Risk management of large scale floodings

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This paper is primarily concerned with the objective description of events before, during and after a flood and the effect that various measures may have on the seriousness and impact of the consequences. Special attention is given to interaction effects between various consequences, the impact on larger (economic) systems, uncertainties in the various possible scenarios and monetarisation of the multi-dimensional effects. It is indicated how that information can be used to find the optimal measures. Detailed information can be found in the various topic reports.

Key words: risk management, flooding, loss of lives, economic loss, environmental damage, agricultural damage

1 Introduction

In a country like The Netherlands the protection against floods is a very essential and basic activity. Without a proper flood defence system at least half of the country would be flooded on a regular and for many parts even on a daily basis. The choice of the right measures is a common task for governmental and local decision makers in cooperation with many experts in social and engineering sciences. In this process risk analysis is becoming more and more a generally recognised tool.

Risk is a measure of the danger that undesired events represent for human beings, environmental and economic values. Risk is commonly expressed in terms of the probabilities and the consequences of the relevant undesired scenarios. A common definition of risk is the product of probability and consequence, or more precise the sum of the product of the probability and consequence for all undesired scenarios.

The major steps in risk management are:

- Identification of undesired events and scenarios;
- Quantification of scenario probabilities;
- Quantification of consequences;

- Assessment of the acceptability;
- Definition of optimal decisions on mitigating measures.

The first step is the recognition and qualitative description of potential hazards that may result in a flood. One can think of basic events like heavy rains and storms, high river discharges, high sea levels, but also of events like human errors, ships hitting flood defence structures and so on. These hazards may cause the initiating of events like a dike breach. The qualitative identification of hazards is a very important step of the approach. Indeed, once the hazards and combination of hazards are recognized, at least it is possible to discuss appropriate measures to overcome their consequences. Generally a variety of techniques exist that may help to recognize possible hazards and sequences of hazards (scenarios). In the flood risk management probably the best way is to follow a chronological analysis. Typical questions to be asked are: What will occur, where and when?

The next major step in risk analysis is the quantification of probabilities and consequences of the named hazards. In flood defence management it starts with the identification of locations where the defence systems may fail as well as the responsible mechanism. Then on the basis of models and statistics for the hydraulic loads and strengths of the systems one may calculate the initiating event probabilities. The modelling of the consequences starts with the calculation of the water depth and water velocity in the affected area. Next one should estimate the various consequences. In these parts of the risk management uncertainties may be present and should be considered where relevant.

Although the interest is on all types of floods the paper is primarily focused on the impact of large scale floodings in the western part of The Netherlands. Many of the results, however, can also be used for other types of floods. Consequences of floods may be classified into a number of categories, like:

- Casualties: fatalities and (mental) injuries;
- Damage to buildings, infrastructure and other material goods;
- Direct economic losses to industry and agriculture;
- Indirect economic losses due to the disruption of production chains;
- Ecological and cultural losses.

In order to enable the assessment of losses in the various categories one needs to:

- Identify the characteristics of the land use in the affected area;
- Estimate flood parameters like water depth, water velocity, warning time and so on;
- Establish relations between flood parameters and consequences (damage).

Given these data one may estimate the various types of losses in quantitative terms as for instance the numbers of casualties, the amount of economic losses, the pollution by various chemical releases and so on. This quantification of each consequence on its own is, of course, already a huge task. However, the feeling is that, for a good and realistic assessment of the risk, it is necessary also to look at possible interactions between the various events that follow the start of a flood. As an example, there may be interactions between the collapse of buildings and the number of casualties or water pollution and the number of people that may get ill. Further it is good to realise that the consequences in a flood are highly uncertain. Looking for instance at the inundation pattern, the mere fact whether a small inner dike will or will not resist the actual water pressure may be crucial. For an analysis to be realistic, randomness in the course of the flooding process itself should be introduced.

Given the probability of flooding and the assessment of consequences, the risk is defined as probability multiplied by consequences, where consequences consist of material damage, (lethal) casualties, environmental and agricultural damage.

Next step is to investigate whether the risk is acceptable. Risk acceptance is based on various criteria of risk that are reference points against which the results of the risk analysis are to be assessed. Criteria are generally based on laws or regulations, standards, experience, and / or theoretical knowledge used as a basis for decision about acceptable risk. Various aspects may be considered, for instance social and economic aspects. Acceptance criteria may be expressed verbally or numerically. Note that the acceptance criteria themselves should also be a matter of debate. Once established, laws and habits need to be updated from time to time due to a continuous change of circumstances and insights.

If risks are considered too large for direct acceptance, one should look for adequate measures. When planning measures, the techniques discussed above for the recognition of potential hazards are very helpful. The aim is to detect those events or processes, where an important effect can be obtained with a small effort only. Possible measures can be technical or administrative, and may cover a wide range of measures in the whole safety chain, including:

- The design and maintenance of the hydraulic infrastructure (dikes, sluices, etc.);
- The use of emergency flood areas;
- Measures, taken shortly before or during the flood (e.g. evacuation);
- Rescue operations, taken in case of an actual flood.

Further analysis should mainly be concerned with an analysis as to whether or not certain measures should be taken or not. Usually, an economic and societal balance between measures and risk reduction should be achieved. In some cases one simply has to accept the (remaining) risk.

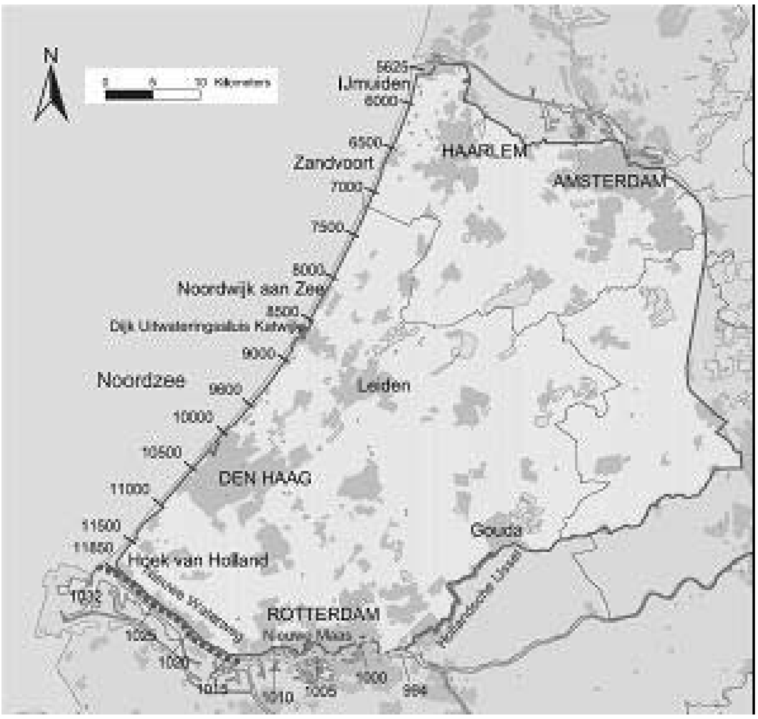


Figure 1: The case study "Centraal Holland"

2 General approach to the analysis of probabilities and consequences

2.1 ***The case study***

In this paper the strategy will be explained formulating a case study. The choice has been made to investigate the risk of flooding of the Western part of the Netherlands, the so-called dike-ring "Centraal Holland" (see Figure 1). A dike-ring is a distinct area surrounded by protecting dikes or other elements. Dike-ring "Centraal Holland" is protected by dikes, dunes, walls, higher grounds, storm-surge barriers, sluices and locks. The dike-ring system is divided into sections, each with its own characteristic flood scenario with unique consequences. In order to calculate the probability of failure of a section, a computer program called PC-Ring was developed in the Netherlands. PC-Ring is extensively described in this Heron issue by Steenbergen et al. In the program, the probability of failure of the several mechanisms is combined. The basic input consists of the statistical properties of load and strength of relatively small dike sections in which these statistical quantities are assumed to be constant. These sections may fail due to several mechanisms, e.g. overtopping, inner slope failure, piping. Mathematical models, some of them by quite extensive computer codes, rather accurately describe each of these phenomena. The results of a PC-Ring analysis are summarised in Table 1, where the reliability indices are given for every dike section i and every mechanism j.

As mentioned in the introduction, the risk is calculated as probability multiplied with consequences. When we consider all possible parts i of a dike-ring and all possible scenario's j, we obtain for the risk:

$$R = E(S) = \sum_i \sum_j P_{Fij} S_{ij}$$

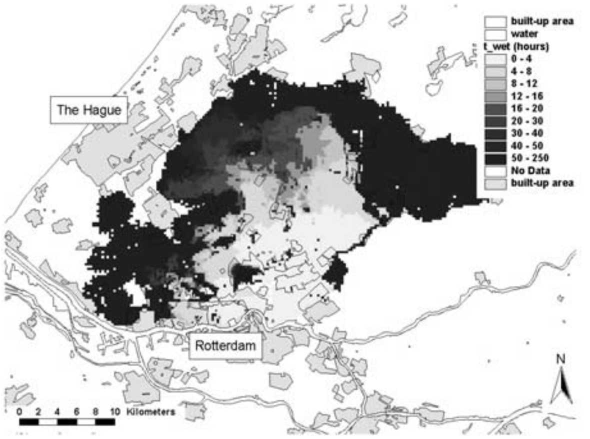
in which P_F is the probability of failure and S the consequence.

2.2 ***Flood characteristics***

To explain the process only the failure of only one section of the dike-ring "Centraal Holland" is investigated further, i.e. section 1 in Table 1, a river dike breach east of Rotterdam. The probability of failure of this dike-ring section is relatively low. The risk however could still be high because of extensive consequences.

The most important data in flood consequence analysis are the geometric properties of the affected area, in particular the ground levels, embankments and the infrastructure of surface waters. These data are direct input for the calculation of the flooding pattern. The flooding simulations were carried out using the 2D hydraulic SOBEK model. These simulations are described in more detail by Asselman and Heynert (2003). The most important results of the simulation for the case are shown in Figure 2. Figure 2a shows the time of flooding in hours after failure of the dike. The flood covers parts of Rotterdam and smaller cities like Zoetermeer and Gouda. The south-east part is flooded within 5 hours. It takes about 5 days or more before places near the boundary of the dike ring area are inundated. The water depth ranges from 6 m in the central part to less than 1 m at the boundary of the flooded area (Figure 2b). Maximum flow velocities follow a similar distribution with very high values of up to 7 m/s near the dike breach, decreasing to about 0.1 m/s at the boundaries of the inundated area (Figure 2c).

a



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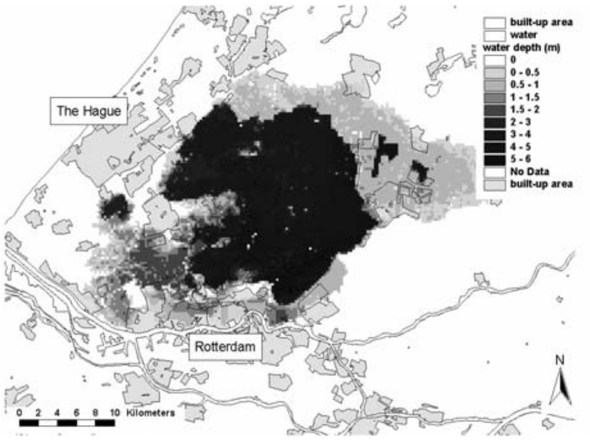

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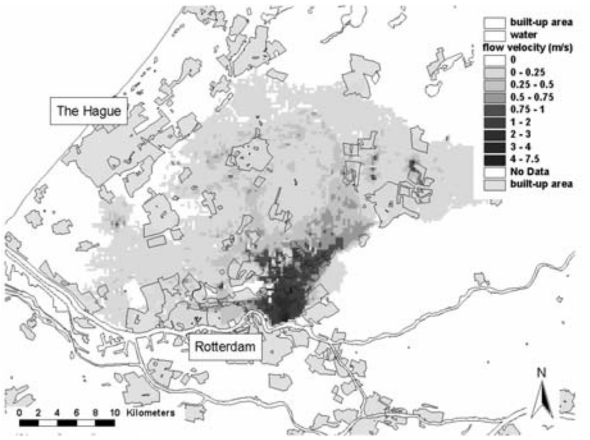

Figure 2: Case study: flood characteristics computed with the 2D hydraulic model: (a) time of inundation (hours after failure of the river dike), (b) maximum water depth (m), (c) maximum flow velocity (m/s)

Table 1: PC-Ring results: reliability indices for defence system "Centraal Holland" (TAW, 2000). The reliability index β is defined as: $\beta = \Phi^{-1}(P_f)$, where Φ represents the standard normal distribution. The total probability of failure of the defence system equals $P_f = \Phi(-3.3) = 5 \cdot 10^{-4}$.

Section	Over-topping	Slope in-stability	Piping	Erosion of revet-ment	Piping artefacts	Non structural failure	Dunes	Total
1	**5.0**	**6.6**	**8.2**	**5.7**				**5.0**
4	4.8			12.0				4.8
6	4.4				4.8	4.8		4.3
15	5.5				4.8	4.8		4.7
18	4.4	11.4	8.1					4.4
19	4.6	8.5	7.2	5.7				4.6
23	4.9				4.8	4.8		4.6
29	5.8					4.8		4.8
30	5.6	6.1	3.3					3.3
33	5.0							5.0
35					4.8	4.8		4.6
38							4.1	4.1
39							4.4	4.4
	4.3	5.1	3.3	5.6	4.5	4.4	4.1	3.3

2.3 ***Flood parameters***

The main results of the flood simulation are: water depth, rise and velocity, weather conditions, duration and water quality. Depth, rise and velocity are self-explaining. For every grid in the model, these parameters are calculated with the hydraulic model as a function of time. The main relevant weather condition is wind, leading to wet up and large waves that may cause damage on one hand and hamper rescue operations on the other. In the case of sea driven inundations there is usually high wind speed during the start of the inundation. For floods initiated by rivers, this correlation is much weaker. Another relevant weather issue is the temperature of water and air, which may play an important role in survival probabilities of people and animals.

The duration of the inundation plays a part with regard to both material damage and immaterial damage. As a rule, material objects suffer greater damage as they are in contact with water for a longer time or become partly or wholly saturated with water. Also, a long period of flooding increases the probability of greater distress and hardship or of people dying as a consequence of exhaustion, disease or hunger.

Finally, polluted water will cause greater damage than clean water. Also, seawater will have a different effect in terms of damage than fresh water. The (hydraulic) inundation model been coupled to models for migration of dissolved materials and sediment transport.
Next it is important to know the land use and population distribution in order to estimate the potential economic losses, environmental damage and loss of human lives. Land use comprises the land use, such as agriculture, industry, urbanisation, wet and dry ecosystems, recreational facilities, etc. Very relevant is information on the nature of the buildings in the affected area (low-, medium-, high-rise, the form of construction (masonry, monolithic concrete), the building materials used, the orientation of the buildings in relation to the flow, the protection of the building by other buildings or vegetation and the amount of debris in the streaming water that may destroy structural elements. The construction depth of the foundation of a building determines the possibility of scour of the foundation. Collapse of buildings is a large potential economic loss, but it may also affect the number of casualties. Further, it is important to obtain information on operational warning systems and evacuation plans prior to the inundation event, and rescue possibilities afterwards.

3 Economic loss

The factors of importance for the economic loss evaluation caused by a flood have been schematised in Figure 3. The extent of economic loss depends mainly on indirect factors that are directed by the flood and area characteristics. Direct damage consists of damage due to loss of properties, recovery damage to recourses and recovery damage to production means. Lifelines comprise electricity, drinking water, sewage system, infrastructure (roads, rail, waterways), gas distribution etc. Floods will affect a great many of these lifelines. This can affect the inundated area itself but also the surrounding areas. The economic losses caused by the loss of lifelines will not only include the repair of the lifelines itself but also the indirect losses caused by the loss of these lifelines. For example business interruption (no flow of goods, no employees). Other indirect damage is cleaning costs and evacuation costs.

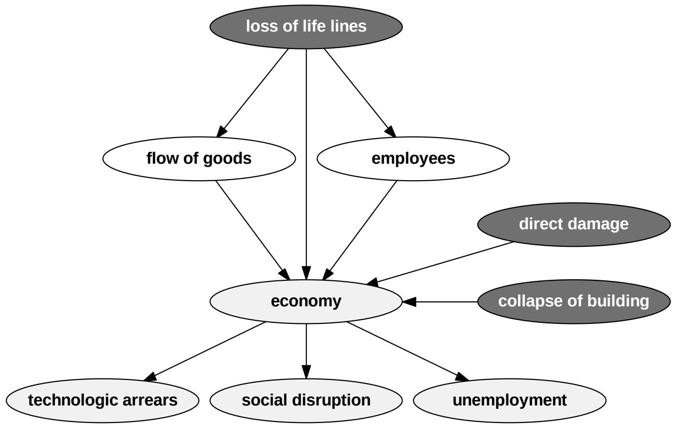

Figure 3: Economic loss by floods

The direct damage is a function of the water depth (and sometimes other flood factors) on the site where the properties are located. This type of damage is suitable to be calculated on the basis of a GIS-approach. For many types of goods, maximum potential losses as well as damage factor curves are available, see for example Figure 4. The damage factor has a value between 0 and 1, which indicates the degree of destruction. This factor depends on the category to which property is assignable and on the flood parameters. By multiplying the value of the object concerned by the damage factor the direct damage caused by a flood can be calculated. The direct losses include also the loss of production for a certain period after the flooding. Indirect economic losses refer to impact of the flood on a larger economic system. For instance, flooding may lead to a blockade of roads and railways, and hamper economic activities in area that may be outside the flooded area. Van der Veen and Logtmeijer (2003) have modelled the effect by means of an input-output matrix. The economic loss for the case “Centraal Holland” is calculated by means of a GIS model, combining the geographical information and flood characteristics. The damage inflicted to the economy in case of a flood is subdivided into direct damage (damage to capital goods in the dike-ring area) and indirect damage (interruption of production). The direct damage has been calculated according to the Dutch ‘Standard method’ (Vrisou van Eck and Kok, 2000). The indirect damage is calculated according to a so-called ‘input-output model’ assuming that 50% of the production loss is overtaken by areas outside the dike-ring. The economic damage equals 29,000 million euro. The indirect damage based on Van der Veen, et al. (2003) is estimated 28,000 million euro.

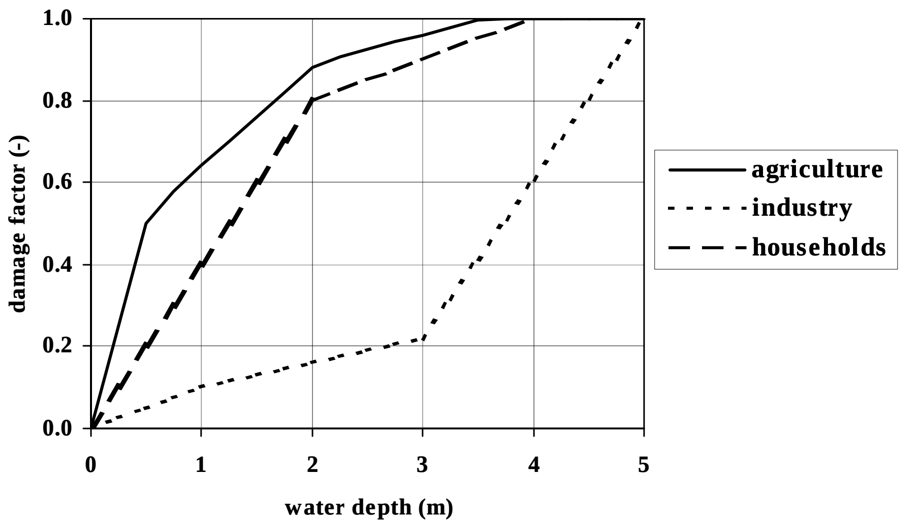

Figure 4: Example of damage function according to Standaardmethode (Kok et al. 2002)

4 Agricultural damage

Van der Most and Van der Bolt (1999) have developed a protocol to quantify crop damage. The following land use categories were investigated: grassland, arable land, high-grade agriculture, horticulture and greenhouse agriculture. Flood damage on agricultural fields is related to deterioration of soil structure and high salt concentrations of flood waters. For three groups of crops and for seven soil types, Van der Bolt and Kok (2000) have modelled this type of damage due to short, extreme precipitation events, both on arable land and on grassland. When extremely shallow groundwater tables develop on arable land, damage to crops is maximal after 72 hours of continuous flooding.

In addition, an assessment was made of the damage that is the result of reduced traffic ability and soil tillage. As data for arable land were unavailable, damage parameters for arable land were based upon damage calculated for grassland on sandy soil (Postma, 1992). The parameter values have been corrected for soil types other than sand and for crops other than grass. The flood damage functions for grass-, and arable land contain coefficients that are seasonally dependent. As a result, flooding of grassland during the winter season will not induce any damage.

Table 2: Estimated maximum crop damage in agriculture

	area		average inundation	produce	damage
crop	**(ha)**	**(%)**	**(m)**	**(€/ha)**	**(M€)**
grassland	36 094	71.4	1.75	900	32
glasshouse horticulture	3 494	6.9	2.35	225 000	786
cereals	2 394	4.7	3.32	900	21
potato (edible)	2 006	4.0	3.41	4 500	9
maize	1 413	2.8	2.14	900	1
sugar beets	1 144	2.3	3.30	2 800	3
orchard	100	0.2	2.92	11 500	1
total					**835**

The calculated damages given in Table 2 appear to be realistic, yet they cannot be verified due to a lack of data. In Van der Bolt and Kok (2000), flood damage to crops was assessed by multiplying flooded areas with average crop yields. The product varied from €900 / ha (cereals) to €30,000 / ha (flower bulbs). In glasshouse horticulture, flooding damage reaches a maximum at 0.5 m flood depth. For flooding events less than 72 hours, the damage is assessed to be 50%; for longer periods 100%. Yield losses range from €185,000 / ha for vegetables to €275,000 / ha for pot- and bed-plants. For the case study, inundation data is specified for the major categories of crops in Table 4. Assuming that crop damage is 100% after 72 hours continuous inundation, which is the case at all agricultural fields in this simulation, the damage was calculated by multiplying the produce (€ / ha) with the associated acreage (ha), yielding a total damage due to flooding of 853 million euro (worst case scenario).

5 Loss of human lives

*5.1 **Approach***

Loss of lives during a flood can occur in many ways. For instance, people can be swept in the water and buildings can collapse. Also indirect causes, such as flood induced heart attacks, shocks and electrocution during the clean up phase can contribute to the death toll. Floods can even result in higher mortality levels in the years afterwards, due to an increase of stress and illnesses, see for example (Bennet, 1970). The many factors that influence the number of casualties by a flood are shown in the diagram, see Figure 5.

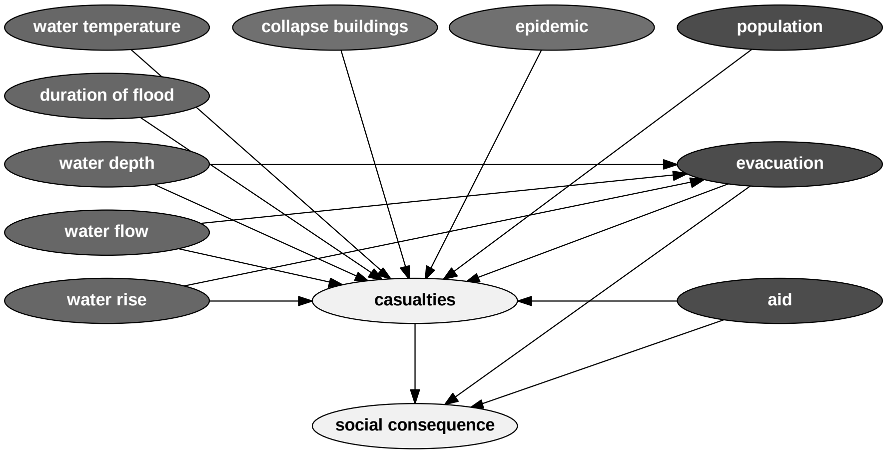

Figure 5: Casualties by floods

Based on the collected data from the 1953 flood the following approach is proposed to relate flood mortality (i.e. the fraction of inhabitants in an area that lose their life in the flood) to hydraulic characteristics of the flood. Three categories of flood deaths are distinguished:

- Drowning persons due to rapidly rising water;
- Drowning persons due to high flow velocities;
- Deaths due to other causes, such as hypothermia, heart attacks, shock, failed rescue, etc.

Analysis of shows that rapidly rising water levels were the main cause of death during the unexpected flood in 1953 in The Netherlands (Waarts, 1992). People will not be able to reach high grounds or even to reach the higher floors of buildings when the water rises rapidly. It is expected that especially the combination of water depth and rate of rising causes the danger. The fatalities caused by rapid increase in water depth during the 1953 flood are shown in Figure 6.
The second mechanism is that due to high flow velocities people lose their stability, fall into the water and drown. Buildings can collapse as well. Especially dangerous situations will occur near the breach (where high flow velocities occur). Tests on the stability of people in flows have been carried out by Abt et al. (1989). Roos (2003) has set up a method to analyse the collapse of buildings during floods. The mechanism of collapse of walls is considered for four types of housing: traditional buildings, Cast concrete and prefabrication. In the model developed by Roos the probability of collapse of a wall can be determined as a function of water depth and flow velocity.

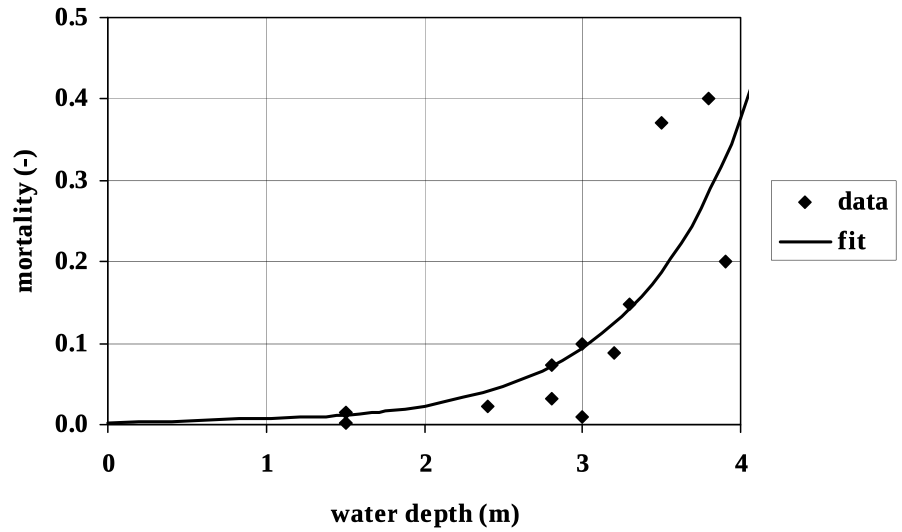

Figure 6: Proposed function for estimation of flood mortality for rapidly rising water

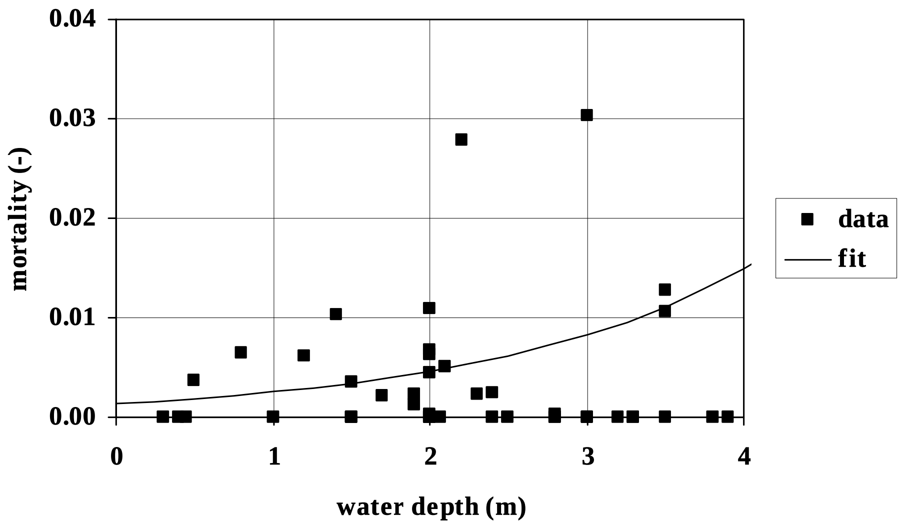

Figure 7: Proposed function for flood mortality estimation due to other causes

If rapidly rising water levels or high flow velocities do not cause fatalities, other causes may also result in fatalities. These causes can be for example hypothermia or fatigue of persons, collapse of building after a long period of hydraulic load. Besides, people drown during rescue operations (also the rescuers). Indirect causes of death, such as heart attacks and electrocution, can be relevant as well. For the 1953 flood the reported mortalities for other causes are shown in Figure 7.

5.2 ***Evacuation***

The probability of drowning may reduce when evacuation is carried out. Barendregt et al. (2002) developed a simple conceptual method to simulate an evacuation of a flood prone area in the Netherlands. This model mainly considers preventive evacuation before the beginning of the flood. A preventive evacuation consists of three stages: the decision-making, initiation of the evacuation, and the evacuation itself. The time needed for each phase depends on the availability of an evacuation plan, the number of people to be evacuated and the available infrastructure. The available time for evacuation depends on the predictability of the water levels at sea or in the river and the failure mechanism. While extreme river discharges in the Netherlands can be predicted up to several days' ahead, extreme sea water levels have a much shorter prediction time (6 – 10 hours). Failure of a dike is relatively easy to predict in case of overtopping, but is much more difficult to foresee in case of the failure mechanism piping. In case of evacuation or escape after failure of the dike, the available time only depends on the travel time of the flood wave to a certain location within the flooded area. The time needed for decision making and initialisation in that case equals the time needed to warn people and for the people to prepare themselves for departure. The time required for evacuation depends on the capacity of the infrastructure. In the case of evacuation after failure of the river dike this will mainly be the capacity of the roads as the railway system is expected to be dysfunctional. Depending on the available time and the requested time, a certain percentage of the inhabitants will be able to escape in time.

The number of casualties of the case "Centraal Holland" is calculated by means of a GIS model, combining the geographical information, flood characteristics and evacuation possibilities. The summarised outcome is presented in Table 3.

Table 3: Estimated number of fatalities for the case "Centraal Holland"

	estimated value
inhabitants dike-ring area	3.6 million
inhabitants inundated area	942,334
inhabitants unable to escape	485,795
inhabitants unable to escape, living in high-rise buildings	40,354
fatalities due to high flow velocities	5035
fatalities due to large water depths, rapid rise	66,453
fatalities due to large water depths, slow rise	2154
total number of fatalities	71,800
% of inhabitants killed	7.6

The high flow velocities in combination with large water depths, strong enough for the destruction of buildings only causes fatalities near the dike breach. The number of fatalities caused by large water depths is much larger. No people are killed near the boundaries of the flooded area. This is because almost everybody is able to escape or because water depths and flow velocities are low. Evacuation during the flood does not significantly reduce the number of fatalities in this case study area. This is because the area where most lives are lost is inundated within a few hours. Escape during the flood is therefore impossible. Only evacuation beforehand would have helped to reduce the number of fatalities in this area.

6 Environmental damage

6.1 ***Introduction***

So far, little research has been carried out into the environmental impacts of floods (Zwolsman et al., 2000). Pollutants are dispersed through the air (not included in this study), dissolved in water and adsorbed to suspended matter. The release, migration, decay and sedimentation of the pollutants is simulated with flow- and sedimentation models. The polluted water and suspended matter affect people and ecosystems - the targets - in the flooded districts.
The environmental damage depends mainly on the magnitude of water flow and water depth. These two factors may also result in damage to structures containing inflammable materials or chemicals that may catch fire, explode or be released. This, in turn, will lead to pollution of sediments, water and air. The release of chemicals can also take place just by overflowing industrial areas without damaging the structures. Environmental damage can be assessed by incorporating cleaning costs, yet profound structural damage to dry and wet ecosystems may be hard to express into quantities.

6.2 ***Transport models***

The water quality module ‘Delwaq’ simulates the spread of pollutants following the flooding event, simulated by the SOBEK model. Grid cells were involved in the water quality simulations only if the water height exceeded 0.2 m. The potential sources of contamination are quite diverse: industries, garbage dumps, farms (herbicides, pesticides), cars, oil tanks near petrol stations, diffuse sources of contamination in the soil and, not in the least, the water of the river Rhine which inundates the polder district. In this paper, a simplified version of Delwaq was adopted, describing the release and migration of pollutants with a limited set of parameters, either dissolved or suspended.
Suspended material is a crucial transport medium for pollutants since key pollutants like heavy metals and insecticides are easily adsorbed to (moving) soil particles. The accumulation and spatial distribution of hazardous toxics is therefore linked to suspension- and sedimentation processes.

When a dike breach occurs, riverine silt- and clay sized material enters the area. The highest suspended sediment concentration in the Rhine and Meuse rivers usually occurs just prior to the peak discharge of the river (Middelkoop, 1997). At high flow velocities, erosion may further enhance the concentration of suspended solids in the water; potential sources are channels/depressions and bare arable land. The sediment transport model that was used in this study was primarily developed to simulate sediment accumulation in so-called Emergency Retention Areas ('ERAs') in The Netherlands (Asselman, 2003; Cuypers, 2000).

6.3 ***Results***

For all toxic substances in the flooded area, sources, volumes, release rates and sedimentation mechanisms were investigated. The release mechanisms depend on the flooding conditions and the way the materials are used or stored. Ten groups of harmful compounds that were regarded the most relevant for this case study were included in the simulations. The selection was based on a combination of 'toxicity' and volumes present, and was based on known flood cases. Toxicity should be interpreted somewhat loosely as 'the capacity to alter or disturb the receiving environment', hence phosphates - fertilising the soil of rural areas - were included.

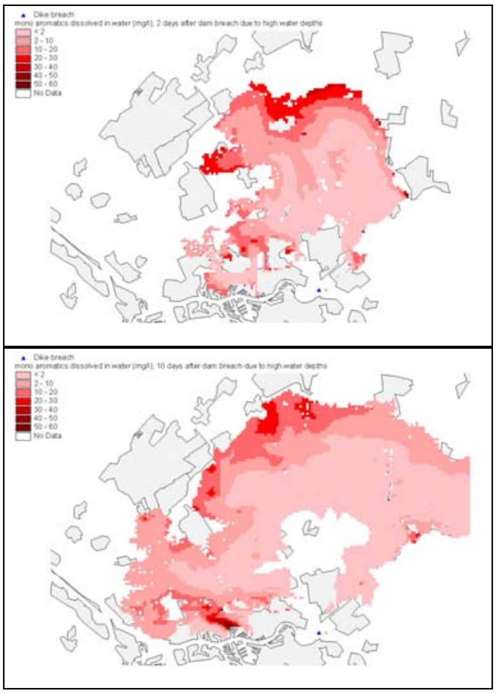

Figure 8: Mono-aromatic concentrations, 2 days after the dike breach (left) and 10 days after the breach (right)

Figure 8 shows a typical result of the study: concentrations of dissolved mono-aromatics. The highest concentrations are found near the downstream borders of the flooded area. Most aromatics originate from the river Rhine. Less than 10% of all simulated mono-aromatics will be benzene. Still, the flooding will lead to concentrations well in excess of the Dutch Intervention value (0.03 mg benzene /l), even after 10 days. Hence a substantial part of the inundated area will be covered with seriously contaminated water for more than 10 days. Due to decay, the concentrations will gradually decrease to values that will not pose any risk to human health.
The environmental damage for the case “Centraal Holland” is calculated by means of a GIS model, combining the geographical information and flood characteristics and is summarised in Table 4.

Table 4: Environmental damage of flooding due to dike breach near Rotterdam

substance	**concentration**
sediment	2 mm
PAHs	40 mg/kg
alkanes	6 g/m^2
DNAPLs	3 mg/l
phosphates	250 kg/ha
heavy metals	700 mg/kg

According to Dutch regulations, all pollution must be removed. The regulations prescribe that all contamination which occurred after 1987 has to be cleaned up. Assuming that this regulation is applicable in case of flooding, a first estimation of cleanup costs can be done. The total amount of sediment deposited in the area is estimated as 388 million kg, which is equivalent to approximately 0.23 million m^3. As it is difficult to remove layers less than 10 cm thick, this could mean that a total volume of 10 million m^3 would have to be disposed of as contaminated soil. With typical soil remediation costs of 35-55 €/m^3 this would amount to total cleaning costs of 350 to 550 million euro. This scenario is not very likely, though. In the flooded area, 15% is urban area and 85% is agriculture land. As outlined above, mixing with underlying soil is likely to take place in agricultural land, apart perhaps from locations with thicker accumulations of sediment. In urban areas, material deposited on hard-covered areas could be collected. This may be cumbersome (and thus expensive) in cases when the sediment has entered areas that are difficult to access. Nonetheless a more realistic cost assessment could be that only about 30% (15% from the urban areas and say another 15% from rural areas) of the sediment would be disposed of as polluted soil. Clean-up costs per m^3 might be higher than stated above (say double). This would result in estimated cleanup costs of about 80 million euro.

7 Decision making

7.1 Risk acceptance

The aim of a risk analysis it to judge whether the risk is acceptable, and if not, to decide on the measures to be taken. The acceptability of risks is usually judged against three criteria:

- The individual risk criterion
- The societal risk criterion
- The economic criterion

First of all it has to be remembered that this case study is only a small part of the risk of inundation of the "Centraal Holland" dike-ring. As mentioned in paragraph 2, the risk should be calculated as a summation of all possible dike-breach locations. Here only one of the many locations has been investigated, i.e. the dike section near Rotterdam. The consequences of the dike breach are summarised in Table 5.

Table 5: Consequences of flooding in the case "Centraal Holland"

Damage type	Consequence
Direct damage	29,000 million euro
Agricultural damage	853 million euro
Indirect damage	28,000 million euro
Fatalities	71,800 persons
Environmental damage (cleanup costs)	215 (=(350+80)/2) million euro

The individual risk limit is based on the idea that a person's fatality rate should not be dominated by one type of hazard. This certainly holds for dangers like floods that are endured on a non-voluntary basis. Therefore the acceptance level of flood risks will be lower than the acceptance level of, for example, skiing. In this case the probability of flooding of the whole dike ring is $4.8 \cdot 10^{-4}$. The probability of fatalities given a flood is equal to 2% (= 71,800/3.6 million). The risk for the total community in defence system "Centraal Holland" is therefore on average approximately 10^{-5}. Compared to the Dutch standards this is acceptable. Note that the inhabitants living near the dikes have a risk equal to $4.8 \cdot 10^{-4}$, which is not acceptable.

The societal risk limit is based on the fact that the society has a great aversion against accidents with many casualties at once. Such accidents are usually presented in the form of so-called F-n-curves. In this case n equals 71,800 and F equals a $2.9 \cdot 10^{-7}$. The case "Centraal Holland" is within the ALARP region (as low as reasonably possible).

In order to fulfil the economic criterion it is essential to seek an appraisal in the sense of weighing the risk, on the one hand, against the cost of constructing a flood defence structure, on the other. In other words: is the expected reduction in risk larger than the cost to reduce this risk.

*7.2 **Optimisation***

The rational scientific approach is relatively easy. The pros and cons of a certain existing or future situation are translated to a one-dimensional scale by setting numbers for every event. These numbers have to match with the preferences of a certain person or group of persons on whose behalf the decisions are made. Following the above approach means that the original multidimensional risk is reduced to a single number, expressing the total risk. Of course this procedure involves a crucial loss of information if possible at all. However, in order to arrive at some rational decision criterion one has to compare the incomparable by definition.
The most common denominator to express all consequences in one uniform way is money. Of course one may argue that not all matters can be expressed in terms of money. It is indeed difficult to express the value of a human life as an amount of euros. On the other hand, one should keep in mind that this amount is nothing more or less than help in making consistent decisions. If one does not have those explicit considerations one is forced to make such decisions implicitly, leading to a result which probably is much less consistent and optimal.
As an alternative to economic or utility optimisation one often proposes the multi criteria analysis (MCA). One should however keep in mind that also in this approach, all consequences are reduced to one scale. So in the end there may be little difference. The techniques of MCA may be help in the process of setting the utilities. In the same way a utility approach may help to find where the structure of a MCA is a logical one and where it is not. Some people prefer the procedure wherein economic optimisation is used for monetary aspects and non-monetary aspects are covered by constraints. These constraints usually give some hard boundaries that cannot be neglected. From the scientific point of view this is not very attractive and logic. However, from a societal point of view such a procedure is clear and often well accepted. When dealing with economic matters one usually discounts future costs and benefits. It may be considered as a philosophical problem how too deal with in this respect to monetary values for human lives, culture and nature.

*7.3 **Options and consequences***

Assume that the current probability of failure of the total flood defence system is $4.8 \cdot 10^{-4}$ ($\beta = 3.3$, Table 1). Consider three options, which may decrease the probability of failure of the defence system. In this example it is of no importance what measure is taken. Here it is assumed that the higher levels of protection are obtained by dike improvement along the full length of the flood defence system (100 km). The improved dikes (as well as the existing ones) have an expected

lifespan of 100 years. The options and corresponding probabilities of failure and dike heights and costs of the options are summarised in Table 6.
It is assumed that the initiation costs of a dike improvement (independent of the desired safety level) are much larger than the variable costs (dependent of the desired safety level). The figures in this table are rough estimates, based on the costs of the execution of the Delta Act Major Rivers (1996) in The Netherlands.

Table 6: Options and corresponding probabilities of failure and dike heights and costs.
The costs of dike improvement are 0.4 million €/km per m dike height plus initial costs of 1.2 million €/km.

option	**β**	**probability of failure [-]**	**dike height [m +N.A.P.]**	**total costs [10^6 €]**
0 (current situation)	3.3	$4.8 \cdot 10^{-4}$	2.8	0
1	4.0	$3.2 \cdot 10^{-5}$	3.55	150
2	5.0	$2.9 \cdot 10^{-7}$	5.05	210
3	5.5	$1.9 \cdot 10^{-8}$	6.0	248

In considering the options mentioned for improvement, many criteria can be taken into account. In this example the following criteria are considered:

- Construction cost [€];
- Damage to 'nature values' (containing landscape, nature and cultural heritage);
- Expected economic losses (direct and indirect) [€/ year];
- Expected number of fatalities [1 / year];
- Expected environmental damage (clean-up costs deposited pollutions) [€].

The damage to nature values (landscape, nature and cultural heritage) are usually difficult to express in a quantitative unit. Landscape and nature in the dunes and along the river dikes have been allocated a very high value almost everywhere. Ancient houses, which are very typical for the Dutch river landscape, have been built directly next to, or on top of the dike. However, it can be assumed that the more drastic the dike improvement, the more damage is inflicted on these landscape and cultural values. In this context it is therefore assumed that option 3 inflicts more damage than 2, option 2 more than option 1, and option 1 more than option 0 (which acts as a reference situation: no measure; no damage).
In the performance matrix, see Table 7, the performance of the options for each criterion is presented. The performance matrix does not give a clear best option; options have simultaneous low costs and high expected damages and vice versa. Two ways are presented which can be used to determine the optimal solution: an economic optimisation and a multi criteria analysis.

Table 7: Performance matrix

	Costs of improvements		Expected damage		
option	**Construction costs [10^6 €]**	**Nature values [-]**	**Economy [€/year]**	**Fatalities [1/year]**	**Environment [€/year]**
0	0	neutral	$2.8 \cdot 10^{7}$	35	$2.9 \cdot 10^{5}$
1	150	bad	$1.8 \cdot 10^{6}$	2.3	$1.9 \cdot 10^{4}$
2	210	worse	$1.6 \cdot 10^{4}$	$2.1 \cdot 10^{-2}$	$1.7 \cdot 10^{2}$
3	248	worst	$1.1 \cdot 10^{3}$	$1.4 \cdot 10^{-3}$	$1.1 \cdot 10^{1}$

7.4 Economic optimisation

To decide which of the four options should be applied, first a strict economic optimisation is performed, taking the construction costs, the economic and environmental damage into account. In order to enable comparison between construction costs and expected damage per year, the initial construction costs are converted into annual costs according to:

$$I = I_0 \frac{re^{rt}}{e^{rt}-1} = 0.023 I_0$$

where I is the annual costs, I_0 the initial investment, r the discount rate (2%) and t the lifespan (100 years). In a simple approach the annual costs may be taken as $0.03I_0$, i.e. the discount plus the annual payment (= 1% for a lifespan of 100 years).

The effects of (the monetary value of) fatalities on the economic optimum are also investigated. It is assumed that one casualty equals to 3 million euro. This value is based on References Rackwitz (2001) and De Blaije (2003). Other values also occur in literature varying from 1.5 million euro to 20 million euro (Seiler, 2000), but it appears that in this particular case the choice of a monetary value has no influence on the final optimum.

The results presented in Table 8 and Figure 9 show that option 2 is the best option, as the total costs of that option are the lowest. The incorporation of the costs of fatalities and environment does not change the location of the optimum.

Table 8: Economic optimisation: total expected costs for the four options

	total expected costs [10^6 €/year]		
option	**construction + economic**	**+ fatalities**	**+ environment**
0	27	132	132
1	5.3	12	12
2	**4.9**	**5.0**	**5.0**
3	5.8	5.8	5.8

The values in bold give the lowest total costs.

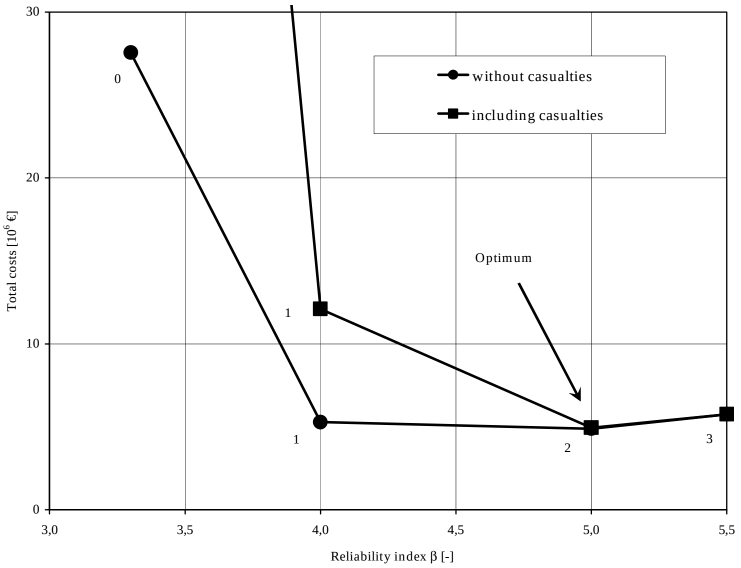

Figure 9: Results of the economic optimisation

7.5 ***Multi criteria analysis***

In order to enable comparison between the various options considering the discussed 5 criteria, it is customary to allot a value score to each criterion between 0 and 10. In this example the following is applied per criterion (costs and damage): 0 is assigned to the worst value, 10 is assigned to the best value; the score for the intermediate values are obtained by linear interpolation except for 'nature values' (as this criterion can only be qualitatively assessed), see Table 9. Scoring can be executed in many other ways, amongst others according to non-linear utility-functions. The scoring applied here is considered to be a rational one and a little more sophisticated than ranking the costs and expected damage from one to four. As a consequence the scoring results for the expected damage are indifferent to options 1 to 3.

Table 9: Scoring for each option

	costs of improvements		**expected damage**		
option	**construction costs**	**nature values**	**economy**	**fatalities**	**environment**
0	10	10	0	0	0
1	4	4	9	9	9
2	1.5	3	10	10	10
3	0	0	10	10	10

In order to take different viewpoints into consideration, different scaling sets are used to weigh the various criteria. The following scaling sets considered are given Table 10.

Table 10: Scaling sets (viewpoints)

	costs of improvement		expected damage		
scaling set	**construction costs**	**nature values**	**economy**	**fatalities**	**environment**
neutral	0.25	0.25	0.167	0.167	0.167
prone	0.4	0.4	0.067	0.067	0.067
averse	0.1	0.1	0.267	0.267	0.267

For viewpoints that are risk-neutral, the costs of protection are as important as the expected consequences in case of a flood. For viewpoints that are risk-averse the *expected damage* is more important than the *costs of improvement*; for viewpoints that are risk-prone it is the other way around. It goes without saying that many other viewpoints can be applied as well. Table 11 shows the results for each option per scaling. It is to be seen that different scaling sets lead to different results.

Table 11: Results of the multi criteria analysis for the two scoring methods

		viewpoint	
option	**neutral**	**prone**	**averse**
0	5.0	**8.0**	2.0
1	**6.5**	5.0	8.0
2	6.1	3.8	**8.5**
3	5.0	2.0	8.0

The values in bold give the highest score with respect to the viewpoint.

In the neutral viewpoint option 1 has the highest score though the difference with option 2 is small. In the risk-prone viewpoint option 0 is highest, which means that no measures should be taken at all. Option 1 has second highest score. In the risk-averse viewpoint option 2 has highest score though the difference with option 1 and 3 is small. The costs of option 3, which would intuitively be the ultimate risk-averse option, are relatively too high.

Option 1 seems to be the option which scores the best considering all the three viewpoints. Note that in the economic optimisation option 2 is the best option and the difference with option 1 is made by the costs of fatalities.

8 Closure

The result of the above decision process is the optimum for a certain individual or a certain group with common interest. Decision-making becomes more complex when the stakeholders with a variety of preferences or interests are present. Not everybody has the same view on the value of masterpieces of art or areas of a great importance for wild life. Even in a purely economic context, people will have different opinions, depending on how they may profit form certain mitigating measures. Finally, apart from "objective items" like probability and consequence, many more psychological matters may play an important role like the degree of voluntariness, the way the authorities are believed to control and assist in case of a disaster, the simple feeling of something being safe. The point is that a citizen is not only interested in "objective safety", but also or even more in a comfortable feeling of being safe. The conclusion is that the final decision about the safety measures is not the outcome of some mathematical calculation, but of a democratic process where many parties with conflicting interest may be involved, and emotions are judged to be at least equally important to arguments, based upon rational technical-, and decision theory.
The main difficulty in the communication about this topic is the divergence of perception for the keywords and numbers between the various partners. Among experts it may be reasonably clear what the definition is of words like probability, consequence and risk and how to deal with them in a rational decision making context. Other people, however, may have completely different opinions and are usually not easily inclined to follow the experts in this very sensitive topic. Especially if experts do not agree on all points, which may easily be the case for small probability large consequence events, there is a legitimate excuse to neglect the expert views completely. In those cases a non-expert is inclined to consider an imaginable event as more likely and vice versa. In particular, recent disasters will increase the imaginability of related events. Events of long ago will generally be considered as being not very likely to happen again.
The final decision is the outcome of a political process where many emotional and psychological influences of individuals and groups may play a role. It is important to pay attention also to this part of the game as in the end only the decisions made in the politics are relevant. It is envisaged that in a follow up of this research the scope will be widened in this direction and cooperation will be sought with other experts like psychologists, sociologists and public administration scientists.

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