FLOOD RISK MANAGEMENT FOR SETTING PRIORITIES IN DECISION MAKING

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Abstract- Risk management as a tool for decision making has found more and more acceptance among scientists, and even for planners of flood protection systems. However, a shortcoming of this approach is that at present it only considers risk cost as management tool. It is at present the basis for most risk based approaches, which start with hazard maps, which can be prepared, in conjunction with Digital Terrain Models (DGMs) and geographical information system, if the necessary basic hydrological and topographical data are available. In fact, in many areas and in many countries it has become good practice to develop maps based on flood areas for different exceedance probabilities, with flood zoning as a preferred information for preparing the public for floods.

For planning decisions, such maps are not sufficient; they must be converted into risk maps – maps in which the potential damage from floods is also assessed. Expected values of economic damage are used as decision criterion, preferably in the context of a benefit cost analysis, in which the costs of generating a flood protection system are compared with the benefits derived from the planned protective measures. This approach will be briefly covered in the first part of the lecture. Today we are challenged toextend the definition of risk to include also environmental and social issues. Environmental aspects mostly concern ecology of the river and the flood plains, issues that will not be addressed in this paper. The social part of risk management consists of the assessment of floods on the well being of people. Part of this is the effect of the monetary damage: damages of one Million US$ are not much in a rich country, or a rich community, but they may ruin the development potential of a whole community in a poor country.

The assessment of such issues requires a people- instead of a Government oriented framework. It includes resistance and vulnerability of

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people at risk. In this paper it is attempted to provide such a framework – which should be simple enough to be used by non-scientists. Resistance and resistance changes are defined by indices describing coping capacity of populations at risk against extreme flood events by using their own resources, indices for vulnerability and vulnerability changes describe the exposure of populations at risk and are defined as the total demands on the available resources. In this way resistance and vulnerability can be quantified for defining an index of vulnerability, which may form the basis for decision making in setting priorities, either on the local level, or for donor programs in developing countries.

Keywords: Vulnerability, Coping capacity, Resistance, Load, time development, flood risk planning, flood risk operation

1. Introduction

It is a primary purpose of governments at national, regional and communal levels to protect their people from harm to life and property. In many parts of the world this is a never ending challenge, as people at risk are threatened by natural extreme events, against which protection is possible only to some degree, depending on the magnitude of the extreme event and the technical and economic capability of the country or community. Absolute protection from extreme natural events, such as floods, can rarely be obtained, in particular if the perceived benefits from living in an endangered area exceed the disadvantages associated with the risk. Present day concepts for management of extreme natural events are based on providing protection up to a certain acceptable level, and to live with the residual risk, i.e. be prepared to prevent disasters when an extreme event strikes that exceeds the acceptable level.

Disasters are often classified by their primary causes, viz. “Natural or Man-Made”, although the definition becomes blurred when looking more closely at the nature of natural disasters: an extreme flood event occurring in an area in its natural state untouched by humans cannot cause a disasters, which requires that a population exists whose lives and property are threatened by the event. A disaster therefore requires both occurrence of an extreme event and presence of a vulnerable population. Insurers speak of a disaster, if consequences of an extreme event are very large, such as number of fatalities, or if property damage exceeds a large amount of US $. The definition to be used in this paper is based on the ability of people at risk to cope, in agreement with the definition given by ISDR (2002). A disaster occurs, if people at risk cannot cope with the consequences of an extreme event and need outside help for recovery. This concept of a disaster applies, in principle, to any societal grouping: a family, a community, a region, a country, or even to all humanity. It implies that a disaster is seen from the perspective of people at risk: destruction of the home of a family which the family is unable to replace for financial reasons is as much a disaster, as the inability of a region hit by a large flood to recover without government help, or international aid programs. This generalization will be adopted here, although the term disaster is usually reserved to events that cause widespread damage, i.e. refers to large population groups (ISDR, 2002).

In agreement with this definition, disaster prevention is defined as the series of actions to prevent the consequences of an extreme event from turning into a disaster. Extreme events cannot be avoided, and some losses must be expected whenever they occur. However, appropriate responses to prevent an extreme event from causing a disaster are possible in most cases if its consequences can be anticipated, evaluated, and measures taken. The evaluation needs indices, which can be used to quantify the combination of factors leading to potential disasters. It is the purpose of this paper to present a framework for such an evaluation.

2. Indices for Quantifying Disasters

It is useful to start with a definition of indicators and indices, as these terms will be used throughout the paper. The definitions have been clearly stated in a number of papers, most recently succinctly in the UN World Water Development Report (UNESCO, 2003), see Fig. 1. Indicators (symbol = capital letters) as used here are quantities based on variables (symbol = lower case letters) which enter into a decision process. The variables describe information from different sources. They can be numbers, such as monetary averages (i.e. cost of certain vital goods, such as price of water), or descriptive (i.e. state of the environment). They are aggregated to form indicators, which can be used to quantify processes, in order to form a basis for decision making. If all indicators are numeric and have identical units, such as monetary units, indices may be calculated by direct use of the (weighted) indicators. If all variables are verbally expressed, such as referring to the state of environment or to social conditions, they may be replaced by weights, (i.e. the state of the environment may be weighted on a scale of 1 to 10, where 1 is an environment in poor condition, 10 in perfect condition). Indicators are used to calculate indices, expressed by the term IX, where I identifies the index and X the type of index. Additional weights describe the importance of each indicator for the decision process. Indices usually are obtained as combinations (i.e. sums) of weighted indicators.

Through its weight each indicator is represented by one number. The accumulation process of variables into indicators and an index is illustrated in Fig. 1 (UNESCO, 2003), which is using the terminology adapted for this paper.

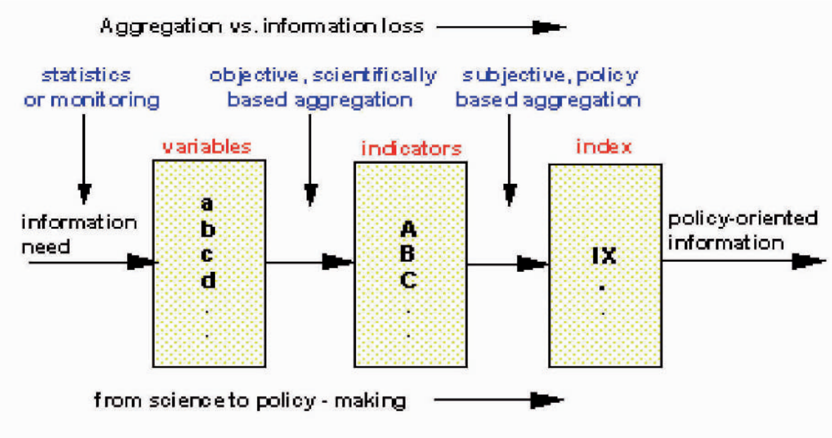


Figure 1. From variables to indices and from scientific information to decision criteria (from UNESCO, 2003)

Traditionally, indicators based on costs and benefits, with benefit -cost ratios as index, have been used. Other indicators are used to describe the state of countries (UNDP, 2000, World Bank, 2000). But for a decision for flood protection, or more generally, for disaster mitigation, monetary considerations are not sufficient. Indicators should include other vulnerability factors: not only costs and benefits, but also human suffering and secondary effects on local to national economies, environmental damage, and social stability need to be considered. How this can be accomplished is an open question, and research is needed to develop indicators which include vulnerability both of persons, and also of ecological consequences. A large body of research connected with defining and using indicators and indices is available (i.e. Betamio de Almeida & Viseu,1997 in which indicators for vulnerability towards dam break floods are discussed), but at present no satisfactory set exists for flood risk management decisions. Selection of significant indicators and formation of an index or of indices is a problem of multi-criteria decision making for which Operations Research techniques must be employed (see for example Zimmermann & Gutsche, 1991). At least in developed countries, environmental benefits and losses are prominently, but usually intuitively, weighted in decision processes , whereas mental anguish and consequences to the social system of a community threatened by extreme events has not yet found an appropriate indicator system (see Blaikie et al., 1994, Bohle et al., 1994).

For developing an index to describe the susceptibility to disasters, i.e. the vulnerability of a population, a community, or a household, it is useful to introduce two sub-indices. The first describes the ability of the people to cope – let this be called the resistance, and let it be denoted by symbol R (in the Figures denoted by V_{crit}). It is a measure of resources available to people at risk. In its simplest definition, applying the notion to a single person or a family, it could be the total annual income of a person at risk. This sub-index should not only cover indicators for monetary resources, but the term "resources" should be used in a much broader sense to include social, health and gender status, vulnerability against changes and other stress factors which might disrupt the lives of any subgroup of people at risk (Blaikie et al., 1994). The second sub-index describes vulnerability of people at risk. We intend to use vulnerability in a broad sense: it is the demands on the resources of the people made to safeguard their general livelihood, - not only, but including, demands on their resources as consequence of extreme events. We express vulnerability by means of a sub-index V, which is split into two parts: sub-index V_s, as a measure of demands on resources due to everyday living, and sub-index V_r to describe the additional demands on resources as consequence of an extreme event. In a simple economic perspective, V_s is that part of a person´s financial resources needed to cover the cost of living, whereas V_r is the economic damage caused by an extreme event. A disaster occurs if at any time sub-index of vulnerability exceeds sub-index of resistance, i.e. when $R – V > 0$.

The relationship among the sub - indices is depicted in Fig. 2. Shown is the distribution over time of average daily values of the sub-indices during a period when an extreme event strikes. Part V_r of vulnerability V is superimposed on the daily value of V_s. We show two hypothetical curves for V_r: curve 1 is a case where coping capacity is not exceeded, consequently, people at risk are capable of handling damages from the event by themselves. Curve 2 is a case where, due to the extreme event, resistance R is exceeded: a disaster occurs. The curves for V do not remain at their maximum peak, in course of time effects of extreme events are reduced, and ultimately a state is reached where $V = V_s$, although the disaster may have such an impact that V_s after disaster is larger than V_s before the extreme event - including in some case values of V_s which for very long times, or even permanently exceed R.

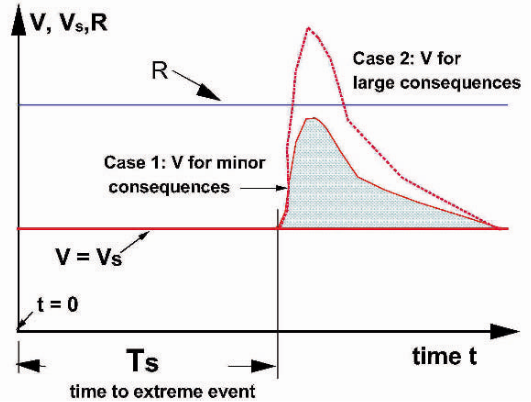


Figure 2. Schematic view of resource use during extreme event

We realize that it is difficult to put numbers on development curves as shown in Fig. 2. But it is evident from this figure that an index of vulnerability from disaster should be a relative measure: people or communities with a large reserve R – V_s are less likely to suffer a disaster than people at risk who are not so fortunate. By relating disasters to the balance of coping capacity and vulnerability, we obtain a more realistic assessment of the actual effect of an extreme event. We shall return to this issue in section 4.

3. Flood Management: Operational Phase

The task of systems managers of a flood protection system is to reduce consequences of extreme events to avoid a disaster. A systematic approach to this task is flood management. Flood management is defined as sum of all actions to be taken before, during, or after any extreme flooding event with grave consequences. It consists of an operational and a planning phase. The operational phase involves all actions necessary for operating a flood protection system, or of being otherwise prepared for an approaching extreme event. These are tasks associated with flood management for an existing system: immediately before, during or after an extreme event as indicated in Fig. 3. It starts with good maintenance to keep the existing flood protection system in working condition, promoting continuous awareness of threats from extreme floods, and to make sure that all necessary tools, equipment and medical supplies are available and in good order. Because no technical solution to flooding is absolutely safe, it is important that personnel are trained so that everybody knows what to do in case of endangerment or failure of the protection system. Even if the system always does what it is supposed to do, it is hardly ever possible to offer protection against any conceivable flood. There is always a residual risk, due to failure of technical systems, or due to rare floods which exceed the design flood. This is the preparedness stage of operational flood management, whose purpose is to provide the necessary decision support system for the case that the existing flood protection system is endangered or has failed.

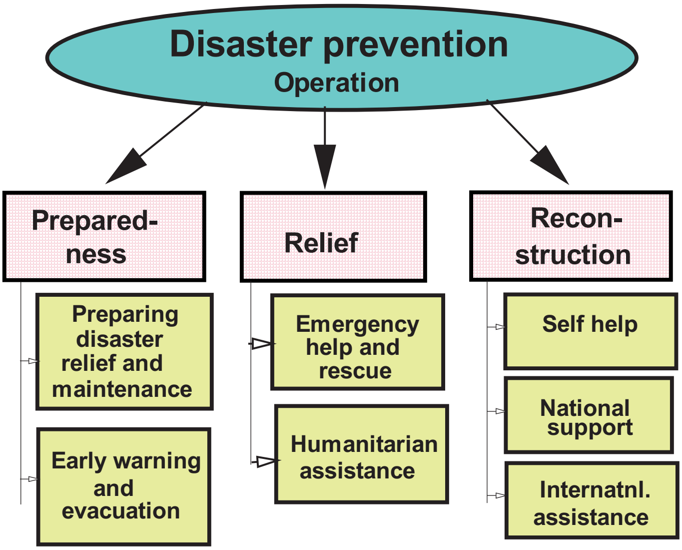


Figure 3. Stages of operational risk management

The second part of preparedness consists of actions for mitigating the effect of an imminent flooding event. An important role is played by early warning systems: the better the event is forecast, and the earlier magnitude and arrival time of the flood wave is known, the better one can be prepared. The effect of all these actions is schematically shown in Fig. 2. If all actions are well executed, consequences of an extreme event may be small (case 1 in Fig. 2), whereas no preparation may lead to a disaster, as indicated by the index development for case 2 in Fig. 2. However, no system can protect against every conceivable event: economic as well as social and environmental constraints may set limits.

The next part of operational risk management is disaster relief: i.e. the set of actions to be taken when disaster has struck. It is the process of first engaging in emergency help and rescue operation, and when this first stage of disaster relief is over, then to organizing humanitarian aid to the victims.

The final part is reconstruction of damaged buildings and lifelines.It is obvious that potential for helping is increased through preparedness and well organized relief. In identifying indicators to be incorporated into sub-indices for vulnerability and resistance, proper weight has to be given to this ability. Reconstruction is to be considered in giving weights to damages to long -term development: self help, which reduces dependency on national and international donors, is an important factor in any recovery, in particular if one considers that external assistance usually is given only over short times: in particular international assistance through donations by individuals tends to be short lived.

4. Flood Protection as a Dynamic Process

Historically, flood protection underwent a number of development steps, depending on flood type: a flash flood obviously required different responses than a flood which inundates the lower part of an alluvial river. Flash floods in mountain areas have high velocities and cause high erosive damage, and only extremely solid structures can withstand their destructive force. The only way for escaping a flash flood used to be to get out of harms way by placing houses and other immobile belongings to grounds which are so high that no floods can reach them. To protect banks from flashfloods they are strengthened with rip-rap or concrete linings against erosion. Damage potential of flash floods is confined to direct neighborhoods of rivers, the total damage usually is not very extensive – although due to high velocities damage to individual structures or persons caught in such floods are very high. In recent times, flash floods caused large losses of life only of people unfamiliar with the potential hazard, such as tourists, which camp in mountain canyons. Flash floods can be avoided by flood control reservoirs. However, this is not always an option because flood control against usually limited total damage is economically feasible only if can be combined with other purposes, such as hydropower generation.

Very different is the response to floods in alluvial plains of large rivers. Velocities are comparatively low, and the main danger to life is from the wide lateral extent of inundated areas, as has been experienced in recent times during floods in Mozambique in February, 2000, in which a large part of Central Mozambique south of the Zambezi river was flooded. In earlier days, people responded to such floods by moving the location of their cities and villages out of reach of the highest flood which they experienced, or of which they had clear indications, such as from deposits on old river banks along the flood plain. Typical is the situation in the upper Rhine valley between Basel and Mannheim, where one finds old villages and cities always on high ground or on the high bank of the old river flood plain. And if an extremely rare flood was experienced, which reached even higher, then people had no choice but to live with the flood damage. In other areas, people learned to live with frequent floods: for example, in Cologne the low lying parts of the city near the Rhine used to experience regular inundations for which they were prepared. Their method of protection today is called object protection: protection through local measures, such as building houses on high ground, perhaps on artificially generated hills, such as was done by farmers on the North Sea, or by temporarily closing openings with sandbags or brick walls, or just by moving one´s belongings to a higher level of the house.

Population pressure and lack of other farmland made people move into flood plains, and to protect themselves against frequent flooding by means of dikes: already the ancient Chinese started to build dikes along their large rivers to protect farmland and villages. The Herculean tasks of building dikes along Yangtse and Yellow river against floods of unimaginable magnitude, united the Chinese people into a nation in which no longer individuals were responsible for their own safety, but where flood protection became a national task. However, the protection by means of dikes cannot be perfect, as dikes can fail, and floods can occur which are larger than design floods. In recent times, failure of dikes caused some of the largest flood disasters in the world. The Oder river flood of 1998 (Bronstert et al. 1999), or the Elbe flood of 2002 (DKKV, 2003, Grünewald et al., 2004) come to mind, but even more striking are floods of China (Wang & Plate, 2002), with floods on the Yangtse a very illustrative example.

Among the most fundamental features of rivers is that in flood plains they are not stationary, but tend to shift their beds continuously. When large rivers leave their mountain confinement, they carry large amounts of sediment into their flood plains, and due to their lower velocity they deposit huge quantities of sediment on the plain. Without interference by man, such rivers build up alluvial fans: moving across a fan shaped area over which they spread their sediments – a rather complex process which only recently has found some theoretical discussion (Parker, 1999). This is in conflict with demands of settlers, who want to have the state of nature to remain unchanged, so that property boundaries are maintained forever. In fact, a study by the University of Bern (Hofer & Messerli et al., 1998) of effects of river floods in the delta of Brahmaputra and Ganges rivers in Bangladesh showed that people in some places were less concerned with flood levels of river floods, which they had learned to live with, than with shifting of river banks during floods, which destroyed land on one side and built up land without owner on the other side of the river.

The effort of keeping large rivers of East Asia or Europe within boundaries set by dikes is an extreme case of man fighting rivers, rather than to live with them – a fight which can only be won temporarily, because by confining the river between dikes, one also confined the area on which sediment is deposited, and a gradual increase of the river bed between the dikes is unavoidable.

Modern options for flood management are not absolute, but depend on three variable factors: available technology, availability of financial resources, and perception of the need for protection, which is embedded into the value system of a society. As these factors change with time, options which one has to consider also change, and new paradigms of thinking may require new solutions to old problems. When one looks at time development of the need for a protection system – not only against floods, but also against all kinds of other hazards – it is evident that flood risk management is a circular process, as indicated schematically in Fig. 4. A state of a system may be considered satisfactory at a certain time, meeting demands on the river both as a resource and for protection against floods. But new developments take place, leading to new demands. Side effects occur, which impair functioning of the system and which may not have been anticipated. After some time, the system is considered inadequate, and people demand action to change existing conditions.

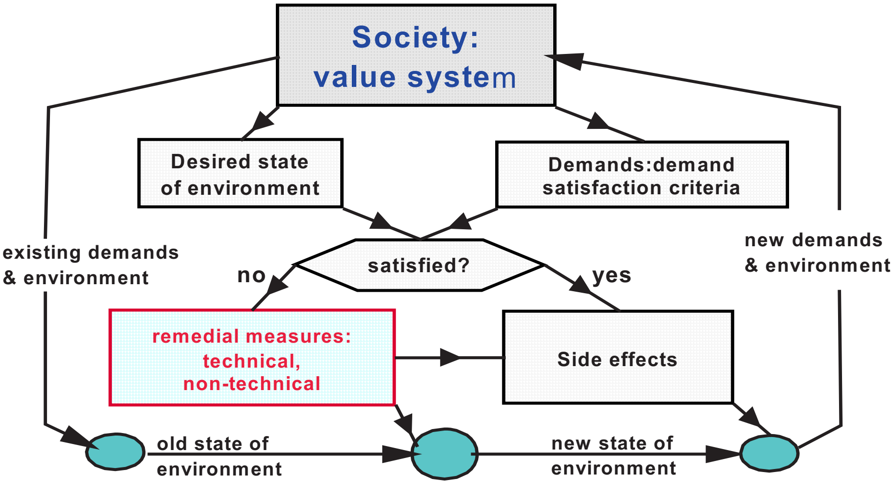


Figure 4. The cycle of responses to changing value systems and changing environmental conditions for water management

Many new possibilities for technological development in flood control have become available through modern communication technology. An important step in improving an existing flood protection system is provision of better forecasting technology and better warning systems. Modern communication technology also permits dynamic operation of flood control systems. A reservoir for flood control can be controlled on the basis of forecasting results to provide maximum protection by chopping off the peak of the flood wave. Series of barrages, such as on the Rhine, can be operated through remote control to provide maximum storage in the system of barrages.

An important criterion is the availability of funds, i.e. the financial resources which can be allocated to flood protection; resources which usually have to come from public funds and are in competition with other needs of society. But finances are not the only issue. Decisions for flood protection also depend on the changing value system of the society, starting with the solidarity of non – flood endangered citizens of a country with those endangered by floods. For example, in the not so distant past infringements on natural environments by engineered river works usually had been accepted as price to pay for safety from floods. However, in recent times flood protection by technical means faces serious opposition, not so much because of concern about long range geomorphic adjustments of the river (which is bound to occur sooner or later), but generated more directly from the fact that dikes and land development cut off natural interaction of river and riparian border. Reduction of wetlands and impairment of riparian border fauna and flora in many – particular in the developed – countries causes great concern of environmentalists and has led to backlash against flood protection by dikes and reservoirs.

Recognition that the adjustment process for flood security is open ended - is a transient only in the stream of development - is basis of the principle of sustainable development: while revising or constructing a flood protection system to meet our needs, this principle requires us to remember, that future generations may have other needs and other knowledge, and that we should not cast our solutions into immutable solidity, such as producing irremovable gigantic concrete structures, or permanently degraded soils. For a discussion of issues involving sustainable water resources management on the basis of the original Brundtland report (WCED, 1987) see Jordaan et al. (1993) and Loucks et al. (1998).

5. Flood Risk Management: Project Planning

Implementation of the concepts: “Living with risk” and “prevention of disasters” is not a task that can be handled only on the basis of experience with one extreme event that has caused a disaster in the past. Instead we must look to the future, and since we cannot forecast when and where an extreme event can occur, we have to make probabilistic guesses, or, in mathematical terms, we have to look at expected values for indices V and R . Accordingly, a criterion for preventing disasters is given through expected values:

$$E\{R\} - E\{V_s\} \geq E\{V_r\} \quad \text{or} \quad E\{R\} - E\{V_s\} - E\{V_r\} \geq 0 \qquad (1)$$

where $E\{V_r\}$ is the risk RI. Consequently, there are three possibilities of preventing disasters. One can increase resistance of people (for example, increase their income), or decrease resources needed (reduce cost of living), or reduce risk. Engineers have little to say in terms of the first two options, although these are perhaps more important than the third. We feel that the best way of preventing disasters is by planning ahead: managing risk RI, in order to reduce impacts of extreme events as much as possible.

It is well known that if for a design the inequality ≥ is replaced by equality = for symmetric distributions of the probability densities of R, V_s and V_r then the actual failure probability is higher in 50% of all cases. Thus it is advisable, not to use the equality, but to use first and second moment of the distributions to obtain an acceptable safety margin. Some further thoughts on this issue are presented in the appendix.

5.1. PROJECT PLANNING STAGES

The response to reassessment of the flood danger, initiated usually after the occurrence of an extreme event with considerable damage, is the phase of project planning for an improved flood disaster mitigation system. Experts involved in risk management have to ensure that the best existing methods are used to mitigate damages from floods: starting with a clear understanding of causes of a potential disaster, which includes both natural hazards of floods, and vulnerability of elements at risk, which are people and their properties. The project planning aspect of risk management is summarized in Fig. 5., which basically consists of three parts: risk assessment, as basis for decisions on which solution to use; planning of risk reduction systems, which involves a great deal of activity ranging from the fundamental decision to go ahead to detailed design; and, finally, making the decision for and implementation of the project. When this is accomplished, the flood management process reverts to the operation mode described in the first part of the paper.

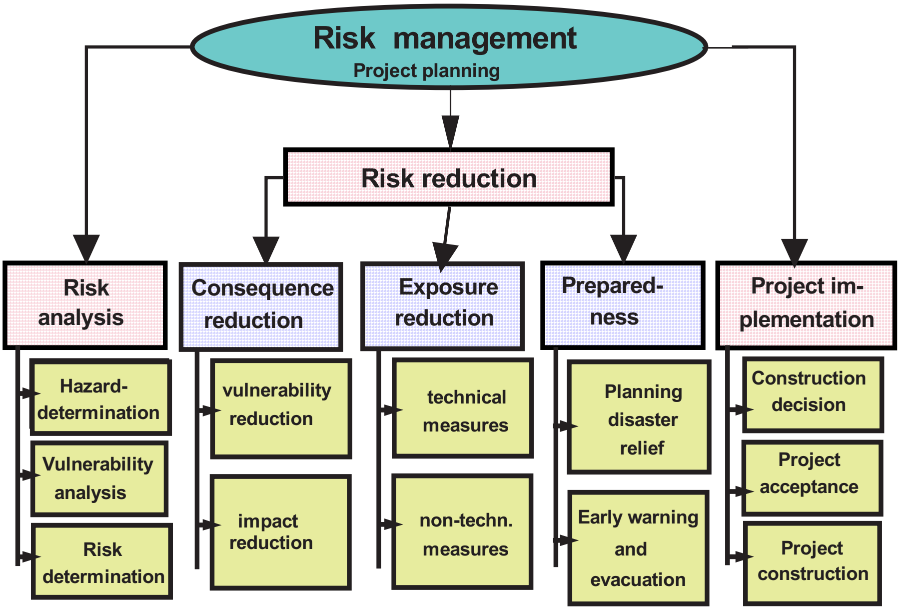


Figure 5. Project planning as part of risk management

Assessment of existing risks and evaluation of hazards should be a continuous process using newest information available: newest data, new theoretical developments, and new boundary conditions, which may change due to human impact on the environment. Catchments may change: forested rural areas are cleared for agriculture, a patch of land used for agricultural purposes is converted into urban parking lots, agricultural heavy machinery compacts the soil and changes runoff characteristics of a rural area. Other causes may be result from pressure of increasing populations on the land.

Hazards are to be combined with vulnerability into risk. Vulnerability of persons or objects ("elements at risk") in the area which is inundated if a flood of a certain magnitude occurs, is weighted with the frequency of occurrence of that flood. A good risk analysis process yields hazard or risk maps, which today are drawn by means of Geographical Information Systems (GIS) based on extensive surveys of vulnerability combined with topographic maps. Hazard maps, as used for operational risk management, are also the foundation of decisions for disaster mitigation. They serve to identify weak points of flood defense systems, and indicate needs for action, which may lead to a new project. Other weaknesses of the system become evident during extreme floods. For example, the Oder flood of 1997 has indicated (see for example Kowalczak, 1999) that flooding of a city in a flood plain may result not only from dike overtopping or failures, but also from seepage through dikes and penetration of flood waters through drainage systems, i.e. through the sewerage system or water courses inside the city. Organisational weaknesses also play a role, such as poorly organized upstream - downstream information exchange which became apparent during the recent large flood on the Elbe river (DKKV, 2003).

Risk assessment does not stop at evaluating the existing risk, i.e. with risk analysis. The risk analysis process has to be repeated also during the planning process, for each of the structural or non-structural alternatives for mitigating flood damage. Good technical solutions integrate protection of rural and urban areas, through coordinated urban storm drainage projects, stream regulation in rural and municipal areas, with bridges and culverts designed to pass more than the design flood. Structures including reservoirs and dikes are usual technical options, but other possibilities adapted to the local situation also exist, such as bypass canals and polders on rivers. There are also many non-technical possibilities, in particular in regions where land can be spared to give more room to rivers and natural waterways, avoiding settlements and to allow the waters to occupy their former flood plain. The advantages of non-structural solutions, in particular their benefits to the ecology of flood plains, has been stressed (for a recent summary, see Birkland et al., 2003). Project planning, naturally, also includes investigating the option to do nothing technical but to be prepared for the flood if it strikes: i.e. to live with the situation as is and be prepared for the floods. Important possibilities exist in creative insurance products which should be explored in each case, for example using insurance premium structure as incentive to avoid building in flood plains.

5.2. THE RISK EQUATION

It is obvious that risk evaluation depends on the technical or non-technical solution contemplated, and therefore, risk mitigation is not independent of risk analysis. For each contemplated alternative for the protection system, the technical or non-technical solution is evaluated, the new hazards determined and the decision basis is enlarged by this analysis. Outcome of each analysis is a different risk, defined as:

$$E\left\{V_r\right\} = RI(\vec{D}) = \int_0^\infty K\left(x\middle|\vec{D}\right)\cdot f_X\left(x\right)dx \qquad (2)$$

Equation 2 is based on a consequence function $K(x|\vec{D})$, where x is the magnitude of the event causing the load S, and $\vec{D}$ is the vector of decisions, for example the height of a dike along a river, that influence the (usually adverse) consequences K (dropping the reference to $\vec{D}$ from here on) of any event x. For flood management, we recognize that Eq. 2 incorporates two factors: the consequence of a flood, and the probability of the flood to occur, once a decision $\vec{D}$ has been made.

Damage potential of a flood is expressed through water level and water velocity, and the first task of flood management is to determine flood magnitude and corresponding flood levels of all floods and to select the design flood or floods. As has already been mentioned, it is important to realize that floods are very different in mountainous regions and in flood plains, and consequently the flood protection measures expressed by the design D must also differ very much. In the mountains, flash floods are common and result in rivers and creeks increasing very rapidly in flood levels and velocities, causing heavy damages to everything in its course. In the flood plains, on the other hand, mostly disasters occur due to widespread flooding, with low velocities, but wide extent - aggravated by cases of dike breaks. The determination of floods is a problem that shall not be covered in this paper, reference may be made to the papers in later sessions of this conference. Second part of the risk equation is the consequence function K. For example, consequences could be costs of repairing damage to be expected from a flood of magnitude or level x. Obviously, consequences depend on decisions $\vec{D}$ as well as on the magnitude of the causative event. Only in exceptional cases is the flood damage independent of the flood magnitude (in which case Eq. 2 reduces to the classical definition of risk as product of exceedance probability and damage). Usually, in risk analysis exercises, the flood damage is expressed through a damage function of the causative event x, (as used for example, by Gocht & Merz, 2004, who did a very comprehensive and thorough analysis of damage for a flooding situation) A more refined analysis separates the consequence function further into two parts: the maximum damage that is possible, and the relative damage, which gives the percentage of the total that is damaged due to the flood level of magnitude x. The function $f_x(x)$ is the probability density function (pdf) of the (usually annual) occurrence of x, so that Eq. 2 is the expected value of the consequences K.

The decision on which possible alternative to use depends on a number of factors, which include the optimum solution in the sense of operations research. The classical approach for optimizing a cost function (i.e. Crouch & Wilson, 1982) has been adapted by Freeze and his co-workers (Freeze et al. 1990) to the case of water projects, and their analysis can easily be extended to the problem of flood protection systems, as was done formally in Plate (2002). But there might be other compelling reasons for deciding on a particular alternative, even if it is not cost effective for flood protection: often one decides not to do what is really needed - money may simply not be available, or other needs are considered more urgent -as is unfortunately frequently the case, because perception of danger fades with time. Or more protection than required from a cost – benefit analysis seems appropriate, i.e. because unacceptable losses of human lives may be expected, or if intangible losses are to be considered. The city of Hamburg, for example, is keenly aware that a flood of her port would seriously undermine customer confidence in the security of transactions through the port, and is prepared to go to a higher degree of protection than dictated by a cost benefit analysis.

The examples show that it might be useful to have an index which allows to weigh all factors that might enter the decision process for a flood protection system. As an example, in addition to indicators of costs and benefits of a flood protection system one may wish to include potential losses in human lives as second indicator for determining a risk. Potential fatalities can also be expressed through the risk equation. K is set equal to number of fatalities when event x occurs with n_o people affected and decision D has been made.

It is not clear how to convert expected value of fatalities and expected monetary damages into the same units in a vulnerability indicator. The use of fatalities avoided as a direct quantity in a decision process based on cost benefit considerations would require putting a monetary value on the life of a human being, which is not acceptable on ethical grounds. Therefore, expected number of fatalities usually enters as a constraint: engineers are required to devise systems in which the probability of any human being losing his or her life is so low that it matches other risks which people are readily exposed to. The question of acceptable risks involving losses of human lives has been discussed by Vrijling et al. (1995) for the dike system of the Netherlands, by means of an analysis which has also been applied to other situations (for example to mud flow hazards, see Archetti & Lamberti, 2003). Fortunately, in Europe casualties in river floods are so few that the expected value of fatalities in flood disaster situations for rivers can be neglected. However, in other parts of the world, avoiding fatalities may be the most important aspect of flood risk mitigation decisions, and for these areas, expected numbers of fatalities are indicators which must have appropriate weight.

We see the key problem of risk assessment in determination of an appropriate vulnerability index. It is evident that a consequence function, or a disaster potential, as expressed through a monetary function K cannot capture social aspects of people involved. Money is only of relative importance, of primary importance is the total capacity to rebuild and to recover from a large extreme event. It therefore is a challenge to researchers working on risk assessment to develop people oriented indicators, and to combine them into appropriate indices. A possible measure is an index of vulnerability, which shall be defined and discussed in the following.

6. An Index of Vulnerability

The description of Fig. 2 may serve very well to illustrate time development of vulnerability, but it is not suitable for decision making, as occurrence of V_s, V_r and also R cannot be predicted with certainty: all three quantities are random variables. If we wish to specify the potential vulnerability of a population over a certain number of years, then we have to make a forecast. Because forecasts always are subject to uncertainty, there exists an error band around our forecasts: this error band is specified by a probability density function (pdf) of $V_s(U_s)$ of forecasts made at time $t = 0$. Note that the error band increases in width with time. The further we want to extrapolate our vulnerability estimates into the future, the wider will be the error margin.

For a decision process it is necessary to statistically combine random variables R and V, describing resistance and vulnerability, respectively. Best estimates of these variables for some future time t are their expected values $E\{R\}$ and $E\{V\}$. $E\{R\}$ describes the expected value of total available resources per person, of a city, a region, or a country. For example, if we look at such a measure for a country this could be the Gross National Product (GNP) per person. For more local measures, corresponding quantities need be defined, such as the local GNP, or total average income of a region, or for a person total annual income. Then we define an actual vulnerability index $E\{V\}$ (or a load) as a measure of resources needed for maintaining local average standard of living per person, again specific for a person, a city, a region, or a nation. Difference $E\{R\} – E\{V\}$ then is a measure for the resources available per person when an extreme event strikes. In the context of such a definition of vulnerability and critical vulnerability, a disaster is a condition where the momentary value of V exceeds the critical threshold $E\{R\}$. This can be caused by slow onset events – also called “creeping events” U_s, resulting in an actual vulnerability index $E\{V_s(U_s)\}$ - or by a rapid onset events U_r, such as floods, resulting in an index $E\{V_r(U_r)\}$, which describes additional increase in vulnerability. Characteristics of events U_r is that they are temporary extreme deviations of natural conditions from some average or normal condition. A drought qualifies as well as a flood or an earthquake, a landslide or an avalanche, and some people also include biological causes, such as an epidemic or a locust infestation, which may destroy health or livelihood of one or many families. It is clear that the risk may also change – one of the issues of climate change is that natural disasters have become more frequent and more costly, and costs for insurance industries seem to increase dramatically, almost at an exponential rate (Munic Re, 2003).

With these assumptions we illustrate schematically in Fig. 6 how vulnerability may be affected by changes. The actual vulnerability index may be slowly changing with time due to many factors: for example, number of people exposed to the extreme event may be increasing, or relative vulnerability may increase due to degrading of land or reduction of financial resources available for coping. A slow onset disasters is found to occur if vulnerability index E{R} (which may actually also change with time) is exceeded due to slowly changing events U_s resulting in changes in index $E\{V_s(U_s)\}$, as shown by the slowly varying curve. This is the condition for a slow onset disaster.

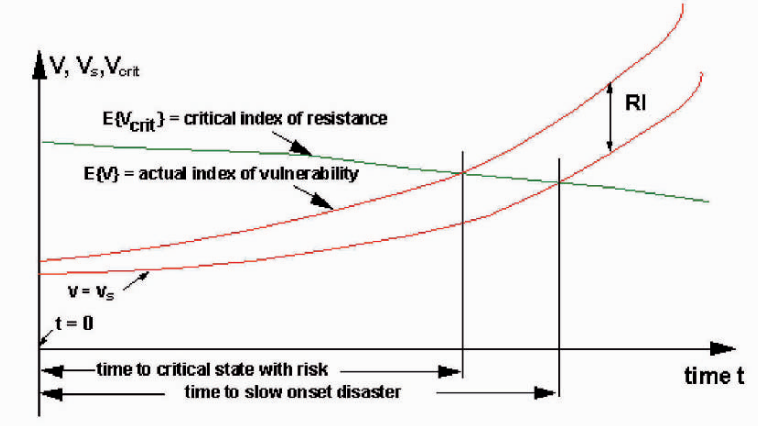


Figure 6. Schematic presentation of the relationship between vulnerability and disaster as a function of time (with $R = V_{crit}$)

At any given time t, the actual state of vulnerability is found by drawing a vertical line through the diagram Fig. 7. If the difference $E\{R\} - E\{V\}$ for this time is positive, people are, on the average, able to manage consequences of a disaster by their own resources, if it is negative, people are no longer capable to handle them and outside help is needed. However, an absolute deviation from the critical level has a different meaning in different countries. Whereas a loss of, say, 1000 US$ may imply financial destruction of a whole village in some poor and developing countries, it is a comparatively minor monetary damage in others. In order to make this quantity meaningful, it is useful to define relative indices, such as an index of vulnerability IV against extreme events as ratio of damages from extreme events to available resources. Without direct reference to imminent extreme events, an index of resilience IR can also be defined, as measure of ability to cope:

$$IV = \frac{E\{V_s\}}{E\{R\} - E\{V_s\}} \quad \text{and} \quad IR = \frac{E\{R\}}{E\{V_s\}} \tag{3}$$

Examples of indices of resilience are shown in Fig. 7. These were obtained by J. Birkmann (UNU-EHS Bonn, oral communication). These indices show that citizens of some smaller cities in the area of Nishny Novgorod are perilously close to being unable to withstand even small consequences of extreme events, although the index does not actually indicate the flood hazard to which the people of these cities are exposed. As this example shows, it may be possible to use the indices without difficulty (in principle), if the consequence function is monetary. However, we will face the difficulty of quantifying non-monetary indicators, such as social or ecological indicators. This is a task which needs to be addressed, if we wish to have a complete assessment of the actual risk to flooding. It is necessary to quantify the different kinds of risks, among them:

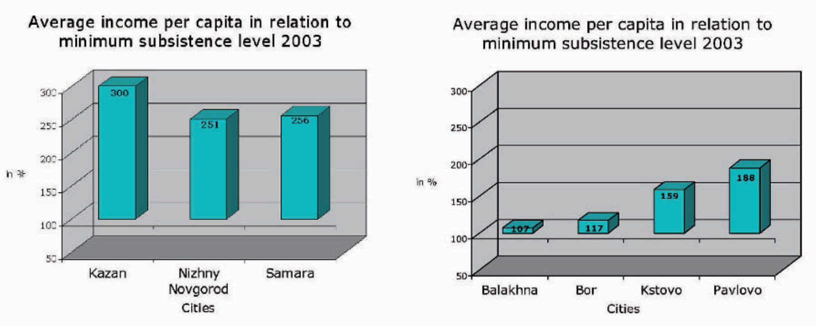


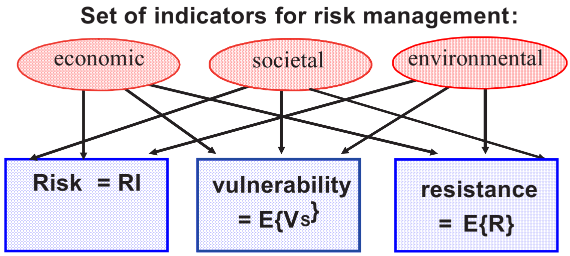
Figure 7. Indices of resilience for larger cities (in the Nishni Novgorod area of Russia) on the left, and for smaller cities on the right (Birkmann, 2004)

<u>Insurance risks:</u> Monetary risks due to failure of structures, i.e. expected cost of repairing the damage to the structure.

<u>Total risk to the community:</u> including not only cost of failure of structures but also of infrastructure damage, as well as indirect cost due to delays, costs due to rebuilding, medical and relief services, and costs due to production losses.

<u>Residual risk:</u> risk for the people due to the failure of the flood protection system, including not only the financial consequences, but also the social risk, i.e. the expected value of the consequences to health and mental state of the people.

Environmental risk: risk to the environment due to failure of the protection system: effect on water quantity and quality, and on the ecology of the flooded region.



Each set of indicators produces a part of each of the indices. The sum of the partial indices, weighted by weightsγ_{ij} yield indices Ri, E{V_S}, and E{V_{crit}}:

$$Ri = \gamma_{11}\, Ri_E \; + \; \gamma_{21} Ri_S \; + \; \gamma_{31}\, Ri_R$$

$$E\{V_S\} = \gamma_{12}\, E\{V_{SE}\} \; + \; \gamma_{22} E\{V_{SS}\} + \; \gamma_{23}\, E\{V_{SR}\}$$

$$E\{R\} = \gamma_{13}\, E\{V_{CE}\} \; + \; \gamma_{23} E\{V_{CS}\} + \; \gamma_{33}\, E\{V_{CR}\}$$

Figure 8. Schematic for generating a general risk index

From these different definitions of risk the need emerges to have a scheme of risk definition by means of weighted indicators taken from economic, social, and environmental areas, which have to be properly weighted in order to obtain a universal risk definition, as is indicated in Fig. 8. Fig. 8 represents a program for further research: research where not only engineers and economists are challenged to make contributions, but also inputs from social sciences are needed. Needless to say that there exists a large literature in the social sciences on vulnerability of different social groups in different social and environmental circumstances. However, there is a long way to go before a unified and generally accepted model will be available for quantitatively describing risk as a socio-economic and environmental quantity. It is recognized that the appropriate determination of the consequence function, in particular as it describes non-monetary aspects, is the key to this, and thus the study of vulnerability is the most challenging aspect of such a model. With some expectations one looks for this to the newly founded United Nations University, Institute of Environment and Human Security (UNU - EHS), in Bonn, Germany, whose central activity will be focused on the issue of vulnerability and vulnerability reduction. But more than one institute will be needed to cover the many questions which this problem poses. It is therefore appropriate that we present this as a challenge at the outset of this workshop, and express hope that from it some further insight, if not for the problem solution, but for a better understanding of the problems involved will be derived.

7. Summary and Conclusions

Threats from floods are increasing world wide. Land use and climate changes, as well as river training measures cause floods to be larger. Populations increase, and continuously people are migrating into flood prone areas, either forced by poverty, or by their own free will in view of benefits obtained from living near rivers. Demands of industry add to increase in vulnerability. Net effect is an increase in risk, which must be compensated by appropriate measures. Many different methods can be implemented for flood protection, ranging from complex technical measures to land use planning and zoning. However, demands on public resources are not keeping up with available funds, and choices have to be made: choices, for which decision criteria are needed. These criteria must be based both on needs and on capacity for self help. Public support, or donor money, therefore must be restricted to those persons or social groups with insufficient resources of their own. Conditions of such persons or groups can be assessed by a suitable vulnerability index. A possible definition for an objective vulnerability index is given. However, without detailed research into quantification of vulnerability and vulnerability indicators this index has only theoretical value.

A major role in the development of vulnerability indicators is the quantification of flood risks. This quantity can be reduced. Whereas vulnerability is to a large extent controlled by social factors, risk management to a large extent is a technical problem and can be handled with technical means (including zoning and other restrictions on the use of rivers and riparian areas). The best way of preventing disasters is to reduce the risk to a minimum level compatible with the self help capacity of the population at risk, i.e. to reduce the risk part of the vulnerability index through appropriate risk management. Because risk is a continuously changing quantity risk management is a process requiring continuous reevaluation. Risk and changes in the social conditions are combined into the vulnerability index which is also a time variable quantity. In order to ensure sustainable development populations at risk are challenged to reduce their vulnerability index to keep it well below 1 for the foreseeable future.

References

Archetti, R., and A. Lamberti (2003) Assessment of risk due to debris flow events. Natural Hazards Review, Vol. 4, pp. 115-125, Am. Soc, Civ. Engr., Reston, Va, USA

Betamio de Almeida, A. and T. Viseu (1997): Dams and safety management at downstream valleys. Balkeema, Rotterdam

Birkland, T.A., R.J. Burby, D. Conrad, H. Cortner, and W.K. Michener: (2003): River ecology and flood hazard mitigation. Natural Hazards Review, Vol. 4, pp. 46-54,Am. Soc, Civ. Engr., Reston, Va, USA

Blaikie, P.T., T. Cannon, I. Davis and B. Wisner (1994): At risk: Natural Hazards, people´s vulnerability, and disasters. Routledge, London

Bohle, H.G., T.E. Downing, and J.M. Watts (1994): Climate change and social vulnerability. Towards a sociology and geography of food insecurity. Global Environmental Change Vol. 4, pp. 37-48

Bronstert, A., A. Ghazi, J. Hljadny, Z.W. Kundzevicz, and L. Menzel, (1999): Proceedings of the European Expert Meeting on the Oder Flood, May 18, Potsdam, Germany. Published by the European Commission

Crouch, E.A.C. and R. Wilson (1982): Risk Benefit Analysis, Ballinger Publisher, Boston, Mass. USA

DKKV, (2003): Hochwasservorsorge in Deutschland: Lernen aus der Katastrophe im Elbegebiet - lessons learned. Schriftenreihe des Deutschen Komitees für Katastrophenvorsorge (DKKV) No. 29, Bonn, Germany

Freeze, R.A., J.Massmann, L.Smith,T.Sperling, and B.James, (1990): Hydrogeological decision analysis: 1. A. framework, Groundwater, Vol. 28, pp. 738-766

Grünewald, U. et al. (2004): Flood risk reduction in Germany: lessons learned.. German Committee for Disaster Reduction (DKKV), German DKKV Publication No. 29e, Bonn

Hofer, T. and B. Messerli, (1997): Floods in Bangladesh.- Institut für Geographie, Universität Bern, Bericht f. Schweizerische Behörde für Entwicklung und Kooperation

ISDR (2002): United Nations Interagency Secretariat for the International Strategy for Disaster Reduction: Living with risk: a global review of disaster reduction initiatives. (preliminary version), United Nations, Geneva, Switzerland

Jordaan, J., Plate, E.J., Prins, and E., Veltrop, J. (1993): Water in Our Common Future: A research agenda for sustainable development of water resources. Paris: UNESCO 1993

Kowalczak, P. (1999): Flood 1997 – Infrastructure and Urban Context. In: A.Bronstert et al.(eds.) Proceedings of the European Expert Meeting on the Oder Flood, May 18, Potsdam, Germany. published by the European Commission, pp. 99-104

Loucks, D.P. et al. (1998): Task Committee on Sustainability criteria, American Society if Civil Engineers, and Working Group UNESCO/IHPIV Project M-4.3 Sustainability criteria for water resources systems. ASCE, Reston, VA. USA

Merz, B. & M.Gocht (2003): Karten für die Hochwasservorsorge und das Risikomangement auf der lokalen Skale. (Mapping for flood defence and risk management on the local scale). Hydrologie und Wasserbewirtschaftung (Hydrology and Water Resources Management - Germany) Vol. 47, pp. 186 -194

Parker, G. (1999): Progress in modelling of alluvial fans, Journal of Hydraulic Research Vol. 37, pp. 805-82

Plate, E.J. (1992): Statistik und angewandte Wahrscheinlichkeitslehre für Bauingenieurere, Verlag W.Ernst und Sohn, Berlin

Plate, E.J. (2002): Flood risk and flood management. Journal of Hydrology, Vol. 276,pp. 2-11

UNESCO, (2003): Water for people - water for life: the United Nations World Water Development Report, UNESCO and Berghahn Books, publisher

UNDP, (2000): United Nations Development Program (UNDP) Human Development Report 2000, Oxford University Press, New York

Vrijling, J.K., W. van Hengel, and R.J. Houben (1995): A framework for risk evaluation. Journal of Hazardous Materials, Vol. 43 pp. 245-261

Wang, Z.-Y., and E.J. Plate, (2002): Recent flood disasters in China. Proc. Institution of Civil Engineers, Water and Maritime Engineering, Vol. 154, pp. 177-188

WCED, (1987): World Commission on Environment and Development. Our Common future. Oxford University Press, Oxford, UK

World Bank, (2000): World development indicators. World Bank, Washington, USA

Zimmermann, H. and L. Gutsche (1993): Multi-criteria Analyse: Einführung in die Theorie der Entscheidungen unter Mehrfachzielsetzungen, Springer, Berlin

Appendix: Uncertainty Analysis of Indices

In the framework of Fig. 7, we have to find the probability for the occurrence of a disaster as a decision variable. This problem can be stated in probabilistic terms as follows: Let the vulnerability of the slow onset effects be V_s, with pdf $f(V_s)$, having an expected (mean) value of $E\{V_s\}$ and a variance of σ^2_{Vs}, and let the incremental increase in vulnerability due to the rapid onset event be V_r with pdf $f(V_r)$, with mean value $E\{V_r\}$ and variance σ^2_{Vr}. In particular, the rare event U_r to cause a rapid onset disaster can occur at any time in the future. It has to be described by a pdf $f[V_r(U_r)]$, and its expected (mean) value is precisely the risk, as defined by Eq. 1, with K quantifying the damages. Furthermore, we can assume that both slowly varying component V_s and rapid change component V_r are fully random and uncorrelated, i.e. each is described by a Gaussian distribution. The sum $V = V_s + V_r$ is also a normal random variable with mean:

$$E\{V\} = E\{V_s\} + E\{V_r\} \tag{A-1}$$

and variance:

$$\sigma^2_V = \sigma^2_{Vr} + \sigma^2_{Vs} . \tag{A-2}$$

Consequently, the two variables can be estimated independently and superimposed afterwards. It then becomes possible to estimate the probability of a disaster at time t by finding the exceedance probability for $E\{V(t)\} > V_{crit}$. In a more general analysis, the critical vulnerability may also be considered a random variable with expected value $E\{V_{crit}\}$ and variance σ^2_{Vcrit} depending on many factors, and second moment analysis may be the way of obtaining an expected value for the safety index:

$$\beta = \frac{E\{V\} - E\{V_{crit}\}}{\sqrt{\sigma_V^2 + \sigma_{Vcrit}^2}} \tag{A-3}$$

to be used as decision quantity for evaluating alternative approaches to the problem of vulnerability reduction for the normal state (i.e. for the state without allowing for disasters: $V_r = 0$): similar to using the failure probability obtained by second moment analysis as decision variable in stochastic design (Plate, 1992). The approach to use is to subdivide the time axis into sections (for example, years), and to determine for each section the probability distributions of V_{crit} and $V_{s,}$ and then to apply second moment analysis to the section.