FLOOD RISK, CONTROL MEASURES AND STRATEGIES FOR RISK MITIGATION

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Abstract: The objective of this presentation is to give an outline about approaches to assess the flood risk, to discuss control measures and to review the policies which have been developed in the last three decades in Europe to cope with flood damage and risk reduction. First some figures are given about recent flood damages, then basic definitions are discussed, some applications and an overview of risk mitigation measures conclude the paper.

1. FLOODS AND DAMAGES

To give an impression about the economic and human losses due to flood events some examples are given.

In the United Kingdom, over 90,000 people are at risk from flooding in the River Thames catchment alone, and the cost of potential flood damage has been estimated at £20 million (Euro 32 million) in Greater London alone1 (Haggett, 1995).

In Spain, the economic losses due to flooding have risen to an average of 50,000 million pesetas per year during the period 1986-1996, and floods have caused over 1,500 deaths over the last thirty five years. During the period 1971-1991, insurance claims for damages caused by floods represented 75% of the total for natural catastrophes. This is to be compared with a world-wide average of 15% of the total. In response the Spanish Government has developed the SAIH (Automatic System of Hydrological Information) Plan which constitutes an important effort to update the hydrological infrastructures and will be the base of a flood forecasting and prevention.

In Italy, one single flooding event in the Piedmont Region in November 1994 caused serious problems within the region. These data are summarised in Table 1 below :

Table 1 : Severe Flood Damages, Piedmont, Italy , November 1994

Damage to Industry	US $ 3,300 million
Damage to Farming	US $ 1,300 million
Damage to Trade	US $ 2,200 million
Damage to railways	US $ 530 million
Damage to road infrastructure	US $ 100 million
Number of Casualties	70
Number of People Affected	> 2000
Number of Jobs Lost	12,000

Indeed within Italy the hydrological risk can be stated as 5,400 floods in the last 80 years, 11000 landslides in the last 80 years, damages of over 30,000 billion liras over the last 20 years and more than 100 casualties in the last three years

Changes in flood losses due to the extension of settlements into the flood plain are demonstrated by the second example. In the floodplains of the Upper and Middle Thames (UK) there was little building development before 1947. But in the post-war period to 1984 over 3000 dwellings were constructed on the floodplain at Maidenhead alone. Land flooded in 1947 (excluding that flooded in 1974) has been generally considered appropriate for residential development at low density: the maximum density allowable has been 4 houses per acre . If the same flood would have occurred in 19990 the respective damages would have been significantly larger (see Table 2)

TABLE 2: ESTIMATED DAMAGES FROM THE 1947 FLOOD IN 1990		
Flood (60 year event)	Estimated number of properties flooded/flood prone	Estimated damage at 1990 values (£) (date estimated)
1947	1 560	1 716 000
1990	3 303	22 485 000

Source: Parker (1995) derived from Thames Water (1986, 1988)

An inventory about flood events and their respective damages is given from the Hydrologic Information from NOAA in US clearly shows the long term trend in increasing flood damages In Fig. 1.

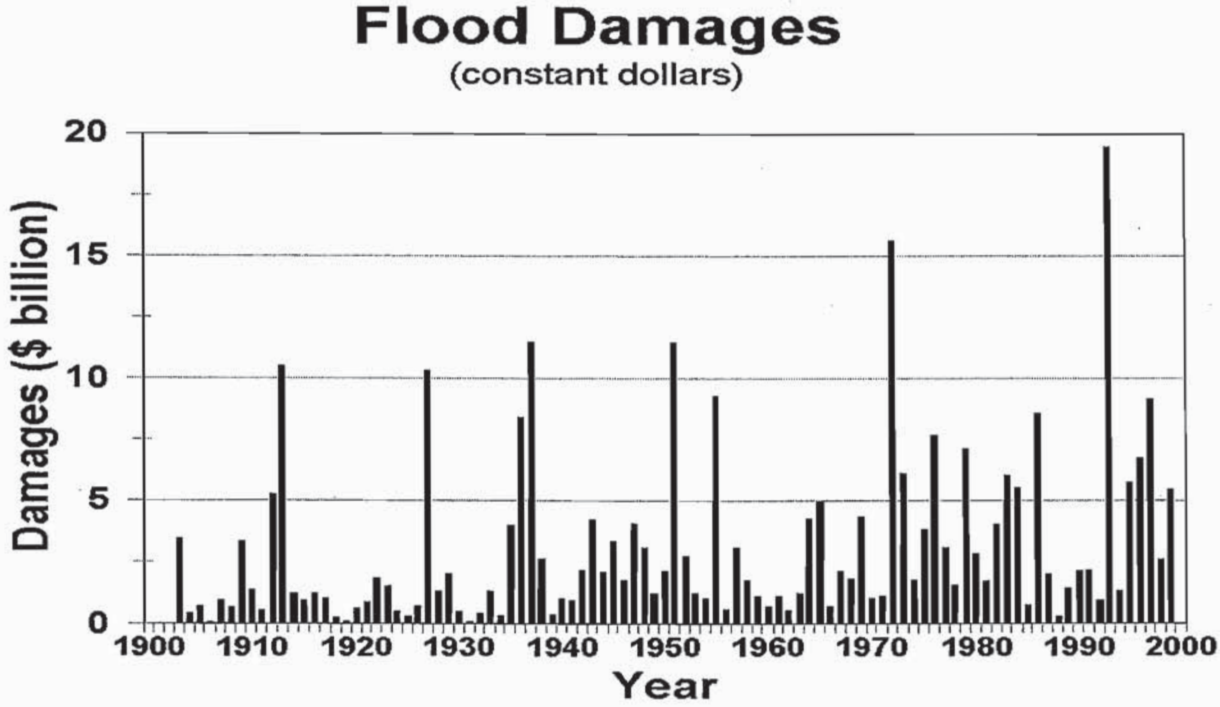


Fig.1 Team Series of Flood Damages in USA

In the summer of 1997 exceptional rainfall caused an extreme flood in the Oder (Odra) river basin. The Czech Republic, Poland, and Germany, were seriously affected by the flood; in Poland and the Czech Republic to a catastrophic extent.

About 120 people lost their lives; more then 200 000 had to be evacuated. The total damage is estimated to be about 5 billion ECU.

2. DEFINITION OF THE ENGINEERING AND HEALTH RISKS

Speaking about risk implies the definition of a loss function and the estimation of the probability of exposure of a region to a hazardous event. In analysing a physical problem there is a characteristic variable, usually considered as an output which describes a specific situation. This characteristic variable is usually called *"load"* or *"exposure"* λ

Table 3 Examples of generalised load λ and resistance ρ in hydrologic systems

Type of Problem	Load	**Resistance**	**References**
Bridge pier	Scouring	Pier pile depth	Laursen (1970) Davis and Dvoranchik (1971)
Flood levee	Flood stage Flood duration Flood exposure Wind	Levee height Hydraulic and soil resistance to sliding, erosion	Szidarovszky et al (1975) Duckstein and Bogardi (1981) Lee and Mays (1983) Plate (1964)
Water supply	Requirements or demands	Supply capacity	Kims et al (1961) Shamir et al (1994)
Flood volume control	Flood volume	Reservoir flood storage	Loucks et al (1961)
Max. flood stage control	Incoming flood stage	Cresting capacity	Yazicigil. et al (1983)
Underground excavation	Piezometric pressure	Permeability of walls	Bogardi and Duckstein
Water quality (Streams, lakes)	Nutrients sediments, pollutant loading	Cleaning capacity, low flow augmentation	Thomann (1972) Burges and Lettenmaier (1975)
Waste management	Hazards (chemical, radioactive)	Physical, individual. Collective	Marsily. et al (1963)
Recreation	Number of visitor-days	Carrying capacity of facility	Knetsche (1974

1. In water resources problems, the exposure such as for instance the daily human nitrate consumption from drinking water, can be estimated with some level of uncertainty. This uncertainty can be encoded with probabilistic methods treating λ as a random variable λ_R. Alternatively, fuzzy set methods can be used to represent uncertainty in the exposure by expressing λ as a fuzzy numbers λ_F

2. The resistance (or capacity) ρ is to be expressed in the same unit as the exposure. The capacity of a water supply system is a typical engineering example. Or, for certain carcinogens a human threshold level, that is, resistance, can be defined. Exposure below this level would not cause cancer. The resistance is also uncertain in many cases. Then probabilistic methods or fuzzy set methods can be used to describe resistance either as a random variable or a fuzzy number.

3. Failure is defined as an event when exposure is larger than resistance $\lambda>\rho$. Due to the uncertainties in l and r this event can be expressed as a probability P $(\lambda_R>\rho_R)$

(see for example the case of a probabilistic approach in a dam-break problem (Ganoulis, 1987)) or as a difference between two fuzzy numbers: Often, a mixed probabilistic fuzzy set formulation can be used. For instance the exposure to a flood levee, the peak flood discharge is a common random variable in hydrology. On the other hand, the resistance of the levee may be expressed as a fuzzy number reflecting uncertainty in the levee soil material, construction and underground soil conditions. In this example, the levee failure event $P\ (\lambda_R > \rho_F)$ is a cumulative distribution function value obtained as a fuzzy number.

4. The consequence of a failure, in engineering risk analysis, is considered as economic loss, loss of human life or other adverse effects. This consequence $L(\lambda)$ s often expressed as a deterministic function of the exposure. A typical example is an economic flood loss as influenced by the peak discharge above the level resistance level. In health risk analysis such as cancer risk from nitrate exposure, the consequence of an exposure dose is analysed by a dose-response relationship $DR(\lambda)$ which determines the probability of an event such as cancer development in an individual given an exposure dose (Zeise et al., 1987), above threshold value p (if any).

5. The perception of risk reflects the human attitude toward various kinds of risk. result in a higher or lower perceived risk as compared to the actual risk. The perceived risk of automobile accidents is generally lower than the actual risk or, the perceived risk of airplanes is higher than the actual risk. It is of high importance to assess the perceived risk since the willingness to pay for risk reduction is controlled by the perceived and not by the actual risk.

3. RISK ASSESSMENT

The distinction between risk assessment and risk management follows the National Research Council (1983) definition. Risk assessment means the characterisation of adverse effects caused by the exposure for a (given (existing) situation. Risk assessment also includes characterisation of the uncertainties inherent in the process of inferring risk.

Risk management describes the process of evaluating alternative regulatory actions (policies) and selecting among them. "This selection process necessarily requires the use of value judgements on such issues as the acceptability of risk and the reasonableness of the costs of control" (National Research Council, 1983).

Thus the ultimate goal for risk management is to evaluate trade-offs: risk versus economic, political or social advantages. The expression of risk depends on the way uncertainties in the elements of risk analysis are considered. The classical probabilistic formulation generally considers the expected value of risk using the probability density function g of exposure In case of the engineering risk ER:

$$ER = \int_{\rho}^{\infty} L(\lambda) \bullet g(\lambda) d\lambda \tag{3.1}$$

A typical water resources example consists of calculating the expected economic flood losses above resistance ρ. Similarly, in health risk analysis the so-called individual (health) risk, HR can be expressed again as an expected value, here expected probability.

$$HR = \int_{\rho}^{\infty} DR(\lambda) \bullet g(\lambda) d\lambda \quad (3.2)$$

Here, ρ represents the threshold dose below which no health effect can be expected. In health risk analysis, the level of exposure is often fixed and the health risk is given by the corresponding dose-response function value. When combined with the size of the exposed population the individual health risk defined in equation (3.2) yields population risk. Population risk may be measured by the incidence of adverse health effect considered (e.g. cancer) in the exposed population per year.

If uncertainty in any element of risk analysis is encoded by fuzzy sets in form of fuzzy numbers, the corresponding risk figure will be also a fuzzy number. Two examples are given:
a) Engineering risk analysis: the exposure is probabilistic λ_R the resistance is fuzzy ρ_F and the loss function is also fuzzy L_F. Then the engineering risk can be calculated as a fuzzy number:

$$ER_F = \int_{\rho_F} L_F(\lambda) \cdot g(\lambda) d\lambda \quad (3.3)$$

b) Health risk analysis: the exposure is fuzzy λ_F there is no threshold:$\rho=0$ and the dose-response relationship is fuzzy DR_F. Then the individual health risk can be calculated as a fuzzy HR (Bogardi et al., 1988):

$$HR_F = DR_F(\lambda_F) \quad (3.4)$$

4. APPLICATION OF THE CONCEPT TO FLOOD RISK ANALYSIS

The main objective for the risk analysis is the establishment of a sound methodology for flood mapping and loss assessments. Principal uses of this methodology is in land use planning and cost/benefit analysis of flood mitigation measures. Central components have been:

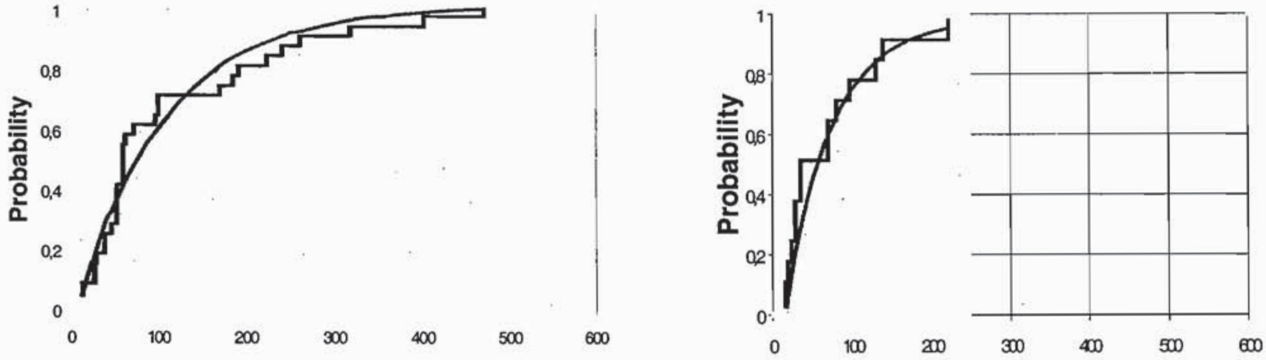
- establish standardised loss functions for various objects, with special emphasis on buildings and cultivated land, based on assessments and inventories;
- flood zoning methodology, including testing of various base map types and laser scanning;
- identification of exposed objects and areas by use of GIS and digital property registers;
- regional flood frequency analysis;
- economic loss risk analysis;
- test and verification of loss curves.
- decision support for "front line" action, i.e. decisions taken locally on incomplete information

Environmental considerations have also relevance for risk analysis and extended cost/benefit analysis like:

- Flood impacts on water quality
- Floods and aquatic life
- Erosion and sediment transport

- Environmental effects of flood mitigation structure, and environment-friendly mitigation activities and designs
- Flood protection and environment conflicts
- Flood and pollution.

What we would need is to establish a loss function and to estimate the probability distribution function characterising the occurrence of flood events. The methods for the estimation of the probability of occurrence of an event (load) are developed. These statistically based models rely on assumptions like stationarity in hydrological time series, sufficiently long observation series and low measurement errors. Besides the effect of long-term climatic changes and regional human impacts on the runoff process our data base is rather poor especially in alpine basins as well as in remote areas. Also, the loss function itself is strongly time dependent because it is related to the level of infrastructural development and land use. Therefore loss functions exhibit a long term trend which is superimposed by a seasonal dependence when agriculture and tourism is being important.



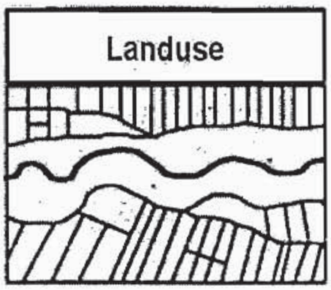
Cumulative distribution of the exceedances (m³/s) for the period from 17.8. to 30.9.

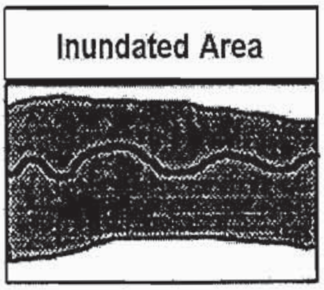
Cumulative distribution function of the exceedances (m³/s) for the period from 3.3. to 18.4.

Fig. 2 Theoretical and empirical distribution functions for different periods within the year (Gauging station, Federaun, Austria)

One of the main problems is how these uncertainties are considered in the risk definition. In general we can say that a decision has to be made about the type of distribution function which should be taken from the numerous types of models being available (Kite, 1991). Assuming that we know which distribution function is correct their respective parameters have to be estimated from observation. Even when we assume that the observations are without any error due to the limited length of observation the parameters can be only estimated and are thus uncertain, or in other words, they have also a probability distribution.

The loss functions can be estimated from historic events and their respective damages and from GIS based loss estimates.





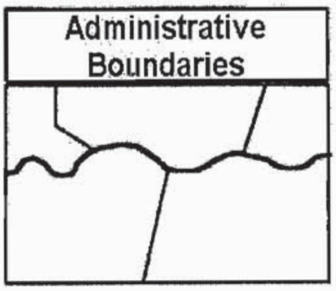


Fig. 3 GIS based information about Land Use, Inundation, Administrative boundaries

Land use maps are already widely available and standards assist in different land uses like unproductive land, forests, grazing areas, arable land, sparsely populated regions, intensive populated areas, infrastructural elements like roads, transmission lines, industrial complexes, etc. To delineate the inundated areas a digital terrain together with a hydraulic model would be necessary. Otherwise land marks from former floods or aerial photos could be used. The damages are primarily dependent on the height of inundation, on the flow velocity, on the duration of inundation, and on the time of occurrence of flood. Based on this information a loss function can be elaborated.

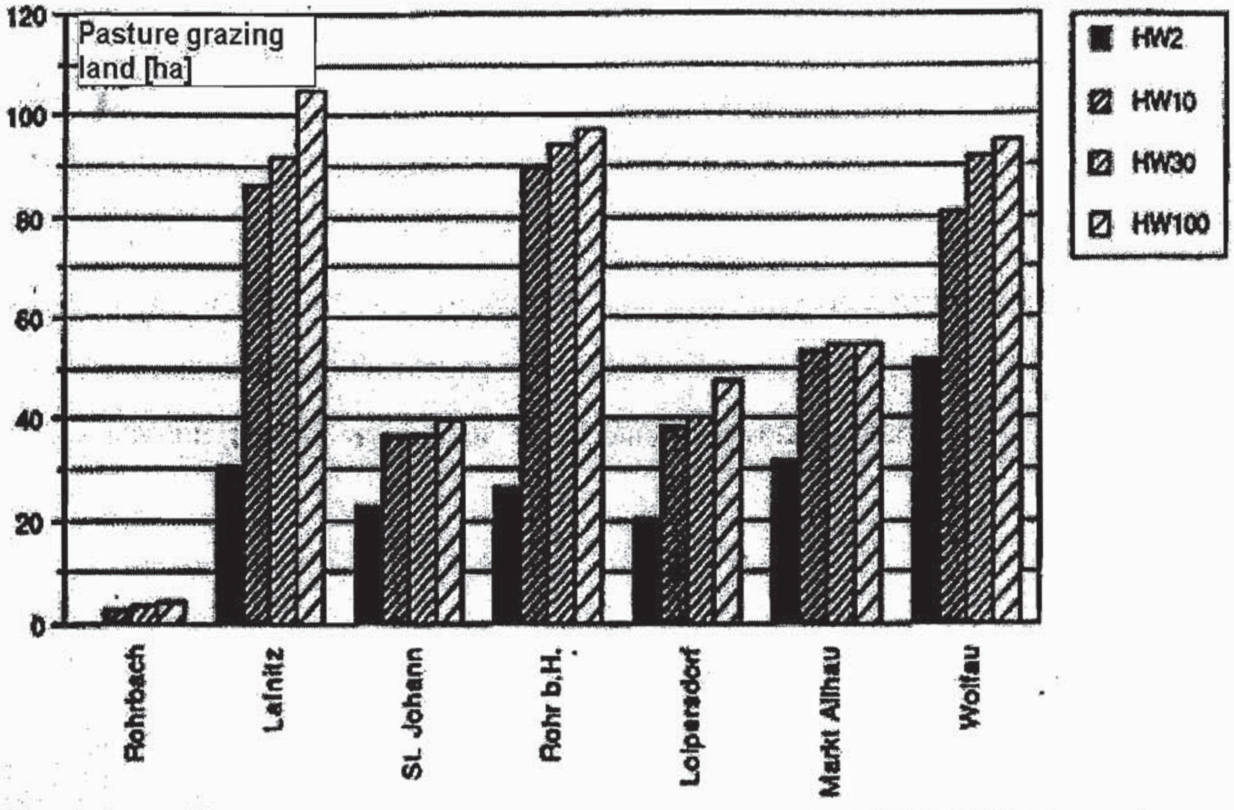


Fig. 4 Area of inundated grazing land in different villages for different flood events

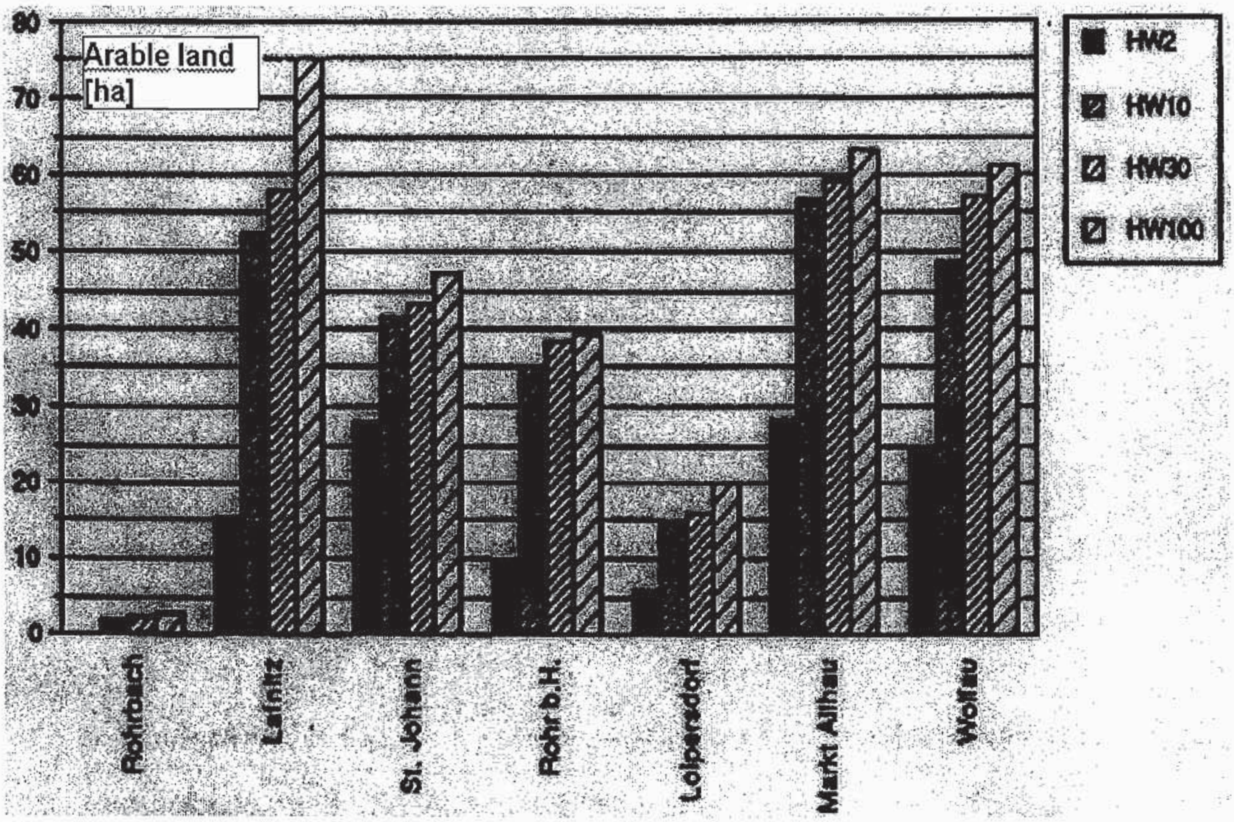


Fig. 5 Area of inundated agricultural land in different villages for different flood events

Given the crop, the time of flooding and the length of inundation a cost estimate can be achieved and a loss function can be established.

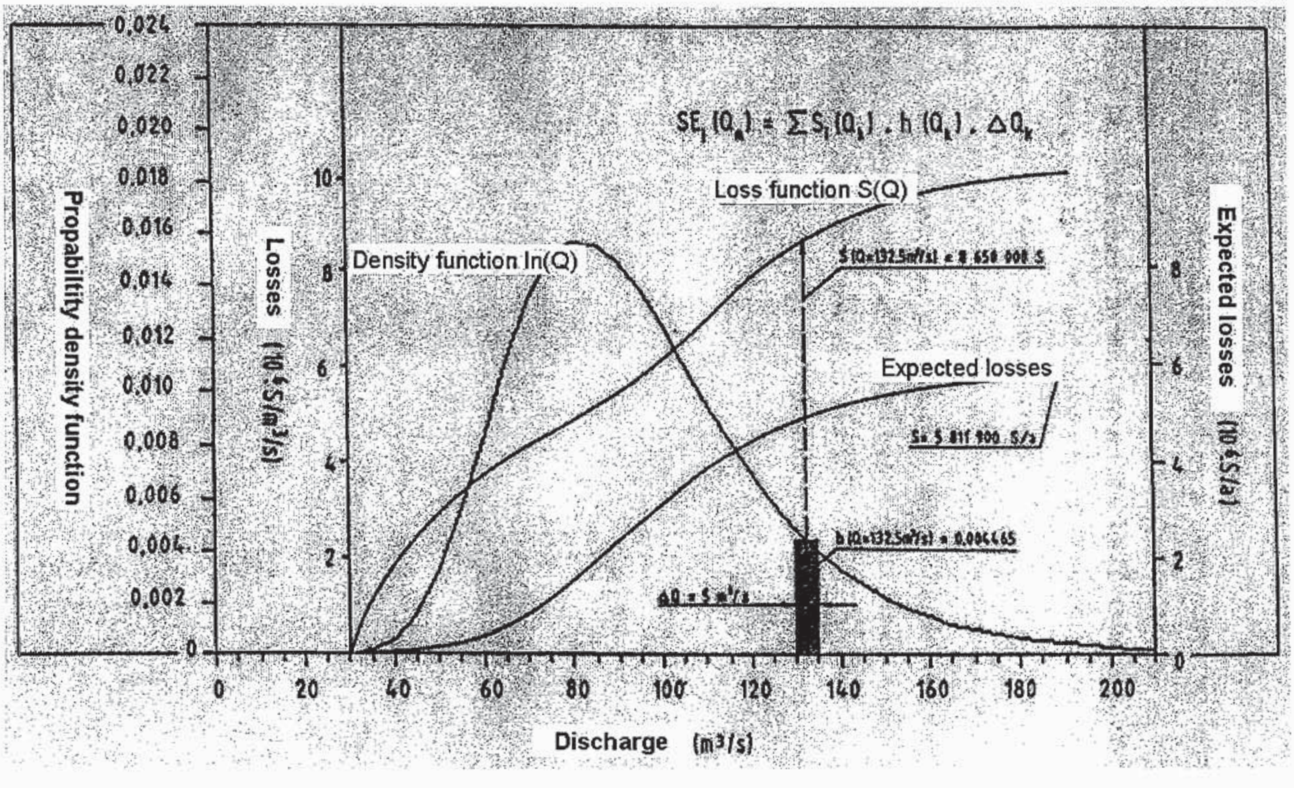


Fig. 6 Probability distribution function for flood peaks, loss function for damages and expected losses

As already discussed the evaluation of risk can be based on different criteria like expectation values, the risk of an event with a predefined occurrence probability and the assessment of the most adverse impact of an event.

For design purposes a purely economically based approach can be applied looking for a design flood peak Q* such that the construction costs C(Q*) plus the discounted accumulated losses over life time T are a minimum

$$Q^* \rightarrow Min\left\{ C(Q^*) + \int_0^T d_t \int_{Q^*}^{\infty} f(Q)L(Q)\,dQ\,dt \right\} \tag{4.1}$$

From an administrative viewpoint a normative approach based on a predefined occurrence probability seems to be appropriate and is frequently used because it provides the same level of protection to all inhabitants independently from the region under concern and from pure economic considerations.

Setting of acceptable levels depends on the object being protected. For example, a sewer system my fail more frequently than a flood protection system since the consequences from the former are much less serious than from the latter. Typical normative design quantities are given below in Table 4, but it is worth to note that there are sometimes differences in the 'standards' among countries.

Table 4: Hazards and Return (Design) Periods

Hazard	**Return Period (years)**
Sewer overflow (residential areas)	2-3
Fluvial flooding of residential areas	100
Reservoir failure for water supply	50-100
Spillways for smaller dams	1000-5000
Large dams	10 000

The return period is equivalent to the mean occurrence of an event of a given magnitude. The individual risk perception would rather refer to single event based concepts which would expose the individual property to damage.

5. FLOOD RISK MANAGEMENT AND MITIGATION MEASURES

Considering that our hydrological observations refer nearly exclusively to point observations like rainfall and runoff data we require regional approaches for the evaluation of risk in a basin. This requires tools for spatial mapping of risk and for this purpose spatio-temporal interpolation techniques are used including water table calculation between gauging stations to delimit areas exposed to inundation, and regionalization techniques for improved estimation of floods.

Linear Measures (Dikes and levees)

Reviewing the last forty years of flood protection policies in Austria three different approaches can be easily identified. In the fifties and sixties linear flood protection measures including dikes and levees, enlargement of the discharge capacity of river channels by straitening, widening and deepening, and bypass channels were built to reduce the inundation probability for settlements to a predefined level which corresponded to a 150 years flood in the alpine environment along torrents while a design flood with a return period of at least 100 years was used for rivers in the valley floors. Also, it was explicitly stated in the federal guidelines for flood protection that agricultural areas were also to be protected against floods but at a lower level. The implementation of these measures resulted among other effects in a reduction of the flood plain, an acceleration of floods and also in the amplification of flood peaks having a medium return period.

Flood storage reservoirs

Recognising these effects and considering the European dimension in agricultural production the second phase of flood protection put the emphasis on the provision of retention capacity by building flood retention reservoirs. A comprehensive reservoir statistics is not at hand but the available information indicates that the reservoirs were mainly designed to cope with a hundred years flood. Mostly all of the flood reservoirs are operated in an uncontrolled way where the outflow is simply a direct function of the water level in the reservoir. Some Austrian provinces, especially those in the prealpine region, gained in the last twenty years valuable experience in operating these schemes. It is worth to note that not only the implementation but also the maintenance and surveillance of these schemes is an important criterion for their efficiency.

Nonstructural measures

In the recent phase of flood protection the emphasis is on non-structural measures including the preservation of inundation areas and of the natural retention capacity. This approach is in harmony with ecologically based objectives like the preservation and improvement of the ecological functioning of river systems. For achieving both objectives including flood protection and ecological preservation a basin wide approach is applied which aims to develop a river prototype model ('Leitbildkonzept') considering the specific features of the catchment. Still, one of the weak points is the deficit in harmonising flood zones with regional development. Since 1990 flood zones are legally defined by the inundation area corresponding to a thirty years flood. General regulations for preserving the flood plain are included in the federal water law but this has no legally binding obligations for land use planning which is in the responsibility of the local and regional authorities.

Real time forecasting and alarm models are now being developed to reduce flood risk. As an example, some of the flood reservoirs are now being coupled with a forecasting system to improve the efficiency of retention volume. Multi-purpose schemes which are used for tourism, hydropower generation and flood protection proved to be efficient in some high alpine regions. For the major rivers in Austria runoff forecasting systems are also being developed which mainly serve hydropower companies to improve operation but are simultaneously used for flood warning. For smaller river basins and torrents no real time forecasting systems are implemented mainly because of the extreme short lead time. In a few selected cases mobile flood protection measures in combination with longer forecasting intervals are seen as a useful alternative to reduce flood risk.

Summarising, to reduce the flood risk the following points are important:

a basin wide hydrological approach for runoff modelling and flood protection

a harmonisation in flooding probability standards among different adminstrative units

a harmonisation among flood zoning and land use planning

an increase in the buffering capacity of basins by promoting non-structural measures.

Several elements of risk mitigation measures have been already discussed. In general, risk mitigation includes risk reduction which is achieved by prevention and by preparedness. Prevention refers to the set of engineering measures to reduce the probability of flooding while preparedness includes early warning systems, mobile flood protection measures, emergency plans and trained rescue teams and technical assistance. In between this two options planning approaches like risk zonation plans, resettlements summarised under non-structural risk mitigation measures have to be considered. Recently, the role of private insurance is gaining more and more importance. Another important aspect is in post disaster management including rescue teams, provision of emergency shelters, medical treatment and provision of drinking water and sanitary equipment's.

More and more, the communication of the risk is gaining importance. This includes the promotion of information that improves public awareness of flood hazard: hazard maps, flood marks, information on typical damage and risk to life. Technical terms that can be misunderstood (return period, risk) should be avoided.

The improvement of the understanding of public response: and the establishment of a better knowledge of public response both to general flood mitigation actions and to flood warnings are essential. The public participation mechanisms in the establishment of hazard and risk zoning, acceptable risk definition, clarification of public and private responsibilities is to be envisaged. Also, the support and training and education on natural hazard issues on all levels from school to university level is a mid-term objective. In-service training of decision makers and operational staff is particularly important.

6. SUMMARY AND CONCLUSIONS

The methodology which was presented is mainly based on an economic approach. Sometimes it is difficult to express all the damages in monetary terms, and therefore additional quantitative and qualitative concepts are applied. For instance, the value of human life is very often not given in monetary figures and also damages of cultural monuments or ecological impacts are difficult to assess.

Recent approaches refer to integrated risk management where the analysis, the assessment, management options including prevention, zonation and warning systems are simultaneously considered. An important factor in this context is the communication of risk.

In making risk management decisions with significant impact, programs should analyse the distribution of the risks and the benefits and costs (both direct and indirect, both quantifiable and non-quantifiable) associated with the selection or implementation of risk management strategies. Reasonably feasible risk management strategies including regulation, positive and negative economic incentives, and other ways to encourage behavioural changes to reduce risks (e.g., information dissemination), should be evaluated. Programs should employ the best available scientific, economic, and policy analysis, and such analyses should include explanations of significant assumptions, uncertainties, and the methods of data development.

Where programs have discretion to choose among alternative approaches to reducing risk, they should do so in the context of prevention programs and account for a broad range of relevant social and economic considerations such as equity, quality of life, individual preferences, and the magnitude and distribution of benefits and costs (both direct and indirect, both quantifiable and non-quantifiable).

Departmental programs should develop criteria and methods to evaluate the effectiveness of risk management decision.

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