However, climate change increases the likelihood of floods and other water-related problems (e.g. droughts and rising sea level). In addition, the population density continues to grow, as do the potential of the economy and, consequently, the vulnerability of the economy and society to flood and drought disasters. These 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 equals probability of flooding multiplied by flood damage). In 1999, the Secretary of State for Transport, Public Works and Water Management and the president of the Union of Water Boards established the Advisory Committee on Water Management in the 21st Century (Anonymous, 2000a). This Committee was charged with developing recommendations for desirable changes to the water management policy in our country, focusing on the consequences of other water-related problems such as 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 (mainly flood risk management) and to reduce the other water-related problems in the 21st century. This approach comprises:

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 prevent-

ing non-river-linked human activities (such as housing and industrial estates) in the floodplains and by adapting municipal zoning schemes. Furthermore, within the context of spatial planning, a so-called "water test" is being added to the present legislation. This test must examine the future effects of proposed zoning schemes on water systems and prevent the gradual decrease in the space allocated to water caused by land-use, infrastructure, housing and other projects (Anonymous, 2001a). 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^3/s (Project Group Resilience Study, 2002). Subsequently, a study has been initiated on the pros and cons of so-called "emergency storage areas" (Figure 5) in order to cope with discharges even higher than 18,000 m^3/s or potential dike breaches (Commission Luteijn, 2002).

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 (e.g. including new insights in social studies, spatial planning and public administration).
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 cooperation 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 cooperation; international cooperation on flood protection and water management must be intensified.

Regarding the last point, considerable efforts have been invested and clear results have been obtained. In particular, the cooperation within the International Commission on the Protection of the river Rhine (ICPR) and the political agreement on a mutual approach between the German Nordrhein-Westfalen 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 May 23, 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, 2001b). 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., 2003), civilians, young people, and scientists worked together in developing proposals for improved flood protection awareness.

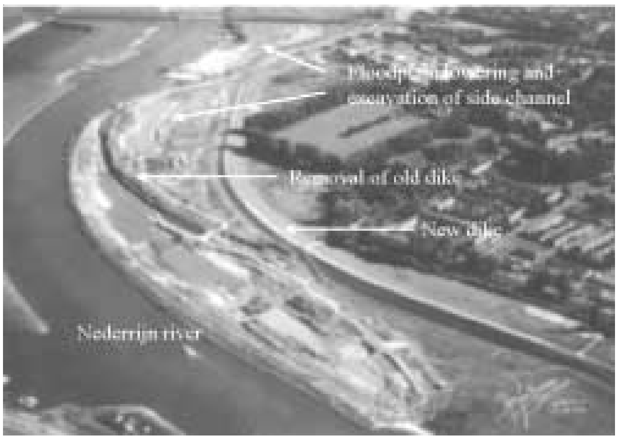

Figure 3. River dike relocation, creation of side channel, and floodplain lowering in Bakenhof along the Nederrijn river at Arnhem. For details on the efficiency of this project see Tables 1 and 2

In the context of the ICPR a so-called "Rhine Atlas" was published (Anonymous, 1998a). 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 "Rhine 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 US$ 80 billion for the Dutch section.

In the above list, the second point (three-step-strategy: retaining, storing and draining) 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 (Hooijer et al., 2002; Van Rooij and Van Wezel, 2003). Because the catchment areas of these two rivers are located in more than one country, flood control inevitably became a matter of co-operation between the relevant authorities. Flanders, France, Germany, Luxembourg, the Netherlands, and Wallonia submitted a joint flood control program to the European Commission within the framework of its INTERREG II-C initiative. This INTERREG Rhine-Meuse Activities (IRMA) program was approved on December 18, 1997. Besides the European Union member states mentioned, Switzerland was also participating in this program on a project basis. The main objective of the IRMA program was to prevent damage caused by floods for all living creatures in and important functions of the catchment area of the rivers, and therefore create a balance between the activities of the population in the areas, the socio-economic developments and sustainable management of the natural resource water.

The program has been completed at the beginning of 2003. During the six-year period of IRMA (1997-2003), almost 153 projects were carried out in the catchment area of the Meuse and Rhine (Van Rooij and Van Wezel, 2003). Table 1 gives examples of innovative flood management measures and evaluates the efficiency, transnational cooperation, and public participation of some representative IRMA projects in various parts of the Rhine and Meuse basin.

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.

Implementing the Three-step Strategy

Catchment Area: Retaining Water by Restoring 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 (Figure 4). 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, several projects are being carried out in the Rhine catchment (e.g. Alzette rivulet) and Meuse catchment (e.g. Niers rivulet) 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 (Van Rooij and Van Wezel, 2003).

Midstream and Lower River Sections: Temporarily Storing Water and Delaying Runoff

In the midstream and lower parts of the river basin – especially in the Netherlands – discharges of inflowing rivulets 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 such as at Noord-

Figure 4. Examples of small-scale experiments aimed at inducing hydromorphodynamics in formerly regulated streams. Left photograph; in order to stimulate the interaction between water flow and sediment, tree trunks are fixed in the bank of a rivulet (left photograph; "Sandbach" Iffezheim, Germany) or wood debris is deliberately left in a stream (right photograph; 'Geul", Maastricht, the Netherlands). In both cases, the channel becomes shallower and wider, and the water discharge decelerates

and Zuid Meene along the Vecht rivulet (4.25 10^6 m^3), landed estates along the Regge and Dinkel rivulets (0.17 10^6 m^3), Starkriet along the Aa rivulet (0.25 10^6 m^3), and Bossche Broek along the Dommel rivulet (8 10^6 m^3) (Van Rooij and Van Wezel, 2003). Retention and storage of water may also provide solutions to problems of extreme droughts (e.g. likelihood of extreme low water levels due to climate change).

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 (Van 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. There is no navigation on the "Grensmaas." It is limited to an existing shipping canal parallel to this river section. The "Grensmaas" project is a joint Dutch-Belgian undertaking (Van Rooij and Van Wezel, 2003).

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 river (Van Leussen et al., 2000). At some locations, the riverbed has become extremely constricted due to urban developments (so-called "hydraulic bottlenecks") (Van Alphen, 2002). From this perspective, measures that increase the storage capacity of the riverbed are now preferred to raising dikes (Anonymous, 2000a). Thus, downstream of the Rhine tributaries, proposed measures concentrate on creating more room for the river. A number of possibilities can be identified for creating more room for the river to increase the cross section or the water discharge capacity of the river (Figure 2). These measures range 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 hydraulic obstacles such as non-flooding areas in the floodplain, summer embankments, bridge abutments, or ferry ramps; and (f) lowering floodplains, for instance by digging side channels, frequently combined with land-use changes from agriculture to habitat restoration and recreation (Pruijssen, 1999; Nijland and Cals, 2001; Buijse et al. 2002; Nienhuis et al., 2002).

Close cooperation 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 (Silva et al., 2001). These options have been screened and collected in a so-called "toolbox," a user-friendly decision support system that enables the river manager or stakeholders to design combinations of measures along a river section to meet the desired increase in water discharge capacity (Van Schijndel, 2003). The user can also choose how to divide extra discharge at Lobith over the various Rhine branches in the Netherlands. Apart from the net hydraulic effect of each combination of measures, the toolbox estimates the total costs and environmental effects. It also contains a selection of aerial and ground pictures of most of the measures. When the user has defined the total set of measures the toolbox produces a summarized report on all the effects. This tool has proved to be very powerful, not only in the development of alternative strategies and planning measures but also in communicating with the people and authorities involved. It gives various stakeholders the opportunity to evaluate their vision on the design of the Rhine delta. By using this toolbox the efficiency of the measures A through F in Figure 2 could be ranked roughly (Silva et al., 2001). For instance, all options for setting back dikes (300 to 600 m over a length of 1 to 5 km) cost less than US$ 0.63 million per mm water level reduction. Groin height reduction can contribute to a decrease in the water level in the Waal end IJssel river varying from 5 to 15 cm. On the Nederrijn, this is a maximum of 10 cm. The costs of groin height reduction are relatively low and the efficiency of this measure is intermediate. On average, the removal of 60 bottlenecks can reduce the water level on the Waal and Nerderrijn/IJssel river some 20 cm and 10 cm, respectively. The costs of widening and deepening the bridge abutments and the removal of ferry ramps vary from less than US$ 2.5 million to more than US$ 75 million for a highway bridge. The costs of excavation embankments and small-scale setting back of dikes are usually in the order of US$ 5 million per project, but it can run up to over US$ 20 million if many homes must be relocated.

In parallel to the planning and design processes, quite a number of projects along the Rhine branches in the Netherlands have already been carried in recent years. Figure 3 shows an innovative "room for rivers" project that combines river dike relocation, creation of side channel and floodplain lowering. Table 2 gives estimations of the costs and effectiveness of some projects. For the next decade, the Dutch government has set aside about US$ 3 billion 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 Rhine river (Figure 5) and for long-term measures relating to design discharges of 18,000 m^3/sec.

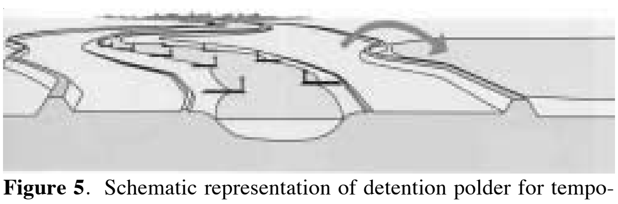

Figure 5. Schematic representation of detention polder for temporary or emergency storage of river water in the hinterland

Table 2. Estimated costs and effects on water level of innovative projects to reduce flood risks along the Rhine River branches in the Netherlands

Project	*Type of measure*	*Effects on water level at design discharge(- cm)*	*Estimated costs (10^6 US$)*
Nederrijn River			
Bakenhof floodplain in Arnhem	Dike relocation (1400 m set back ca. 200 m), creation of side channel and floodplain lowering	7	9.6
Weir at Driel	Lowering of weir isle and construction of fish passage	8	8.8
Rosande polder near Oosterbeek	Modification abutment of railway bridge	10	62.5
Waal River			
Hydraulic 'bottle neck' at Nijmegen	Relocation of homes, dike relocation (1500 m set back max. 350 m) and creation of side channel	45	281.3
Afferdensche and Deestsche Waarden	Floodplain lowering and creation of side channel in combination with ecological rehabilitation	8	15.0

Focal Points for the Future

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. Following the high-water situations in 1993, 1995, and 1998, the national and international co-operation in flood defense has gained momentum. Public opinion, which was extremely critical regarding 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. 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 national and international projects (such as road and railway construction projects), which also involved changes in land use. In order to keep public awareness at a high level, the municipalities must be supported in the realization of hazard maps, emergency services and information material by superior authorities (Böhm et al., 2001). A key role for success of event management is communication, which therefore must be very well prepared and checked regularly.

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, 1998a), and was accomplished for the Rhine through the actions of the treaty participants in the ICPR. The "Rhine Action Program on Flood Defense" was approved at the 12th conference of Rhine Ministers, held in Rotterdam, the Netherlands (Noteboom, 1998). The objectives of this plan are: (a) reducing the damage risks by 10 percent by the year 2005 and by 25 percent 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. Until this point, it proved politically impossible to coordinate the formulation of an action plan within 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 ICPR. The "Meuse High Water Action Plan" was established by the Belgian, Dutch and French ministers in Namurs (Belgium) in 1998 (Anonymous, 1998b). 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.

The European Union supported the implementation of the flood action programs for the Rhine and Meuse catchment with the formulation of the abovementioned IRMA program during1997 to 2001. This program has stimulated international co-operation and building of networks between planners, managers and research groups (Hooijer et al., 2002; Van Rooij and Van Wezel, 2003). It is recommended that these networks should be kept active, extended and exploited further. Certainly, international co-operation requires transboundary understanding, and this is only possible if all parties concerned are not cooperating on an ad-hoc basis, but within long-term international and interdisciplinary networks.

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, strategies for budget funding and new economic incentives have to be found to facilitate these changes. Böhm et al. (2001) recommended a fundamental change in financing of flood protection towards burden compensation between regions and incentives for acting regions or municipalities.

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 make in the near future to improve this cooperation.

Another economic driving force for flood defense measures can be found in the construction and selling of houses. In the Netherlands, living near the riverside is becoming increasingly attractive because of scenery and recreational opportunities. Private enterprises have recently suggested some interesting ideas combining "adapted" urban planning with floating villages and with moving dikes further inland. People are willing to pay high prices for (floating) houses near the riverside and may financially contribute to innovative flood defense measures. However, 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. Finding a good balance between a sustainable flood defense strategy and the quality objectives of multiple spatial planning will be a challenging task for the Dutch government in the present era.

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. For instance, the Netherlands Center for River Studies (NCR) is an example of a fruitful collaboration of major developers and users of expertise on river science and management (Leuven et al., 2003). In 1999 NCR has been asked to manage a large research umbrella project in the framework of the Interregional Rhine Meuse Activities of the European Union (IRMA-SPONGE). In this project more than 30 scientific, governmental, and educational institutes from six European countries (The Netherlands, Germany, France, Belgium, Luxembourg and Switzerland) cooperate to improve the flood forecasting and prevention possibilities in the Rhine and Meuse catchment areas (Hooijer et al., 2002). The overall aim was defined as "The development of methodologies and tools to assess the impact of flood risk reduction measures and scenarios. This to support the spatial planning process in establishing alternative strategies for an optimal realization of the hydraulic, economical and ecological functions of the Rhine and Meuse River Basins." The main objectives of IRMA-SPONGE were to enhance the level of scientific input to flood management and to promote transboundary scientific co-operation.

It is the government's task to ensure proper education on this subject at schools, universities, and the general public. 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.). Technical curricula should focus more on how to manage dynamic river systems without bridling the hydrosystem so much that it loses its resilience (Smits et al., 2000). 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. Non-technical curricula should focus on multiple uses of space for water, public perception of flood risks and land-use changes, methods to assess societal support of management measures in advance, and economic mechanisms and processes, which can accelerate the implementation of the new approach to flood defense.

Acknowledgements

The authors would like to thank J.P.G. van de Kamer, R. Postma, J.S.L.J. van Alphen (Ministry of Transport, Public Works and Water Management), and W. Silva (Institute for Inland Water Management and Waste Water Treatment - RIZA, Ministry of Transport, Public Works and Water Management) for critically reading the manuscript. J. Klerkx was responsible for language editing.

About the Authors

Ir. Hein T.C. van Stokkom was regional managing director of Rijkswaterstaat (Ministry of Transport, Water Management and Public Works) in the eastern part of the Netherlands. He was responsible for the river and water management of the upstream sections of the Rhine tributaries and canals located in this part of the country. The task of river management comprises flood management, guidance of shipping traffic, and water quality management. Over the past years he has been actively involved in the development of a new flood management strategy in the Netherlands, which emphasizes the importance of cooperation between stakeholders and enhanced public involvement. Furthermore, he is a member of the supervisory board of the water management related professorial chairs at the Radboud University Nijmegen and the Erasmus University of Rotterdam, The Netherlands. He currently works as general director with the regional Waterboard Brabantse Delta in Breda, The Netherlands. E-mail: h.van.stokkom@brabantsedelta.nl.

Professor Dr. Antonius J.M. Smits teaches and carries out research related to sustainable river and water management at the Radboud University Nijmegen and the Erasmus University, Rotterdam (both in the Netherlands). The professorial chair at the Radboud University Nijmegen focuses on environmental and ecological aspects, while the chair at the Erasmus University is directed at the socio-economic aspects of sustainable water management. He has had over ten years practical experience related to water management at the Ministry of Transport, Public Works and Water Management (The Netherlands) where he held various positions in this field. Within this ministry he is still active as adviser "Integrated Water Management." Email: a.smits@sci.ru.nl.

Dr. Rob S.E.W. Leuven is associate professor at the Department of Environmental Studies and chair of the Examination Board for Environmental Education at the Faculty of Science, Mathematics and Computing Science of the Radboud University Nijmegen (The Netherlands). His research and teaching activities focuses on concepts for sustainable water management and ecological rehabilitation of river basins. He was project leader of research commissioned by the European Commission (Interregional Rhine Meuse Activities), Partners for Water Program, the Dutch Ministry of Housing, Spatial Planning and Environment, the Dutch Ministry of Transport, Public Works and Water Management (Directorate General Water Management), several advisory boards and non-governmental organizations. E-mail: r.leuven@sci.ru.nl.

Discussions open until August 1, 2005.

References

Anonymous. 1993. *Der Rhein unter der Einwirkung des Menschen – Ausbau, Schiffahrt, Wasserwirtschaft*. Koblenz: KHR-Arbeitsgruppe: Internationale Kommision zum Schutze des Rheins.

Anonymous. 1995. *Declaration of Arles on tackling the problems caused by the high water level of Rhine and Meuse*. Arles: Ministers of Environment of France, Germany, Luxembourg and The Netherlands.

Anonymous. 1998a. *Action Plan on Flood Defense*. Koblenz, Germany: International Commission for the Protection of the Rhine (ICPR).

Anonymous. 1998b. *Meuse High Water Action Plan*. Namur, Belgium: International Commission for the Protection of the Meuse.

Anonymous. 1999. *Fourth National Policy Document on Water Management*. The Hague, The Netherlands: Ministry of Transport, Public Works and Water Management.

Anonymous. 2000a. *A Different Approach to Water, Water Management Policy in the 21st Century*. The Hague, The Netherlands: Ministry of Transport, Public Works and Water Management.

Anonymous. 2000b. *Final Memorandum Water Management in the Wet Hart (WIN)*. The Hague, The Netherlands: Ministry of Transport, Public Works and Water Management.

Anonymous. 2000c. *Integrale Verkenning Benedenrivieren*. The Hague, The Netherlands: Stuurgroep Integrale Verkenning Benedenrivieren.

Anonymous. 2001a. *Making Space, Sharing Space; Fifth National Policy Document on Spatial Planning 2000-2020*. The Hague, The Netherlands: Ministry of Housing, Spatial Planning and the Environment.

Anonymous. 2001b. *Umsetzung des Aktionsplans Hochwasser bis 2000*. Koblenz, Germany: Internationale Kommision zum Schutze des Rheins (IKSR) (in German).

Böhm, H. R., P. Heiland, K. Dapp, and B. Haupter. 2001. *Spatial Planning and Supporting Instruments for Preventive Flood Management*. Report IRMA-SPONGE Project 5. Delft, The Netherlands: Netherlands Center for River Studies. (www.irma-sponge.org).

Buijse, A. D., H. Coops, M. Staras, L.H. Jans, G.J. van Geest, R.E. Grift, B.W. Ibelings, W. Oosterberg, and F.C.J.M. Roozen. 2002. "Restoration strategies for river floodplains along large lowland rivers in Europe." *Freshwater Biology* 47, No. 4: 889-907.

Commission Luteijn. 2002. *Final report Emergency Storage Polders*. The Hague, The Netherlands: Commission Emergency Storage Polders (in Dutch).

Dister, E., P. Obrdlik, and E. Schneider. 1990. "Water management and ecological perspectives of the Upper Rhine's floodplains." *Regulated Rivers* 5: 1-15.

Havinga, H. and A.J.M. Smits. 2000. "River management along the Rhine: a retrospective view." In Smits, A. J. M., Nienhuis, P. H., and Leuven, R. S. E. W., eds. *New approaches to River Management*. Leiden, The Netherlands: Backhuys Publishers. 15-32.

Huisman, P., W. Cramer, G. van Ee, J.C. Hooghart, H. Salz, and F.C. Zuidema. 1998. *Water in the Netherlands*. Delft, The Netherlands: Netherlands Hydrological Society.

Hooijer, A., F. Klijn, J. Kwadijk, and B. Pedroli. 2002. *IRMA-SPONGE, Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins, Main Results*. Report 18e-2002, Delft, The Netherlands: Netherlands Center for River Studies. (www.irma-sponge.org).

Leuven, R. S. E. W., A.G. van Os, and P.H. Nienhuis. 2003.

"Current themes in Dutch river research." *Proceedings NCR-days 2002*. NCR-publication 20-2003. Delft, Netherlands: Center for River Studies.

Middelkoop, H. and C.O.G. van Haselen. 1999. *Twice a river. Rhine and Meuse in The Netherlands*. Arnhem, The Netherlands: RIZA, Ministry of Transport, Public Works and Water Management.

Nienhuis P. H., A.D. Buijse, R.S.E.W. Leuven, A.J.M. Smits, R.J.W. de Nooij, and E.M. Samborska. 2002. "Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe)." *Hydrobiologia* 478, No. 1-3: 53-72.

Nijland, H. J. and M.J.R. Cals. 2001. *River Restoration in Europe; practical approaches*. The Netherlands: RIZA, Ministry of Transport, Public Works and Water Management.

Noteboom, S. 1998. *Rhine Conference in Rotterdam sets course for river.* The Hague, The Netherlands: Ministry of Transport, Public Works and Water Management. Official Press Release.

Olsthoorn, A. A. and R.S.J. Tol. 2001. *Floods, Flood Management and Climate Change in The Netherlands*. Amsterdam, The Netherlands: Institute for Environmental Studies.

Project Group Resilience Study, 2002. *Final report Resilience Study*. The Hague, The Netherlands: Project Group Resilience Study (in Dutch).

Pruijssen, H. 1999. *Working together with nature in the river regions*. The Netherlands: DLG, Ministry of Agriculture, Fisheries and Nature Management.

Silva, W., F. Klijn, and J. Dijkman. 2001. *Room for the Rhine branches in The Netherlands. What the research has taught us*. RIZA report 2001.031. Arnhem, The Netherlands: RIZA, Ministry of Transport, Public Works and Water Management.

Smits, A. J. M., H. Havinga, and E.C.L. Marteijn. L. 2000. "New concepts in river and water management in the Rhine river basin:How to live with the unexpected?" In Smits, A. J. M., Nienhuis, P. H., and Leuven, R. S. E. W., eds. *New approaches to River Management: New Approaches to River Management*. Leiden, The Netherlands: Backhuys Publishers. 267-286.

Smits, A. J. M., H.T.C. Van Stokkom, and J. Van de Wouw. 2003. *Hochwasser Verbindet*. Arnhem, The Netherlands.

Van Alphen, J. S. L. J. 2002. "How to eliminate a hydraulic bottleneck: Nijmegen, the first example in the Netherlands." *Second International Symposium on Flood Defense*. Beijing, China.

Van de Ven, G. P. 1976. *Aan de wieg van de Rijkswaterstaat: wordinggeschiedenis van het Pannerdens Kanaal*. Nijmegen, The Netherlands: University of Nijmegen (in Dutch).

Van Leussen, W., G. Kater, and P.P.M. van Meel. 2000. "Multilevel approach to flood control in the Dutch part of the river Meuse." In Smits, A. J. M., Nienhuis, P. H., and Leuven, R. S. E. W., eds. *New approaches to River Management*. Leiden, The Netherlands: Backhuys Publishers. 287-305.

Van Rooij, P., and H. Van Wezel. 2003. *Impending floods, united we stand! IRMA makes all the difference*. IRMA Program Secretary, The Hague, The Netherlands (www.irma-programme.org).

Van Schijndel, S. A. H. 2003. "The planning kit for the Resilience Study for the Rhine branches." In Leuven, R. S. E. W., van Os, A. G., and Nienhuis P. H. , eds. *Current themes in Dutch river research*. Proceedings NCR-days 2002: 66-67. NCR Publication 20-2003. Delft, Netherlands: Center for River Studies.