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Long term claims on the Dutch river area: handling climate change, safety, navigation and nature

R.M.J. Schielen
Ministry of Transport, Public Works and Water Management, Centre for Water Management, P.O. Box 17, 8200 AA Lelystad, The Netherlands, and
Twente University, Faculty of Engineering Technology, The Netherlands

H. Havinga
Ministry of Transport, Public Works and Water Management, Regional Directorate Eastern Netherlands
Delft University of Technology, Faculty of Civil Engineering, The Netherlands

ABSTRACT: The Netherlands have a long lasting history of water management. In the early days, water management mainly focused on safety against floodings, and many other elements such as nature development, recreation or housing were not concerned or just forbidden to take place in the floodplains. Nowadays, this no longer holds, and water management asks pre-eminently for an integrated approach. The Room for the River program is a good example. However, also for the mid and long term future (2050-2100), action is needed to keep the Netherlands a safe country in which people can live, work and recreate light-hearted. There are lots of developments which claims the river area. Not only is there a concern to mitigate possible effects of climate change (increasing river discharges and sea level rise), but also the European Framework Directive (aiming at a good ecological state of the river area), other European developments like Nature2000, urban expansions, mining activities and long term visions on the river area as a whole lay a pressure on the river area. The question is how to deal with all these different claims, and how to weight them in order to make a balanced choice. In this paper, we will analyze the task these claims give rise to, and we will explore solutions. The solutions vary from defence measures (rising dikes, make more room for the river) to raising awareness and construct new, innovative unbreakable dikes. The analysis asks for special tools, in order to visualize the problem and the solutions to the stakeholders in general (the public as well as (local) authorities). The Delta program aims at preparing the necessary measures with the goal to be ready *before* the big flood comes.

Keywords: Flood management, Climatic changes, Anticipation and awareness

1 INTRODUCTION

A total number of 634 million people (almost a tenth of world's population) is living in coastal areas that lie within 10 meters above sea level (McGranahan et al. (2007)). In coastal areas the largest urbanisation takes place as well as the largest economical activities and food production. As there is a tendency that more and more people are going to live in cities, and delta cities belong to the most populated cities (UN (2008)), it is fair to say that also the pressure on coastal deltas is increasing. Yet, it are these deltas which are most vulnerable to climate change (Nicholls et al. (2007)), Ericson et al. (2006)). This can also be noted from an interesting web-site on which the impact of sea level rise is visualised (see http://geongrid.geo.arizona.edu/arcims/website/slrworld/viewer.htm). The large coastal deltas immediately show their vulnerability.

One of those deltas is the Rhine-Meuse delta in the Netherlands. Among the developed countries, the Netherlands are probably the most threatened country by climate change, as almost 25% of the country lies below sea level and two-third of the country is prone to floods from a river or from the sea. Although a sea level rise of 1 meter can relatively easy be dealt with, it is clear that even more sea level rise, combined with other consequences of climate change (more and intense rainfall, and hence more extreme (high and low) river discharges, problems with fresh water supplies) will cause serious problems for the upcoming decades. In 2007 a State Commission gave several recommendations which are actually the starting point for further research
(see www.deltacommissie.com/en/advies).

Apart from 'climate-claims', other initiatives claim space in the delta. There are European directives (framework directive, flood directive), nature development and shipping demands. Moreover, to stop or mitigate negative autonomous processes like river bed degradation caused by regulation works and shoaling caused by river rehabilitation schemes, measures are demanded that also require space.

These claims will inevitably put a pressure on precious space in the Netherlands. The key-question is then how to deal with these often contradictory claims. What issues need to be solved, which are possible trade-offs, on what terms and what are the costs. Which interests are harmed, what parties will benefit? Is it, for example, possible to incorporate innovation or energy production in handling the claims?

In the process of solving the above questions, it is important to think in scenarios and multiple, diverse strategies. There is no direct urge to *act* right away. Depending on the developments of the coming decades, one strategy or the other may turn out to be the most beneficial. Monitoring the various systems is vital to prepare for the right decision and to be able to redirect whenever possible. In this process, also politics and policy plays an important role. Integration (taking into account all the necessary disciplines) and hence, close co-operation between Ministries, local authorities, NGO's, etc is a necessary condition to reach solutions that have sufficient support in the society. At the highest administrative levels, the willingness as well as the ability to allocate money is required in order to get to an optimal solution.

This paper describes more or less the plan of the Delta-programme Rivers, established to deal with above topics. The reference situation is discussed in section 2, details of future claims on the river area are discussed in section 3, the problem and approach is further defined in section 4, section 5 explains the uncertainties in data and strategies. Section 6 (Discussion) puts things into the long term perspective and in section 7 some conclusions are drawn.

2 REFERENCE: THE YEAR 2015

The year 2015 is an important year in Dutch water management. It is the year that the flood defence system of dunes, dikes and dams in the Netherlands should be up-to-date after about 15 years of planning, designing and constructing protection measures. Up to date in this sense means that the system complies again with the very strict standards that are put forward in Dutch legislation (roughly speaking a probability of 1/1250 per year for the river area, increasing to 1/10.000 per year for the coastal zones). Not only should the last project of Room for the River be completed, also the dike-restoration projects along the main Rhine-branches should be finished, and the closure dam (separating Lake IJssel from the Wadden sea) is reinforced. In short, in 2015 all dikes should be high enough and strong enough such that, together with the floodplain restoration projects, the hinterland is protected with respect to the standards that were agreed upon. For the Meuse river, the same holds: a large project called The Meuse Works is in progress, which provide the necessary safety for the communities along the river. Between 1995 and 2015, a total amount of over 7 billion euro's has and will be spent on flood protection measures, being the total budget for Room for the River, Meuse Works, and the restoration of the dikes and dams (including the closure dam at Lake IJssel).

The geometrical description of the main channel (or summer bed) and the winter bed (main channel and floodplains combined) that goes along with this 2015-situation is the starting point for the forthcoming analysis. In the mathematical models that are used in this study, a special way of constructing this reference situation is used. Starting from a known actual situation in 2005 (based on measurements of bed levels, floodplain conditions and dimensions, and vegetation) we superimpose all known new initiatives (like e.g. all the Room for the River projects) on this base situation. The resulting situation is the best possible description of the reference situation in 2015.

Special attention in this is needed for the description of the summer bed. It is difficult to make a prediction of the morphological changes between 2005 and 2015. A more fundamental question however, is what the exact policy will be regarding the summer bed. The upstream parts of the Dutch Rhine Branches are degrading with several centimeters per year (Ten Brinke (2004)) and river management strives to stop this autonomous bed degradation. Reasons are that there are fixed layers in the bed that do not degrade and hence are a potential thread for shipping. Another reason is that constructions like bridges and sluices are at danger with a degrading bed. This is the reason that dredged material (coming from managing the navigation channel) is not allowed to be removed from the system but is dumped back in deeper stretches upstream. To fully stop the autonomous bed degradation demands a vast set of measures (suppletion of material in the German part of the Rhine, for instance) that is considered as one of the strategies resulting from navigation claims.

In contrast to the upstream part, the downstream Rhine branches close to the sea (approximately 70 km's from the shore, where the influence of the tide is substantial) tend to aggregate and a lot of dredging takes place. Dredging is allowed as long as the overall bed level is not degrading too much. To overcome issues related to bed degradation in upstream areas as well as excessive dredging in downstream areas, river authorities are considering to define a base level for the summer bed which should be maintained (with respect to certain margins) at all times. It is this bed level that can then be included in the 2015-reference model.

3 LONG TERM CLAIMS ON THE RIVER AREA

As already mentioned in the introduction the possible consequences of climate change is one of the triggers to make an inventory of the possible claims on the river area. Some of these claims are more crisp described than others. In this section, we will shortly address the most important ones.

3.1 *Long term claims due to an expected increase of the river discharge*

The current design discharge is 16.000 m^3/s at Lobith for the Rhine River, and 3.800 m^3/s at Eijsden for the Meuse River. Partially based on the climate scenario's of IPCC, the expectations are that these discharges will increase to 18.000 m^3/s for the Rhine and 4.600 m^3/s for the Meuse (maintaining the same frequency of exceeding (1/1250 yr)). To accommodate this, more space in the floodplains is needed in the rivers Rhine and Meuse, but that is not enough. From previous research, it is already known that also space on the landside of the dikes will be needed. These areas have been mentioned in policy studies and hence have a certain status (restrictions with respect to rural developments do apply).

3.2 *The EU Water Frame Work Directive (EWFD)*

The aim of EWFD is to reach a good ecological state for the river area (http://ec.europa.eu/environment/water/water-framework/index_en.html).
For this, many projects have been designed for the floodplains of floodplains of the Rhine and Meuse rivers. Side channels are often part of the schemes, as they are very beneficial as spawning areas for fish. Apart from the increase of the conveyance area, these plans often go along with nature development, which has a potential negative impact on the design flood levels. The resulting positive effect for flood protection is therefore expected to be minimal.

3.3 *Nature 2000 areas*

Nature 2000 is a European initiative to protect areas in which important flora and fauna can be found. It has a legal status. In the Netherlands, Nature 2000 consists of 1.1 million hectares (69% water, 31 % land). Part of the Nature2000-areas are located in the floodplains. In general, for reasons given above, these initiatives will result in increasing flood levels and hence must be compensated by mitigation measures.

3.4 *(Counteracting) Subsidence*

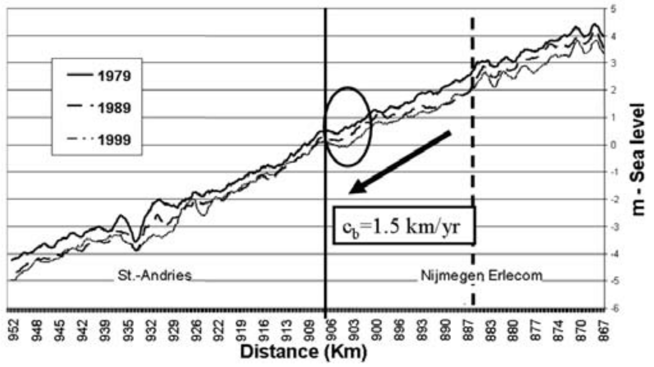

Figure 1. Bed degradation of the Waal river in the period 1979-1999 with an erosion of approximately 0.5 m in total.

The Rhine River regulation measures (dikes, groynes, bend cutoffs) have inflicted smaller slopes and larger depth's resulting in ongoing degradation of the bed level. Figure 1 shows the (moving averaged) bed level development of the Waal river for the period 1979-1999 (from Havinga et al. (2005). The bed level degradation of about 0.5m in 20 years can clearly be observed. This scouring of the bed will 'autonomously' go on for at least another 100 years (Baur (2003)). The problem that this causes are immediately clear from the figure by looking for instance at the location of Nijmegen.

There, an armoured layer was constructed in 1985. Hence, the bed levels of 1989 and 1999 are the same there. This fixed point however, causes erosion that travels downstream, leaving the layer as a potential future bar. No upstream effect (yet) can be deducted. Studying the graph in Figure 1 in detail and ignoring the autonomous degradation, one might draw the conclusion that the erosion pit travels downstram with an average rate of 1,5 km/year, which equals the assumed theoretical celerity of a disturbance in the bed (c_b) (see the circle in the figure and note the location of Nijmegen).

3.5 *Navigation and morphology*

In general river measures are not allowed to hamper inland navigation on the Rhine, as this mode of transport is of utmost importance for the Dutch economy. So, potential new bottle-necks in the navigation channel should be avoided. As the principle of flood protection according to the room for the river principle is to increase the flood conveyance through measures like side channels, excavation and removal of obstacles, this will lead to shoaling in the main channel bed and hence possible hindrance for navigation. How severe this is depends on the current situation and on the impact. To this end it is needed that a reference level is defined which is characterised by minimum fairway dimensions during low discharges. These dimensions are different for the different Dutch Rhine river branches. For the Waal river dimensions are: a fairway width of 150 m and a depth of 2.8 m below the low water reference level (denoted by LWR-2.80, LWR being the water level that is exceeded in 95% of time, 2.80 m being the draught needed). For the IJssel and Nederrijn, the dimensions are 2.50m by varying widths. To test whether navigation conditions are violated, morphological analyses will have to be carried out using a 2D-morphological model. The results must be combined with a data analysis to pinpoint a possible problem. A solution may be found in measures like adaptation of groynes or constructing longitudinal dams as an alternative for groynes. In Figure 2, an example of such a dam in Germany is shown.

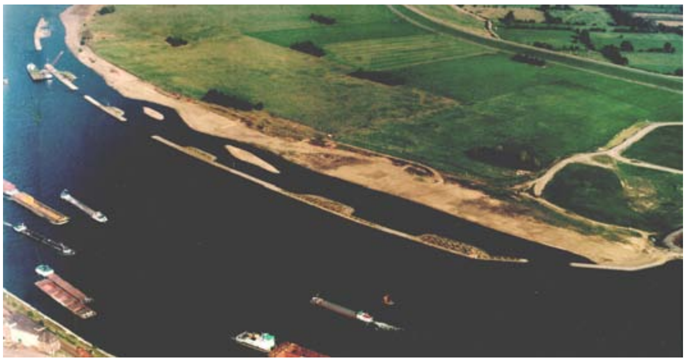

Figure 2: Longitudinal dam in the Rhine river at Bruckhausen (Duisburg), Germany.

3.6 *Sea level rise*

As already indicated in the introduction, sea level rise may become a major problem for the Netherlands. When, and to which extend is not clear at this moment. It is generally believed that a sea level rise up to 1 meter can relatively easy be dealt with in the sense that dunes and dikes can be reinforced over time (sometimes denoted as ‘growing with the sea level’). An increase of more than 1 meter is a different story. Yet, it is expected that the sea level rises up to 1.30 meters by the end of the century (see Van den Hurk (2006)). Sea level rise puts a claim on the land along the coast but at the same time on the land along the rivers. The reason is that the barriers along the coast will be closed more frequency, and then the rivers cannot discharge any more to the sea. This excess discharge has to be stored for some time.

3.7 *Local developments*

More and more, local authorities within the river area are using the planned projects or Room for the River as tool to accomplish their own initiatives with respect to housing, recreation etc. This usually goes along with an extra claim on the available space. Besides, the intention of the local authorities is then to carry out (the combined) construction works, with a certain commitment to the population that they will not return to this particular area with extra works in the next decades. Hence, the combined project should not only solve the short term problem (in terms of increasing design water levels) but also the (more vaguely defined) long term problem.

3.8 *Miscellaneous*

Apart from the above mentioned more specific claims, claims of different nature exist on the available river space. For example the fact that the floodplains are much more vegetated than is accounted for in the models (caused by insufficient maintenance and nature values). Hence, model and reality differ substantially in this respect. Compensating for these rougher floodplains may cause yet another claim on the space. Another aspect concerns a dike stability problem related to heaving. This may be solved by reinforcing the slopes, which off course consumes space. Finally a complex discussion is going on with respect to the current system of standards in the Netherlands. Other standards (based on risks numbers instead of exceeding frequencies) may lead to additional measures and hence claims. As this is beyond the scope of this paper, we refer to Roos and Van de Geer (2008).

4 PROBLEM, SCENARIO AND SOLUTIONS

4.1 *Problem*

The effects of the long term claims mentioned in the previous section, together with the effect of the scenario’s define the problem. This problem varies from area to area (rivers, lake IJssel, South-Western Delta area, Rhine-Meuse estuary, etc) and can be visualized on a map of the Netherlands. The idea is that every claim as well as the scenario’s causes a potentially rise of the (design) flood levels which obviously have a cumulative effect.

4.2 *Scenarios*

To explore the problem of dealing with multiple claims on the river area, it is important to define the possible scenarios that we are facing for the (near) future. For the Netherlands, an important starting point for this is the report of the Delta Committee (see the Introduction) who discussed two important scenarios: sea-level rise and increased discharge of the Rhine and Meuse rivers. These long term strategies are discussed below.

For the sea-level rise, the Dutch interpretation of the fourth assessment report of the IPCC-scenario's (see Van den Hurk et al. (2006)) is used. This resulted in an upper bound of the sea level rise of 0.85 m in 2100. Specific research (including the most recent studies) done for the Delta Committee resulted in a 'plausible upper bound' of the (relative) sea level rise of 1.30m in 2100 (and 2-4m in 2200).

Room for the River also uses a long term discharge scenario of 18.000 m^3/s. Explorative studies for the Meuse (which results are now already used in policy) use a long term discharge of 4.600 m^3/s for the Meuse. For the discharges of Rhine and Meuse, the figures will also be the leading numbers for future studies.

The Delta Committee mentions a range of 17.000-19.000 m^3/s for the Rhine in 2100 although this will be considerably reduced due to flooding in Germany. In this respect, the figure of 18.000 m^3/s (which is nowadays actually a political fact rather than the result of scientific research) may be questioned, especially when it is coupled to the return period of 1/1250 year.

4.3 *Solutions*

Once the problem has been explored, outlines of solutions can be drawn. Now, an important remark has to be made. The underlying study is a long term study, with a time horizon of one, and perhaps several centuries. It would be affront only to suggest that *the* solution to this problem exists. Although climate change is a continuous process (according to the IPCC the anthropogenic factor in climate change is practically beyond any doubt) a low lying country like the Netherlands will face it's consequences. However, the current problem-definition as well as solutions most likely will change over the coming decades, due to revised and new insights and findings. Besides, it's not the task of scientists to propose *the* solution. Scientists have to propose *several* solutions (or strategies, alternatives, directions) and it is then up to the policy makers and politicians to decide upon the solution as well as the time frame. So that is what we will do in this section: give an overview of possible solutions, in which we accept that at some stretches, the claims present a problem which simply cannot be solved!

The solutions fit within the three-layer safety concept: prevention against flooding, reduction of damage in case of a flood and crisis-management (together with evacuation and/or self reliance). We now discuss some of the solutions.

1. Delta-dikes (or super-levees).

Raising dikes can be a solution when higher floodlevels (resulting from the claims) are accepted. Dikes are typically build for a time period of 50-100 years. This means that all existing dikes will face serious maintenance in the coming decades. The concept of Delta dikes is based on the fact that with relatively little effort, (existing) dikes can be adapted such that they will not fail after overflowing (due to an excess discharge) or overtopping (of waves, due to wind). This means that the hinterland does not face inundation depths of several meters due to a breach, but merely hindrance of several decimetres of water due to water flowing over the dike. The idea is that over the coming periods, dikes that need maintenance anyway, can be adapted in this way with relatively few extra costs. Preliminary calculations show that up to 2100, some 6.5 billion euro's is needed.

2. More Room for the River

Accommodating discharges of 18.000 m^3/s for the Rhine and 4.600 m^3/s for the Meuse without raising dikes means creating more river space. This demands rigorous measures within the floodplains as well as on the landside of the dikes. Spatial (land) reservations along the Rhine branches and the Meuse, anticipate on this. However, from studies carried out in the process of Room for the River, it is already known that also within the floodplains, a lot of extra space is needed. Even if all the possible floodplains are going to be used to increase the discharge capacity, still some critical stretches are left, especially along the Waal river. This would also affect the typical river landscape to an unacceptable degree. This major branch simply has too little capacity to transport it's part of the 18.000 m^3/s (around 2/3). A solution may be found in changing the discharge distribution over the two bifurcation points (see figure 3). However, given the fact that also the Nederrijn cannot convey more discharge, it means that critical stretches will emerge at the river IJssel. One way or another, it will turn out that by just creating more room for the river, the problem cannot be solved for all the branches. At some stretches however, more room will definitely be a possible solution.

Already in 1998, a study was carried out with a very extreme scenario: a discharge of 20.000 m^3/s for the Rhine and a sea level rise of 1 meter (Delft Hydraulics (1998)). Whenever very clear choices are made (protecting the vulnerable Western part of the Netherlands by guiding the excess discharge over the IJssel branch to the North) even this scenario could be dealt with.

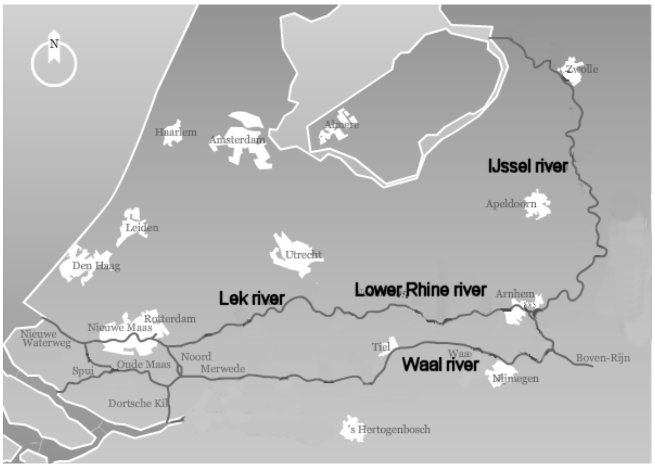

Figure 3: The major rivers in the Netherlands. The Rhine river enters from Germany and bifurcates in three branches (Lower Rhine is Nederrijn).

3. Awareness and self reliance.

The topic of awareness gets more and more attention in Europe nowadays, as preparation for floods may be an attractive way to cope with the consequences of floods. This may result in the acceptance of higher flooding frequencies, yielding less costly measures. Examples are the initiatives taken in the INTERREG IIIB projects Freude am Fluss (FaF (2007)) and Sustainable Development of Floodplains (SDF (2008)). Since November 2007, the European Flood Directive entered into force (http://ec.europa.eu/environment/water/flood_risk/index.htm).

That directive requires EC-member states to map the flood extent, assets and humans at risk in flood prone areas and to take adequate and coordinated measures to reduce the flood risk. In 2013, flood hazard and flood risk maps have to be available, and in 2015 also flood risk management plans must be available. In the Netherlands, awareness is also increased by broadcasting TV-spots. Schielen and Roovers (2008) observe an interesting complication in the communication about flood risks in the Netherlands. The return period for a design discharge is very high (1250 years). For the general public, they state that this ‘close to meaningless and is often interpreted as: safe under all circumstances.’ Schielen and Roovers (2008) propose a promising new safety concept: adaptation and self reliance. They propose a resilient society in which a flood is ‘just another normal situation’ than can be coped with because people are prepared.

4.4 *Coherence*

It is important to recognize the coherence in the Dutch (main) water system. The issues of for instance safety during high discharges (or floods), sufficient fresh water and demands with respect to inland navigation during low discharges, salt intrusion in the delta and consequences of sea level rise are closely connected. Up to now, the discharge distribution at the bifurcation points is determined by geographical conditions and resistance to flow and is assumed to be fixed. The height of the dikes at the various Rhine river branches is related to this fixed ratio. However, in times of low discharges, it might be desirable (or sometimes even necessary) to divert more water to the north to buffer fresh water in lake IJssel, or more water to the west to counteract salt intrusion. Hence, a (dynamical) regulator at the bifurcation points might be necessary for future applications. In the south western delta, ecological problems occur due to algae. This is the consequence of the closure of the basins in the seventies. Also, as a result of sea level rise, the barriers need to be adapted in the next decades. Removing (some of) them, as the Delta Committee suggested, might restore the ecology, but asks for other measures to guarantee the supply of fresh water as well as safety against flooding from storm surges. These are just a few examples of the close interconnections of the various sub systems in Dutch water management. It is believed that integration of the different national watermanagement subsystems could reduce the problem.

5 UNCERTAINTIES

Especially in case of long term studies, dealing with uncertainty should be considered with care. The Delta Commission already mentions the large uncertainty intervals in river discharge and sea level rise. Presenting results in which uncertainty is taken into account is crucial, but also challenging. Results and uncertainty should be presented such that the combination really adds to the understanding. Often, uncertainty is used as an argument to settle for the safe side (‘better safe than sorry’) and is hence a worst case approach. Janssen et al. (2009) studied to which extent presenting results without uncertainty, with only a qualitative description of uncertainty, and with uncertainty made explicit in band widths around a mean value would affect decision making (in this specific case choosing a river management strategy). They found that adding uncertainty information leads to risk-avoiding behaviour. The band widths are not used to estimate how (un)certain a prediction will be. Instead, people indicate that they use the information to be on the safe side; only if the mean plus (or minus) the uncertainty is in the correct interval, they choose for a certain strategy. Generally, this should not be the goal. An important disadvantage of this approach therefore, may be that unnecessarily large investments are done.

There are several ways of handling uncertainty. One way is to assume a probability distribution around on the uncertain parameters. Using for example a Monte Carlo simulation, this results in a probability distribution around the final result one is interested in (for instance water levels, or inundation frequencies). This probability distribution is then used to determine a accuracy band width around a mean value. An important question then remains: how should one interpret this bandwidth.

Another option is to integrate over all possible probabilities, i.e. use the "weights" inherently present in the probability distribution. The outcome in that case becomes a single expected value (again, a critical water level, or an inundation frequency). By definition this expected value takes into account the uncertainties and the shape of the probability distributions. This value can then be used to decrease (or perhaps omit) the factor in the design of dikes that accounts for uncertainty (now a default value of 30 cm).

In the discussion with respect to uncertainty, it is important to distinguish between the various 'sources' of uncertainty. In general, one distinguishes between epistemic uncertainty (uncertainty due to lack of knowledge, for instance modelling wind or water levels) and uncertainty due to natural variability (roughness of summer bed, shape of discharge wave). Sometimes, a third category is added: uncertainty due to future developments. Every source may need a different analysis to take the consequences into account.

6 DISCUSSION

River management has to deal with the natural dynamics of the river. The related uncertainties limit flood safety, navigation and ecological opportunities. In the past centuries coping with these uncertainties was also translated in a river lay-out in which (most) people could survive flooding and accepted the nuisances, e.g. small draughts or light shipping opportunities. The goal of the Delta program, however, is to sustainably integrate all major interests and minimising negative impacts on these interests. As future developments are uncertain, solutions may be found by dealing openly with these uncertainties. This touches upon a whole range of "river flow" subjects related to forecasting of discharges, water levels, hydraulic roughness, vegetation succession, bed levels and bed forms, in which uncertainty plays a major role and where probabilistic approaches are appropriate.

All the measures that are considered for a mid or long term perspective will not prevent that serious flood events will eventually take place on a (very) long time scale. These events are a statistical certainty. In the aftermath of such events action is then taken to repair, restore and often improve the situation to prevent that a similar event will happen again. Examples of this approach can be found in the Netherlands (the Delta works, after the flooding of the South Western part in 1953, or the improvement of the levees along the river Meuse, after the floods of 1995) in Germany (after the floods of the Elbe in 2002) and in New Orleans (after the hurricane Katrina in 2005). Apart from these event-driven actions, there are structural measures that are carried out to maintain or improve safety standards without any preceding flooding events. Examples are the Room for the River program in the Netherlands, the New Vásárhély program in Hungary or the storm surge barriers in the Thames and in St. Petersburg. The analysis that is now proposed in the Netherlands by the Delta Committee however, may be labelled as a new approach. Not only are the current safety standards maintained or even improved, also an inventory of various actions is studied to prepare for upcoming situations on a long time scale, only to prevent hazardous situations on that long time scale. The (simple) idea is just not to wait for a (major) event, but take all the necessary precautions to prevent it from happening.

By no means does the Delta–programme proposes a blueprint of solutions for the coming decades or even centuries. The eminent problems of the upcoming eras will be solved by the community that is then living. Having the intention to solve those problems now is almost preposterous. What the program aims at is to develop several strategies to solve the problems that we see now, based on scenario's that are now likely to occur. This may results in some long lasting investment programs (i.e. the political implementation of the proposed strategies) to keep the Dutch society resilient against the water. These programs may start in the coming years. It is then crucial to provide them with some flexibility, such that whenever the scenario's change, the programs can relatively easy be adapted and the investments are no-regret. Without any doubt, there continuously will be crucial changes in the scenarios (and perhaps also is the basic assumptions) in the coming decades that make interventions and changes in the strategies necessary. The Delta programme Rivers faces the following (new) challenges:

First, morphology, ecology and hydraulics affect each other. Modelling this is the key element of the field of ecohydraulics and many interesting questions related to maintenance and management need to be solved to really understand the integrated question.

Second, every analysis is accompanied with uncertainty. Taking uncertainty into account, and communicating that outcome (especially towards the policy makers) will become very important. Up to now, the results are feeble. Policy makers escape in risk avoidant behaviour, or neglect uncertainty altogether.

Third, there is a task to improve the awareness among the Dutch public. Although the Netherlands is probably the safest delta in the world, the inhabitants should not forget that two-third of the land is prone to floods. This awareness, and the consequent behaviour (basic knowledge of the river and coastal system, self reliance, knowing what to do in case of threads, etc) is something civilians should have general knowledge of.

Fourth, and perhaps most provocative, in weighing the various strategies for the mid and long term strategies, the boundary conditions and assumptions of the Dutch safety approach should be dealt with carefully. It may very well turn out that the starting points (current method of flood protection, return times and heights of design discharge, coping with sea level rise) have to be reconsidered, simply because the consequences for the stakes become too serious.

7 CONCLUSIONS

The demands on the layout of the Dutch Rhine river branches are large. The claims on the precious space are numerous. The desire to obtain sustainable (and manageable) solutions to maintain the safety level also in the mid and long term, and meanwhile optimise the user functions (of which navigation and ecology are probably the most important ones), poses complex questions. As there is no direct urge to act right away (for the safety level is already quite high), monitoring the various systems for e.g. morphological changes, and vegetation developments of the floodplains is vital to prepare for the right long term decisions. To interpret the solutions, advanced morphological analyses are needed.

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