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Dealing with Uncertainty in Flood Risk Assessment of Dike Rings in the Netherlands

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Abstract. Current flood protection policies in the Netherlands are based on design water levels. This concept does not allow for a proper evaluation of costs and benefits of flood protection. Hence, research is being carried out on the introduction of a flood risk approach, which looks into both the probability of flooding and the consequences of flooding. This research is being carried out within the framework of a major project called the Floris project (FLOod RISk in the Netherlands). To assess the probability of flooding the Floris project distinguishes different failure modes for dikes and structures within the dike ring. Based on a probabilistic analysis of both loads and resistance the probability of failure is determined for each failure mode. Subsequently the probabilities of failure for different failure modes and dike sections are integrated into an estimate of the probability of flooding of the dike ring as a whole. In addition the Floris project looks into the different consequences of flooding, specifically the economic damages and the number of casualties to be expected in case of flooding of a particular dike ring. The paper describes the approach in the Floris project to assess the flood risk of dike rings in the Netherlands. One of the characteristics of the Floris project is the explicit attention to different types of uncertainties in assessing the probability of flooding. The paper discusses the different starting-points adopted and presents an outline on how the Floris project will deal with uncertainties in the analysis of weak spots in a dike ring as well as in the cost benefit analysis of flood alleviation measures.

Key words: flood risk, dike rings, uncertainty, failure modes, flooding probability, the Netherlands

1. (Current) Flood Protection Policy in the Netherlands

Historically, the containment of floods has been a main concern in Dutch water management. As most part of the “low countries” are actually below sea level, water management is largely about *keeping our feet dry*. From the first settlers some 5000 years ago, flood risk has been a part of life in the Netherlands. At first people lived on higher ground. Over time this higher ground was connected by dikes. Dike rings were created to protect the land

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In 1953, a storm tide hit the Netherlands. Catastrophic flooding occurred in the South Western Delta area. Almost 2000 people died during these floods and the economic damage was enormous. The conceivable reaction was: "This must never happen again". The *Delta committee*, established soon after the event, published its important *Delta Plan* in 1960. It comprised a large set of engineering works to raise protection from the sea: the Delta Works.

The Delta committee also introduced a completely new approach to determine the required level of protection against flooding. After the last "real" flood event in 1926, engineers had determined the required height of the embankments on the basis of the following principle: *the highest observed water level plus* 1 m. On the basis of a *cost-benefit analysis,* the Delta committee determined a new optimum level of protection, formulated as *return period* for the design water level. Taking into account the variances in risk and possible damage, different return periods for the Delta and rivers were established (see Figure 1).

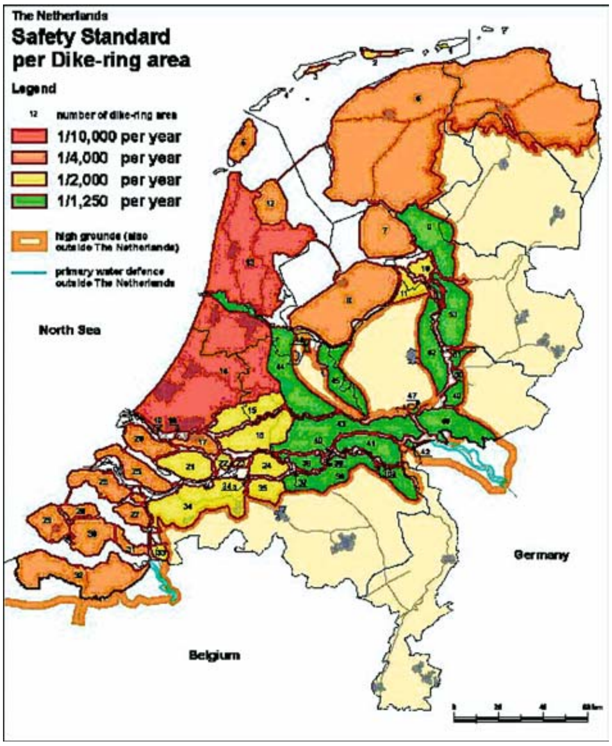

Figure 1. Dike rings in the Netherlands with their associated protection level.

For the central western part of the Netherlands where the main cities Amsterdam, Rotterdam and The Hague are located, a return period of 10,000 years was adopted; for the dikes along the river Rhine, a return period of 3000 years was proposed. The protection level along the branches of the river Rhine was adjusted to a return period of 1250 in the 1970s as a response to growing protest against the rigorous dike reinforcement programs which led to destruction of landscapes and cultural-historic sites.

As the Netherlands receive a large inflow of water from Germany and Belgium through the rivers Rhine and Meuse a part of the country is also susceptible to flooding from rivers. In 1993 and 1995, serious flooding occurred in the basin of the river Meuse. On both occasions, there were no casualties but the economic damage mounted up to 200 million Euro. Early 1995, there was an even more serious risk that the dikes of the river Rhine would collapse. This would lead to the inundation of a large area along the river with depths up to 6 m and a sincere risk of casualties. The authorities evacuated 250,000 inhabitants in the areas at risk. In the end, the dikes did not collapse but the evacuation costs were substantial and it seriously disrupted daily and economic life.

The 1995 flood placed the dike-reinforcement program high on the political agenda. A *Delta law* for the large rivers was rushed through parliament. The dike reinforcement program gained momentum and by the year 2000 nearly all parts of the reinforcement program of hundreds of kilometers of river dikes had been realized. The 1995 flood event also triggered a rather proactive policy response: the policy directive “Room for the river” was passed in parliament. This policy directive restricted the use of land for construction and commercial activities in areas prone to floods. The floods of 1993/1995 in combination with the international debate on the effects of global warming raised the awareness about the risks of floods and droughts.

Considering the fact that flood management is vital, the Dutch Law on Water Defences orders that hydraulic boundary conditions, i.e., design water levels and wave heights, should be updated every 5 years and that water defences should be evaluated for these new conditions. The flood events of 1990, not only put flood management higher on the political agenda it also led to a significant adaptation of the river flow statistics. The new boundary conditions for 2001 implied a further reinforcement of the dikes by 0.5–1 m, at a time when the reinforcement program based on the former statistics was nearly completed. Understandably, water managers proved very reluctant to further raise the river dikes. At the turn of the millennium, serious doubts were raised whether the Netherlands could go on enforcing the dikes. Now, alternatives were studied and debated in order to reach a more sustainable response to the impacts of climate change and improve the spatial quality of the flood plain areas. The alternatives relied on strengthening the resilience of rivers and nature by giving room to the rivers to counteract the expected rise in the design water level. Typical measures include widening the flood plain through dike realignment and excavating side channels in the flood plains (Dijkman and Heynert, 2003). In a relatively short period of time, the policy paradigm of policy makers, engineers and water managers changed significantly: dike reinforcement changed from most preferred to least preferred option, only to be used when other flood protection measures such as giving space to the rivers were unfeasible.

The current flood protection policy is still based on design water levels. The current approach only looks into the probability of flooding. Dike reinforcements are designed to cope with the design conditions. The designs look for minimum costs, while preserving the values of landscape, nature and cultural-historic sites. A major drawback of the current approach is that is not possible to compare the costs and benefits of flood protection measures. Also it is difficult to evaluate measures that aim to minimize damage, such as spatial planning and emergency measures. To overcome such limitations the Technical Advisory Committee on Flood Defence initiated the development of a flood risk approach.

2. New Developments: Introduction of Flood Risk Approach

The methodology developed for assessing flood risk differs from the current approach on a number of aspects (Technical Advisory Committee, 2000).

1. The analysis is no longer limited to individual dike sections; the dike ring as a whole is being analysed. So the analysis provides insight into the strength of an entire dike ring, which typically consists of dikes, hydraulic structures and dunes.
2. The analysis takes account of all failure modes of a dike ring, whereas the current approach focuses mainly on the failure mode of overtopping.
3. All uncertainties are explicitly included in the calculation in a systematic and verifiable way.

The calculation of the flooding probability of a dike ring is based on the principle that a “chain is as strong as its weakest link”. The calculation reveals all the weak links in a dike ring. It also shows that not every weak link contributes in an equal manner to the total flooding probability. This understanding provides opportunities for a step-wise improvement of a dike ring. Improvement measures may include raising the crest of a dike, improving the operation of a hydraulic structure or reinforcing the dunes. Addressing the weakest link first is often the most beneficial measure to reduce the calculated flood probability. So, application of the method may assist in prioritizing the different weak spots that may be present in a dike ring.

When calculating flooding probabilities, various forms of uncertainty are taken into account in a systematic and verifiable way. This is an important difference to the current approach based on exceedance frequencies, which only considers the natural uncertainty in water level. In the current approach, after determining the design water level, a safety margin is added to include non-explicit uncertainties. The calculation of the flooding probability includes uncertainties in water levels and wind, in strength of dikes and structures and in calculation models for the different failure modes. It should be noted that the calculated flooding probability is always an estimate of the actual flooding probability. As the uncertainty in models and data decreases, the approach will improve in accuracy.

The development of the methods started in the 1990s. During its development the methodology was applied to illustrative case-studies. The development was concluded with a successful application to four different types of dike ring (Technical Advisory Committee, 2000).

3. Floris Project

The application of the newly developed methodology to the four dike rings also revealed the presence of a number of weak spots within these dike rings. Especially structures like sluices and dams appeared to be relatively weak links within the water defence system. The findings of the study triggered the Ministry of Transport, Public Works and Water Management to launch a major project (the VNK or Floris project) to assess the probability of flooding for all dike ring areas in the Netherlands. The objective of the Floris project is to gain insight in the probabilities of flooding in the Netherlands, the consequences of possible floods and the uncertainties that effect the assessment of both probabilities and consequences (Parmet, 2003). The execution of the project will help to identify weak spots within a dike ring. Also cost estimates will be made for the improvement of weak spots. Along with the insight in the consequences of a flood, these outputs provide information for a soundly based appraisal of the desirability to reinforce the weak spots within the various dike rings.

The project is carried out by the national government in cooperation with the water boards and the provinces. The water boards provide the available information of the flood defence structures, whereas the provinces share their knowledge of the inner dike ring area. The national government compiles all required data and carries out the necessary calculations with the assistance of various engineering consultants. Transfer of knowledge and technology to the private sector is also an objective of the Floris project. That is why the major Dutch consultancy firms are involved in the execution of the project.

4. Dealing with Uncertainty: The Starting-Points

Many uncertainties play a role in the assessment of the flood risk of a dike ring. Table I presents an overview. A distinction is made between inherent uncertainties and knowledge uncertainties. Of these types of uncertainties, only knowledge uncertainties may be reduced through research within a reasonable span of time. To deal with natural variability, the concept of probability is commonly adopted. Knowledge uncertainty, however, is dealt with in very different ways, ranging from neglecting the uncertainty to approaches in which all uncertainties are taken into account in a comprehensive manner.

The traditional approach to deal with knowledge uncertainties is to make conservative assumptions ("better safe than sorry", "worst case"). This approach has one major disadvantage: it is quite difficult to assess what degree of safety is actually provided. To overcome this problem probabilistic approaches or risk analyses have been developed. All uncertainties (in input) are described using probability distributions. The outcome of the analysis is a probability distribution as well. Based on such distribution, conclusions can be drawn for example on the probability of failure.

Table I. Overview of uncertainties in determination of flood risk (examples)

Type	Source			
	Categories of uncertainty	Hydraulic loads	Strength of water defences	Consequences of flooding
Inherent uncertainties	Natural variation	Temporal variation of discharges, waves and water levels	Spatial variation of soil properties	Economic consequences of flooding
	Future developments/ policies	Climate change, Space for river policy		Economic and demographic development
Knowledge uncertainties	Lack of data (statistical uncertainty)	Probabilistic model of discharges, waves and water levels	Characteristics of dikes and subsoil, Idem structures	Casualties in relation to evacuation
	Lack of knowledge of processes (model uncertainty)	Mathematical models for water levels and waves	Mathematical models for failure mechanisms 'Aging' of dikes, structures	Mathematical models of flood dynamics, Behaviour of people during floods

The Floris project has defined a number of starting-points on how to deal with the uncertainties in the assessment of flood risk due to the whims of nature and human failure. The major starting-point of the Floris project is that all uncertainties are included in the analysis to avoid unnecessary conservative assumptions. To promote mutual comparability of calculated flood risk between dike rings, all uncertainties identified are dealt within a systematic and consistent manner. To this end a probabilistic approach is adopted. This approach shows how uncertainties affect the outcome of the analysis, e.g., it becomes clear which uncertainties have the largest influence on the calculated flood risk. Based on such understanding a deliberate choice can be made to either reinforce the water defences or to reduce the uncertainties through research.

Although there is a lot of knowledge available on different aspects and processes that affect the flood risk, there are still areas where knowledge is lacking. These include the possible existence of residual strength, the possible impact of emergency measures and the systems behaviour of dike rings along rivers. Time and budget constraints of the Floris project did not allow to develop a proper probabilistic model for these areas. In these cases a deliberate choice was made to adopt conservative assumptions to avoid unjustified optimism. As a consequence "pleasant surprises" will be more likely to occur than disappointments when knowledge increases over time after appropriate research.

Due to knowledge uncertainties the calculated flood risk has a limited reliability. This reliability may be expressed through reliability intervals. Decision-makers, however, generally have difficulty in dealing with reliability intervals. When is information sufficiently accurate to make decisions? It is the art of engineering to draw sufficient conclusions from insufficient data. Within the Floris project another approach is adopted in dealing with uncertainty. All available information is integrated in a statistically justified way. The calculated flood risk comprises the best estimate of the flood risk *given the available knowledge*. Uncertainties are directly incorporated in the decision-making process by raising the question to what extent the reliability of the calculated flood risk can be increased through (additional) research.

This definition implies that the calculated flood risk may not only change because of physical reinforcements but also because of research which may reduce uncertainties. Whether research results in a lower probability of failure depends on the actual outcome of the research. The extent to which uncertainties can be reduced for that matter is limited. Uncertainties in knowledge of local circumstances may be reduced through field research. Model research may reduce uncertainties in "failure" models. It should be realised, however, that more sophisticated models generally are more data intensive. As a consequence the uncertainty may shift from model uncertainty to statistical uncertainty. Unless additional field research is carried, the net gain may be limited. Statistical uncertainties in hydraulic conditions can not be reduced through research within a reasonable period of time. The period of observation is generally too short compared to the return period of the events considered.

5. Assessment of Probability of Flooding of Dike Rings

A dike ring normally consists of large segments of dikes or dunes interrupted by a few hydraulic structures such as locks, pumping stations, tunnels, discharge sluices, etc. Engineering experience shows that there are many different modes that may lead to failure of flood defence structures. Insufficient height may lead to large overtopping rates, which will erode the inner slope. Structures can also be undermined through eroded “pipes” in the subsoil. Then of course water pressures can build up and lead to loss of stability. Slope protection of dikes (grass, stones or asphalt) may get washed away under severe wave attack, which leads to erosion of core material and possibly a breach. The gateway function of hydraulic structures adds another failure mode: the non-closure of the gate. Human failure may play a very important role with this failure mode. Figure 2 depicts the different failure modes of dikes within a dike ring.

To be able to determine the failure probability of a particular failure mode both the hydraulic load to the dike as well as the strength of the dike section are described in probabilistic terms. The failure probability is then the probability that the load is larger than the strength of the dike or structure.

The probability of failure of a particular dike section is subsequently assessed by combining the probabilities for each possible failure mode, taking

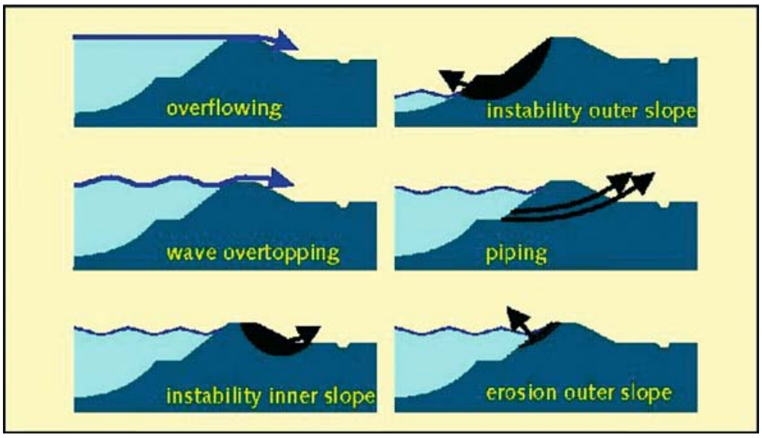

Figure 2. Overview of failure modes for dikes.

into account the dependences between the failure modes. Each failure mode is modelled in such a way that its occurrence will lead to an initial breach. So the result of the calculation is actually the probability of an initial breach in a dike section. With the same combination procedure the failure of different dike sections is combined into the failure of dike rings (Lassing *et al.*, 2003). The dependence between the dike sections is taken into account in this process. Actually this dependence is already introduced at the lowest level: the input variables of the calculation models for the different failure modes. For each variable a correlation function (in space or time) is specified.

The model generates two main results for every single "element" within the dike ring: the probability of failure (often described by the reliability index β) and a set of coefficients of influence for all input variables (often described as α_i). The combination procedure combines the output of two elements and the coefficients of correlation into a combined reliability index and a new set of α_i. This procedure is repeated until all elements within the system are dealt with.

The importance of taking into account the dependency between dike sections can be shown with the following example. Consider a dike ring situated along the Rhine consisting of 25 dike sections. For each dike section the probability of failure due to overtopping is 1/1250 per year. The probability of failure due to piping for each dike section is taken ten-times smaller, 1/12,500 per year. A first indication of the system's probability of failure can be found by calculating an upper boundary (sum of the probabilities of failure of all elements) and a lower boundary (probability of failure of the weakest link). This leads to the following estimates for the dike ring as a whole:

$$\begin{array}{lcl}
1/1250 < & \mathrm{P}_{\mathrm{f,\ overtopping,\ dike\ ring}} & < 1/50 \\
1/12500 < & \mathrm{P}_{\mathrm{f,\ piping,\ dike\ ring}} & < 1/500 \\
\hline
1/1250 < & \mathrm{P}_{\mathrm{f,\ dike\ ring}} & < 11/500
\end{array}$$

A calculation which takes into account all dependencies results in:

$$\begin{array}{l}
\mathrm{P}_{\mathrm{f,\ overtopping,\ dike\ ring}} = 1/1000 \\
\mathrm{P}_{\mathrm{f,\ piping,\ dike\ ring}} = 1/850 \\
\hline
\mathrm{P}_{\mathrm{f,\ dike\ ring}} = 1/800
\end{array}$$

The failure probability of the dike ring for overtopping appears to be close to the lower boundary, the weakest link approach. This can be explained by the dominating influence of the discharge of the river Rhine. A high discharge leads to high water levels for all dike section. As a result there is a strong dependence of failure of these dike sections. The failure probability of the dike ring for piping tends more to the upper boundary. For piping the influence of the discharge of the Rhine is less dominant; the influence of specific soil characteristics is more important. These soil characteristics are relatively independent, which leads to relatively independent failure of the dike sections. Although piping has the largest probability of failure for the ring as a whole, there is still some influence of overtopping on the overall probability of failure of the dike ring.

6. Assessment of Consequences of Flooding

The assessment of the consequences of flooding comprises the determination of the hydraulic consequences, the economic damage and the number of casualties. To determine the hydraulic consequences of flooding both global and detailed models are being used. Global models make use of simplifying assumptions to obtain a quick estimate of the maximum inundation depths and associated damage that may occur. Detailed inundation models, based on the generic Delft 1D2D model, are used to analyse the dynamics of an inundation due to a breach in the dike (Hesselink *et al.*, 2003; Stelling *et al.*, 1998). The magnitude of the hydraulic consequences of a dike breach will depend on the location of the breach and the speed with which the breach will grow. Also limitations in the incoming discharge may play a role. To account for these factors different inundation scenarios are analysed. The application of the inundation model requires a detailed schematisation of the dike ring area. This includes a digital terrain model (including relevant line elements that may obstruct the flow) and the land use because of the hydraulic resistance. The detailed inundation model provides a regionally distributed picture of the development over time of inundation depths, stream velocities as well as the rate of water level rise (see Figure 3 for an example).

The hydraulic consequences are input to the assessment of economic damages and the number of casualties due to flooding. The economic damages are calculated using a standard method (Vrisou van Eck *et al.*, 2000). Information on economic value and vulnerability to flooding of land use is combined with information on the expected inundation depths of dike rings. Figure 4 illustrates the procedure.

The assessment of economic damages includes both direct and indirect economic damages. The direct material damage is defined as damage to objects, capital goods and movables due to the direct contact with the water. This includes repair damage to real estate, repair damage to means of production, damages to household effects and damages due to loss of raw materials and products (including agricultural yields). Also economic losses due to stagnation in production is taken into account.

The indirect economic damages pertains to damages to supplying and buying companies outside the flooded area as well as to additional travel costs due to interruption of traffic though the flooded area.

The Floris project also looks into the number of casualties to be expected. This number of casualties will depend on the characteristics of the flood. Very

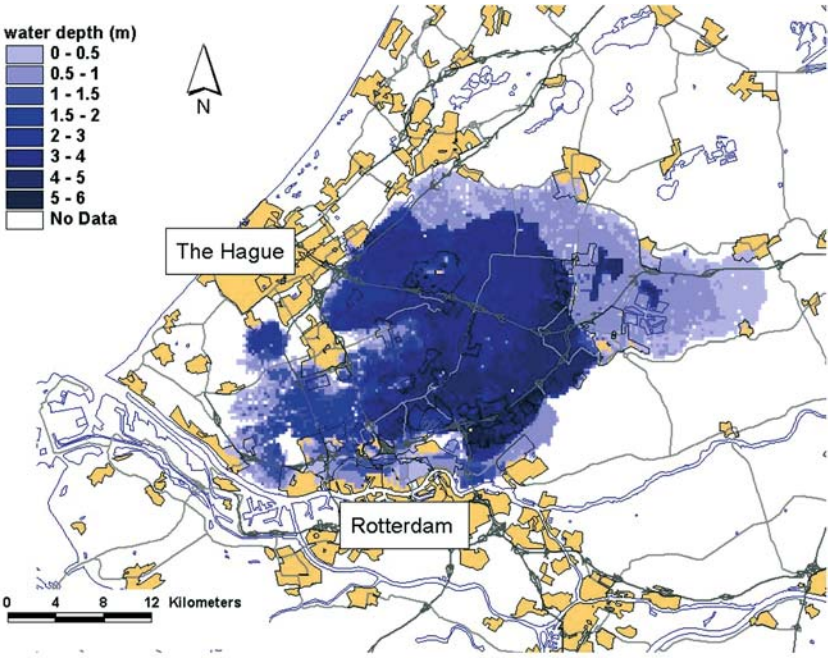

Figure 3. Example of calculated pattern of inundation depths for a dike ring.

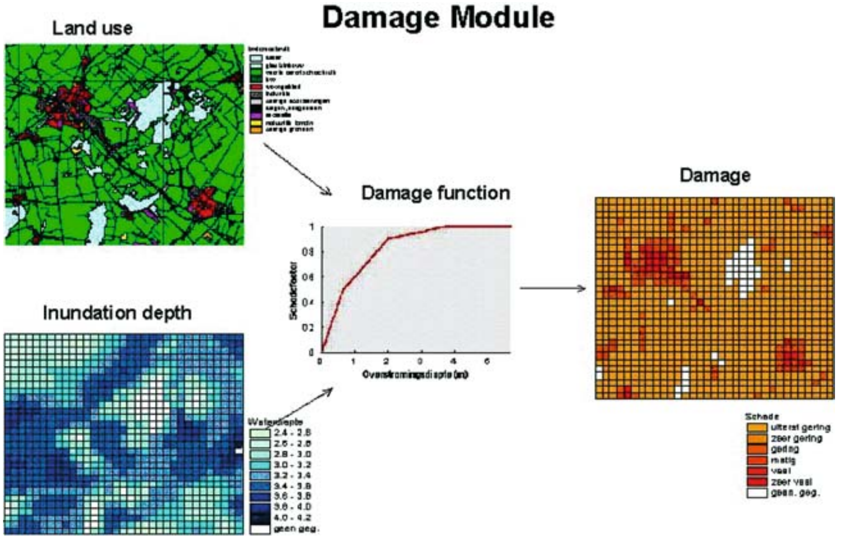

Figure 4. Combining hydraulic consequences and land use into economic damages.

important is of course the inundation depth, but also stream velocities and the rate of water level rise play a role. Experience shows that it is in particular the combination of high rates of water level rise with larger inundation depths that result in relatively large numbers of casualties.

Another important factor is whether or not preventive evacuation has been carried out. To assess the contribution of preventive evacuation in reducing the number of casualties of a possible flood, a Preventive Evacuation Model is being developed. This model estimates which fraction of the inhabitants of the dike ring will be evacuated in the course of time. Time is the key factor in a successful evacuation. The model looks into both the time needed and the time available for evacuation. The time *needed* depends on the extent of preparation and the presence of infrastructure. The time *available* depends on the predictability of the flood, which in its turn depends on the type of threat (from the sea or from a river).

Not all people that are present in a dike ring during flooding will become a victim of drowning. A large part of the people will be able to flee to safe places or will be rescued. Evidence from past floods suggests that many casualties are to be expected close to the breach in the dike. Due to high stream velocities people lose their balance; also buildings in which people have found shelter may collapse. It is assumed that buildings will collapse when the stream velocity amounts to more than 2 m/s and the product of inundation dept and stream velocity is larger than 7 m^2/s (Rescdam, 2002).

For the areas further away from the breach the percentage of casualties depends on the inundation depth and the rate of water level rise. The Floris project distinguishes between two different situations. In areas with a high rate of water level rise (rate of more than 1 m/h) people will have difficulty in reaching safe places. As a consequence the number of casualties due to drowning is relatively large. In other areas with a lower rate of water level rise it is assumed that people generally will succeed in finding shelter temporarily. In such cases casualties will have other causes. People may die due to hypothermia or fatigue or they may get stuck in houses that collapse later on during the flood. Figure 5 shows a casualty function for the situation with a high rate of water level rise (Asselman and Jonkman, 2003).

With these casualty functions information on hydraulic consequences together with information on the presence of people and buildings can be combined to obtain estimates of the expected number of casualties in a particular dike ring.

7. Analysis of Weak Elements Within the Dike Ring

The Floris project has adopted a systematic and consistent approach in dealing with uncertainties in the determination of flood risk. Dealing with

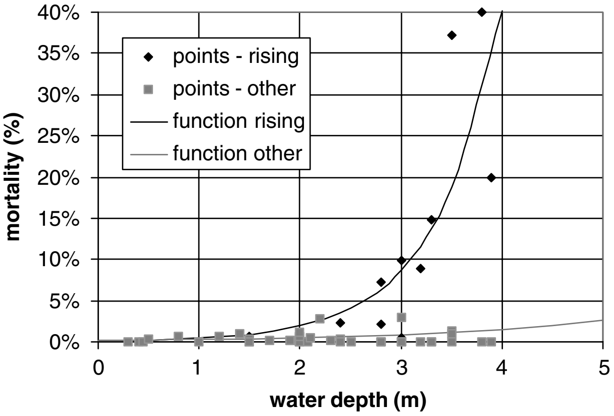

Figure 5. "Casualty function": mortality as a function of inundation depth.

uncertainties, however, goes beyond the mere quantification of flood risk. It is also important to incorporate uncertainty in *decisions* on the protection against flooding. Knowledge uncertainty is e.g., an important factor in the identification of weak spots within a dike ring. Is a particular dike section indeed a weak element or is the large contribution to the flooding probability of the dike ring mainly due to knowledge uncertainty?

Within a dike ring there will be stronger and weaker dike sections and hydraulic structures. Based on its contribution to the probability of flooding of the dike ring a dike section or hydraulic structure can be identified as a weak spot. The calculated contribution reflects the best estimate given the available information. Additional research may provide different inputs to the failure models. The outcome of additional research is of course not known beforehand. One can only make assumptions on the outcome. A structured *sensitivity analysis* can be carried out to investigate the possible consequences of additional research.

For strong sections within the dike ring an unfavourable outcome of additional research is assumed. If under such conditions the contribution to the flooding probability of the dike ring is still negligible, then the section can be most probably be considered as strong. Similarly for weak spots it is investigated whether a favourable outcome of additional research or field work would change the perception of the section being weak. Figure 6 summarizes the approach. For the category "(yet) undetermined" actual additional research has to clarify whether these sections/structures are really weak spots or not.

The sensitivity analysis focuses on the stochastic variables which have most impact on the probability of failure. The sensitivity analysis is only applied to knowledge uncertainties; these are the uncertainties that may be

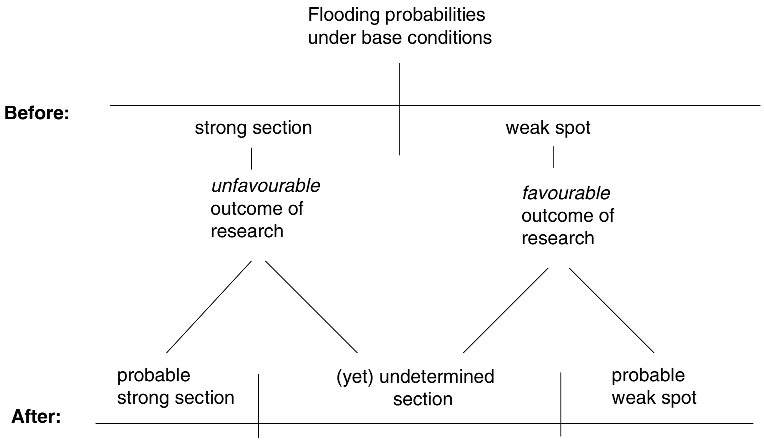

Figure 6. Classification of dike sections into weak, strong and undetermined.

reduced with additional research or field work. The classification in weak spots and strong sections can subsequently be used to develop a cost effective program for additional (field) research. It also provides a comprehensive picture of the quality of the dike ring. Such understanding can be used in defining alternative reinforcement programs for dikes and hydraulic structures within the particular dike ring.

8. Cost–benefit Analysis of Flood Alleviation Measures

Uncertainties play also a role in the cost benefit analysis of flood alleviation measures. In a general cost benefit analysis the benefits of an activity are compared with the costs of the activity. If the benefits are higher than the costs, the activity is attractive (it generates an increase in economic welfare). In flood management this means that the costs of flood alleviation measures are compared with the decrease in expected flood damage (risk reduction). Costs include investments costs (fixed and variable) and costs for maintenance and management.

The attractiveness of a measure will depend on the ratio between investments and damage reduction. If the ratio is (sufficiently) higher than 1.0, it will be economically attractive to carry out the measure. In the Floris project it is recognized that both costs and benefits are not exactly known; they contain a certain amount of uncertainty. Costs for instance are not based on a specific design, but assessed with the use of unit costs. Therefore the accuracy is limited. Due to the lack of knowledge some safe assumptions are made in the calculation of the risk reduction which probably results in an overestimation of the benefits of the measure. Hence it is conceivable that for a certain measure the costs will be higher than the benefits, although the "average" benefit–cost-ratio exceeds 1.0.

The issue of how to deal with uncertainties in the cost–benefit-analyses has not yet been solved. The idea of a classification of measures based on their "average" benefit–costs-ratio (for instance very attractive, attractive, possibly attractive and non-attractive) has been suggested. The establishment of boundaries between these classes will require a probabilistic approach to both costs and benefits of the measure. This will be further investigated within the project.

9. Conclusions and Outlook

The paper has presented an outline of the flood risk approach, which is currently being developed and applied to the various dike rings in the Netherlands. The focus in the Floris project is on a detailed assessment of the contribution of dikes, dunes and hydraulic structures to the flooding *probability* of a dike ring. For most dike rings the consequences of flooding are assessed in a rather global way. This is done for pragmatic reasons. For some dike rings, however, the consequences will be analysed in more detailed way as described in this paper.

The current application shows that not all required information is readily available. Adequate information on subsoil and inner material of dikes as well as on the foundation of hydraulic structures is lacking in quite a few cases. In the absence of sufficient data, (conservative) assumptions have to be made. Additional field research will help to reduce such uncertainties. The methodology developed, provides a systematic framework for assessing which research may offer the largest gain in reducing the flooding probability.

The Floris project introduces a new concept of safety against flooding. Hence, communication of approach and findings of the project is given ample attention. The project will not only provide information on flooding probability, but also information on flood risk in terms of economic damage and expected number of casualties. These types of outcomes open a new arena for use in policy making. Flood risk in terms of casualties may be compared with other risks in society such as industrial risks and risks in transport and aviation; see Jonkman *et al.* (2003) for an overview of quantitative risk measures for loss of life and economic damage. Such comparison should of course be carried out with great care, as different sets of assumptions may have been used in risk assessments for the various domains.

Information on flood risk in terms of economic damage may provide input to a societal debate on the required level of protection to flooding (Vrijling, 2001). The current flood protection levels of the various dike rings were determined in the 1960s. Thanks to economic and demographic developments the values that are protected have increased enormously. In addition there is the impact of climate change, which will result in larger loads on the water defence structure. Overall there appears to be enough reason for a reconsideration of the current protection levels of the various dike rings. The Floris project will provide valuable information to support such a process.

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