ICOLD BULLETIN

INTEGRATED FLOOD RISK MANAGEMENT

DAMS AND FLOODS COMMITTEE

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TABLE OF CONTENTS

PAGE

FOREWORD

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

TABLE OF CONTENTS

LIST OF BOXES

TABLE OF CONTENTS (cont'd)

LIST OF APPENDICES

FOREWORD

FOREWORD

Floods are amongst the worst devastating natural disasters and human civilizations have always applied the most efficient means at their disposal to protect their lives and infrastructures against them. Dams and large hydraulic works are amongst the most efficient means adopted for protection against these disasters and, during the past century, the technology for the construction of these structures has evolved considerably, making them ever larger and more efficient.

Since its foundation, in 1928, ICOLD has been at the forefront of the progress in dam technology through international cooperation and exchanges. A specific ICOLD committee has been set up to discuss international experience and advances in the technology of flood protection - where dams play a key role – and to promote stat- of-the-art practices in this field. As of now, the work of this committee has been reported in two bulletins, namely "Dams and Floods - Guidelines and Case Histories" published in 2003 and "Role of Dams in Flood Mitigation", published in 2006.

These reviews show that the practice and philosophy of the use of dams for flood protection have evolved over time, and more specifically during the past century. In an initial trend, the tendency was for larger and more efficient structures, implicitly assuming that all the concerned parties shared the same enthusiasm in controlling large floods and overlooking the benefits naturally provided by "normal" floods. However, human technology quickly learns from its experiences and a more holistic approach to dam implementation and flood protection has emerged during the end of the last century, and dam design and operation are now viewed in the wider context of Integrated Water Resources Management.

"Integrated Flood Risk Management" is a specific application of Water Resources Management, and it presently constitutes the framework adopted for flood control. This concept is relatively recent, and is presently known mostly through an abundant literature and through some implementations, mainly in developed countries. Transboundary implementation of this concept over international watersheds in less developed countries is presently underway under the direction of large international agencies. This concept will ultimately lead to more efficient and more widely accepted flood protection systems; however, its application is more cumbersome that the traditional "economico-technocratic" approach, as it requires a genuine involvement of all concerned stakeholders and a final agreement between all of them through good faith negotiation. Experience shows that this process is frequently slowed down due to the inability of some stakeholders to give up some of their privileges or by the introduction of some outside parties not really concerned by the project or the overall benefits to the country or the community. This process requires significant diplomatic and organizational skills on the part of the project leader in order to overcome a host of unexpected difficulties.

Nevertheless, "Integrated Flood Risk Management" is now generally adopted for projects where flood protection is a significant component, and it is the purpose of this bulletin to outline the main principles of this approach and provide guidance to people assigned technically or managerially with the task of flood management and control. Without giving preference for any method, this bulletin aims to describe the fundamental knowledge needed for flood management according to the current state-of-the art and to provide help in selecting the most appropriate design and implementation strategy, based on basin-specific characteristics. This bulletin also updates some of the technical tools applied in flood management, which had been presented in earlier ICOLD bulletins.

The preparation of this bulletin was only possible thanks to the genuine and enthusiastic collaboration of each of the 26 members of this committee, who shared their experience and their time to make this bulletin as useful and instructive as possible. All along this experience, my role was similar to the one of a "Conductor" in a large orchestra. Once again, I heartily thank all those contributors for their precious collaboration.

Christian Guillaud

Chairman, Committee on Dams and Floods

1. INTRODUCTION

1 INTRODUCTION

Floods constitute one of the most devastating natural hazards, in terms of physical damages, as well as loss of human lives (ICOLD, 2006); and in recent decades, the intensity and severity of all the natural hazards, including floods, has been following an alarmingly increasing trend. The main reason is the rapid population and wealth growth in most countries. As a result, flood damages and casualties are increasing because of the concentration of population and infrastructures in flood plains.

Some of the more efficient tools available for controlling floods are civil works such as dams, levees and canals, which are structural measures. Dams enable storing excess water and controlling the natural flow in rivers; levees protect low lying areas; and canals divert excess water away from sensitive areas. However, large or extreme floods are rare by definition, and therefore, flood protection works are used infrequently. These structures must be designed in such a way that, under normal conditions, they may be used for other purposes and interfere as little as possible with other human activities and natural processes.

Structural measures only cover the physical aspect of flood control. Flood protection and flood control also require a complex and efficient organisation, in order to operate flood control tools in the most efficient way, to synchronise flood control activities when floods occur, and to plan flood plain developments to minimise exposure to floods. Therefore, flood control structures and flood management activities are intimately meshed with both human activities and the planning of infrastructures in the flood plains and cannot be carried out separately.

However, until recently, most of the currently implemented flood protection measures overlooked the fact that floods also generate some kind of "benefits" to the flood plains, in terms of deposition of nutrients and of contribution to the annual life cycle of many living species. Because the costs associated with structural flood control measures are high and with increasing awareness of the environmental and social benefits of limited flooding, a new approach has been introduced where society aims to manage the *risk* of floods. The general idea of flood risk management is to maximise the benefits generated on the flood plains, while at the same time accepting the risk of floods and mitigating the damages caused by them as far as possible. This new approach has been possible due to increased understanding of flood characteristics and effects, as well as the development and more general use of risk analysis in societal planning.

The introduction of a more holistic approach to flood management has yielded new terms, such as "Integrated Flood Management" and "Flood Risk Management", and has created a plethora of literature published in scientific journals, at conferences and on the internet. Although these publications all share the same goal of managing floods better, they may differ significantly in their focus and proposed methodology. Furthermore, the possibilities for flood management vary significantly from one river basin to another, because of differing physical characteristics and the region's economic development. Proposed flood management measures may be fully motivated and reasonable in a developed country, while the same measures would have limited effects in a developing country, and vice versa. For the individual engineer, city planner or policy maker, faced with the task of designing a flood management strategy or implementing flood control measures, the steps to take can therefore be quite confusing. It is a difficult decision to determine which measures are applicable for "my" case and possible to implement and operate from a practical point of view.

Therefore, the purpose of the present bulletin is to give guidance in integrated flood risk management to people assigned technically or managerially with the task of flood management and control. Without giving preference for any method, the bulletin aims to describe the fundamental knowledge needed for flood management according to the current state-of-the art and to provide help in selecting the most appropriate design and implementation strategy, based on basin-specific characteristics and the framework of integrated flood risk management.

The prerequisites for all flood management are the understanding of flood characteristics and how to calculate both the magnitude and frequency of floods. Equally essential are the understanding of the impacts of floods, both negative and positive, and how to quantitatively and qualitatively evaluate these. The knowledge of flood characteristics and impacts is a fundamental input to the risk analysis, which forms the basis for integrated flood management. Therefore, the bulletin is structured into three main chapters dealing with the flood characteristics, impacts and management:

Chapter 2 describes the methods used to evaluate the magnitude and the characteristics of large and extreme floods;

Chapter 3 describes the flood impacts, in terms of physical damages and potential benefits and their relation to land use. It introduces the various types of flood protection measures. An example of the economic analysis of benefits and costs of a flood protection project is also given in this chapter;

Chapter 4 describes the current practices related to Integrated Flood Risk Management;

The "theoretical" developments presented in Sections 2 to 4 are concluded in Chapter 5. They are illustrated by the description of specific applications of Integrated Flood Risk Management programmes or flood control activities throughout the world:

- The "Integrated Flood Control in the Czech Republic in March 2006" provides a detailed description of an efficient flood management system, which has been continuously improved based on feedback from actual floods, and outlines measures for further refinement.

- The case history of the Kitakami River, in Japan, describes the infrastructures designed to control flooding in an efficient manner while minimising interference with other human activities.

- The case study of the Al Wahda dam in Morocco demonstrates how it has greatly helped in improving safety in an area where devastating floods were frequent and has also helped to boost the social and economic development of the area.

- The synchronised operation of reservoirs with the purpose of curbing flood magnitude in Switzerland provides an example of how sophisticated technological tools can help to reduce flood damage and maximise benefits from flood inflow.

- The description of the actual flood control capability of a flood control system in Germany shows the necessity of interaction between flood control organisations and the public living in the flood plain, in order to maximise the flood control benefits and to avoid unrealistic expectations from the public.

Flood management, flood control and flood consequences have already been extensively dealt with by ICOLD. Results of these discussions and expertises are presented in the proceedings of the triennial ICOLD congresses, and in several bulletins, namely bulletins 35, 50, 65, 82, 86, 96, 100, 108, 116, 125, 130, 131 and 142 (ICOLD, 1982, 1985, 1988, 1992a, 1992b, 1994, 1995, 1997, 1999, 2003, 2005, 2006 and 2010).

2. FLOOD MAGNITUDES

2 FLOOD MAGNITUDES

A flood, by definition, results from higher than normal flows which inundate land outside the stream channel. This bulletin addresses floods caused by precipitation on a catchment and not those caused by tsunamis, tidal surges, levee breaches or dam failures, which result from different processes and, therefore, require different means for investigation and protection.

Integrated flood management necessitates operating hydraulic structures over a wide range of flood magnitudes. Normally the floods of concern have recurrence intervals ranging from about 2 years to the probable maximum flood. Floods with recurrence intervals less than about 2 years generally remain in the channel and do not produce flood damages. The probable maximum flood (PMF) is “the maximum runoff condition resulting from the most severe combination of hydrological and meteorological conditions that are considered reasonably possible for the drainage basin under study” (FEMA, 2004).

Floods naturally occur annually or more frequently. Damages are normally observed when the magnitudes of floods exceed a certain value, which is specific to each river. The following sections provide indications on the relative magnitude of floods. Section 2.1.1 outlines maximum floods observed around the world and Section 2.1.2 describes the evaluation of floods of different recurrences for selected rivers in the world.

2.1 Examples of Flood Magnitudes

2.1.1 World’s Maximum Floods

An indication of the range of maximum flood magnitudes observed around the world has been compiled by Herschy (2003), the largest 54 of which are presented in Figure 2-1. This information is based on an earlier data set first compiled by Rodier and Roche (1984), who comment that “... it is probable that for a good many of these floods the return period is indeed less than 100 years” (p 344), where the rarest event in this set of observed maxima was estimated to have a return period of around 2,000 years (based on an isotope dating approach). However, it needs to be recognised that the reported return periods are based on the length of the observed records, and do not take into account the joint probability of the event occurring in both time and space (within homogeneous hydrometeorological regions). In reality, the probability of a flood exceeding these magnitudes at a specific location is likely to be much rarer than that indicated by the availability of at-site records, and it is worth noting that this envelope of observed maxima has been shown to be consistent with estimates of the Probable Maximum Flood (eg Nathan et al, 1994). It should also be noted that maxima observed for floods in Europe lie below the envelope of these world maxima.

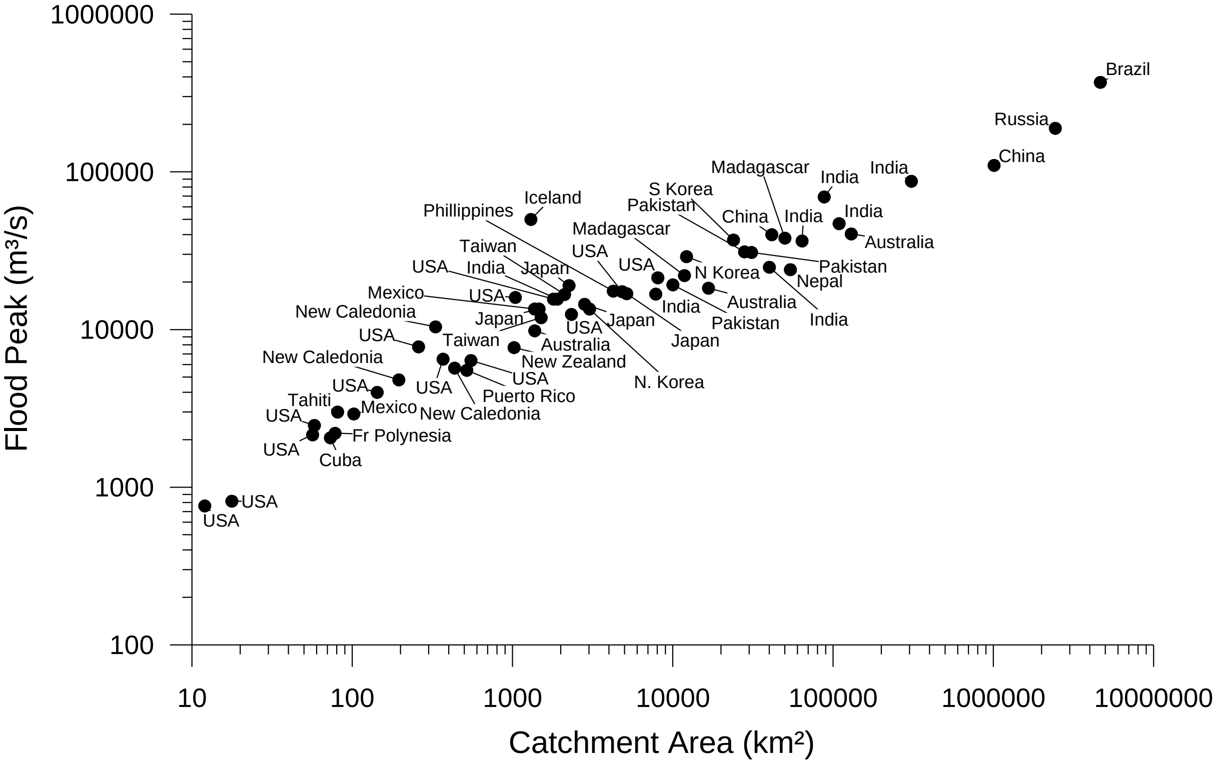


Figure 2-1 – Variation in discharge with catchment area for the world's maximum floods (after Herschy, 2003)

2.1.2 Flood magnitudes for selected rivers

Table 2.1 shows the evaluation of floods of various recurrences for selected rivers around the world. It outlines basic natural features which determine the range of flood magnitude for the watershed, namely the general climatic conditions, the prevailing topography and the size of the watershed. The data in this table is extracted from various studies carried out by SNC-Lavalin (Canada).

Table 2-1 - Example of order of magnitude of floods

River		**Mersey**	**Ravi**	**Dordogne**	**Rupert**	**Kagera**	**Godavari**	**Saska-tchewan**	**Congo**
Location		Upper Lake Falls (Canada)	Chamera II Site (India)	Argentat (France)	Rupert Dam (Canada)	Rusumo Falls (Rwanda)	Dummugudem (India)	Nipawin (Canada)	Inga (RD Congo)
Drainage area	km^2	1,671	2,593	4,420	30,525	30,700	281,000	287,000	3,700,000
Climate		Maritime; cold	Monsoon	Temperate	Cold	Equatorial	Monsoon	Continental; cold;	Equatorial
Topography		Low hills	Himalayas	Low mountains	Low hills	Hilly	Hilly	Plains	Flat; low hills
Type of regulation		Natural	Natural	Regulated	Natural	Natural	Some regulation	Natural	Natural
Mean annual flow	m^3/s	46	104	106	637	210	2,225	406	40,850
Mean flood	m^3/s	157	1,130	610	1,050	416	32,000	2,170	61,200
Max. flood of record	m^3/s	N/A	3,156	1.650	1,420	637	81,720	8,870	89,800
50-yr flood	m^3/s	381	3,820	1,500	1,500	711	87,700	5,320	89,000
500-yr flood	m^3/s	620	8,070	2,150	1,700	881	127,000	8,470	106,000
PMF (1) or 10,000-yr (2)	m^3/s	1995 (1)	N/A	3,120 (2)	3,470 (1)	1,082 (2)	184,000 (2)	20,300 (1)	137,000 (2)

2.2 Flood Characterisation

Floods have several characteristics that impact on management plans and the effectiveness of flood retention systems, namely: peak discharge, volume, duration, hydrograph shape, time of occurrence, and frequency of occurrence. Many types of land use are precluded by floods with short recurrence intervals (frequent floods) such as residential, industrial, commercial, agricultural, and some recreational uses. Low flood frequencies (rare floods) may still allow agricultural and recreational uses as long as the flood duration is short enough to avoid large flood damages. The peak discharge, volume, and hydrograph shape influence the design of hydraulic structures for flood regulation and protection. The time of occurrence affects reservoir operating rules to efficiently use storage capacity, in order to balance the need for downstream flood protection against other uses for conservation storage. Environmental needs for fish, wildlife, and wetland conservation generally can withstand flooding.

Numerous factors influence flood characteristics. Rainfall intensity, duration, and distribution are the primary factors that determine the peak discharge, flood volume and duration, and hydrograph shape. Other factors also influence flood characteristics including initial soil moisture content, catchment topography, drainage network, size, and shape; soil types; vegetal cover; and river morphology. In colder areas of the world, snow accumulation and distribution, as well as temperature distribution over the watershed are also significant flood generation parameters. In addition, man affects flood characteristics through land use and structural changes, such as the construction and operation of dams and reservoirs, levees, stream channelisation projects, and river diversions.

This bulletin categorises floods as ”large”, ”rare”, or ”extreme” based on flood frequency and magnitude (Nathan and Weinmann, 2001). These flood categories are shown in Figure 2-2. Large floods generally encompass events for which direct observations and measurements are available and have recurrence intervals less than about 100 years. Rare floods represent events located in the range between direct observations and the credible limit of extrapolation from the data.

The credible limit of extrapolation varies considerably based on the type and amount of data used in the flood frequency analysis, with the credible limit of extrapolation estimated as approximately double the station-years of record used for the analysis. Extreme floods generally have very large recurrence intervals (or very small annual exceedance probabilities - AEP), which are beyond the credible limit of extrapolation but are still needed for design and flood management.

Extreme floods border on the unknowable. Uncertainty is very large and unquantifiable. Since data cannot support flood estimates in this range, hydrologists and engineers must rely on our knowledge and understanding of hydrologic processes to estimate extreme floods. These floods may often result from unforeseen and unusual combinations of hydrologic parameters generally not represented in the flood history at a particular location. One potential upper bound to the largest flood at a particular site of interest is the probable maximum flood (PMF). The PMF is caused by the Probable Maximum Precipitation (PMP), which is defined as theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year (U.S. National Weather Service, 1982).

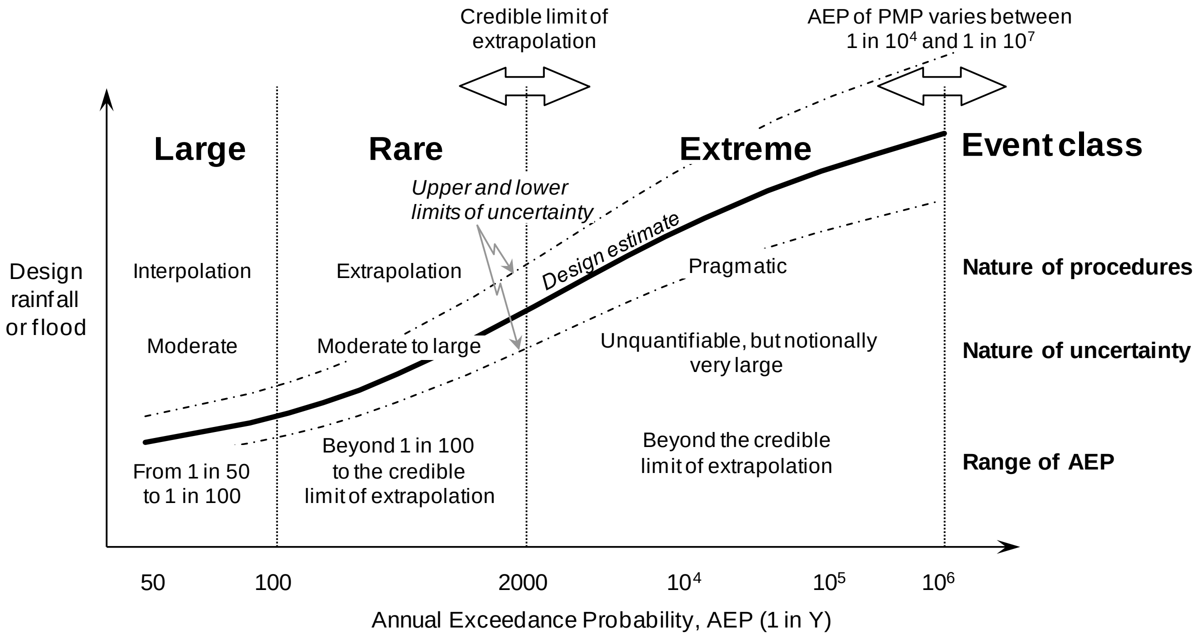


Figure 2-2 - Characteristics of notional floods as a function of annual exceedance probability (AEP); (Nathan and Weinmann, 2001).

2.3 Design Flood Considerations

The elements selected for incorporation in a hydrologic analysis of floods must consider the purpose of the investigation, available hydrologic data, possible analysis techniques, resources available for analysis, and tolerable level of uncertainty. The purpose of the investigation impacts the type of hydrologic information needed to assess the problem. Some problems may require only a peak-discharge frequency curve, while others may need complete hydrographs or a seasonal analysis. The available data, possible analysis techniques, resources available, and needs of the decision makers influence the selection of elements to be included in developing the design flood.

The flood characteristics of interest in a particular study depend upon the type of flood impacts that the analyst is trying to avoid or minimise. Development of the design flood should consider the tolerable frequency of flood impacts in formulating the flood management plan. Usually very large social or economic consequences will necessitate use of a design flood with an annual exceedance probability (AEP) less than 1 in 100 (rare or extreme floods). Smaller consequences allow use of smaller design floods. The design flood frequency is often established by local governmental regulations or policies.

Once the desired flood frequency is selected, other flood parameters of interest can be determined such as the peak discharge, volume, duration, hydrograph shape, and time of occurrence. The need for these parameters is based on the flood management alternatives considered. Establishment of a reservoir operation plan usually requires examining all of these flood parameters to avoid flood damages downstream. In general, flood frequency analysis is needed to develop a design flood and to evaluate the expected reliability of the flood management plan. Other characteristics can be derived from rainfall-based hydrologic models. In general the flood parameters of interest, as well as the desired flood frequency, determine the choice of flood estimation technique.

2.3.1 Data Sources

The type of data and length of the data record should determine extrapolation limits for flood frequency analysis. For large but frequent design floods, it may be possible to interpolate within the data. However, for rare and extreme floods extrapolation is necessary to provide information needed to satisfy project design requirements.

The sources of information used for flood frequency analyses include streamflow and precipitation records and paleoflood data. Streamflow records consist of data collected at established gauging stations (systematic records) and indirect measurements of streamflow and flood stages at this and other sites (historical records), including historical observations of flood stage that may be available in newspaper articles and other extant records. In the United States and Australia, streamflow records at a single site most often range in length from about 20 to 60 years. Precipitation and temperature records vary considerably in length and quality, but in most cases are limited to less than 100 years. Other meteorological data, such as snowfall, snow water equivalent, solar radiation, and wind speed and direction, are used for hydrologic modelling and usually have less than 30 years of records. In Europe and some parts of Asia, it may be expected that longer period of record than these are available.

Paleoflood hydrology is the study of past or ancient flood events, which occurred before the time of human observation or direct measurement by modern hydrological procedures (Baker, 1987). Paleoflood data do not involve direct human observation of the flood events. Instead, evidence of past floods is determined from geomorphic and stratigraphic records. The advantage of paleoflood data is that it is often possible to develop records that are several thousand years long. These data generally include records of the largest floods that have occurred in the catchment, or could at least provide the limits on the stages of the largest floods over long time periods. However, this information only provides an order of magnitude for possible extreme floods, which can be expected in the future, because the climate which prevailed, when paleofloods occurred, was probably significantly different from the present climate and from the climate which can be expected within one century or so.

Evidence of past floods is also determined from old books, descriptions in newspapers, etc. For instance in The Netherlands someone scrutinised thousands of old books and other publications on storm surges and river floods between the years 517 and 1700 and found hundreds of river floods and consequential flooding in many rivers all over Western Europe. In Argentina, Motor Colombus (1979) studied historical floods on the river Parana at Corrientes and analysed data about floods in 1812, 1858, 1878, 1905 and 1966.

2.3.2 Limits on Extrapolation

The type of data and the record length used in the flood frequency analysis form the main bases for establishing a range on credible extrapolation for flood estimates. The objective of flood frequency analysis and extrapolation is to provide reliable flood estimates for a wide range of frequencies to allow formulation of an appropriate flood management plan. In order to improve reliability of the flood management plan, flood frequency relationships should include an estimate of the uncertainty around the median values. The data used in the analysis provide the only basis for verification of the analysis or modeling results, and as such, extensions beyond the data cannot be verified. The greatest gains to be made in providing credible estimates of extreme floods can be achieved by combining regional data from multiple sources. Thus, analysis approaches that pool data and information from regional precipitation, regional streamflow, and regional paleoflood sources should provide the highest assurance of credible characterisation of rare and extreme floods. Table 2-2 lists the different types of data that can be used as a basis for flood frequency estimates and the typical and optimal ranges of credible extrapolation. In general, the optimal ranges are based on the best combination(s) of data envisioned in the United States in the foreseeable future. Typical ranges are based on the combination(s) of data that are commonly available and analysed for most sites (Bureau of Reclamation, 1999).

Other countries have different record lengths which should be used for determining appropriate flood frequency extrapolation limits. The information presented in Table 2-2 is only intended to assist in determining the type and amount of data needed for a particular analysis; each situation is different and should be assessed individually. The ranges of extrapolation should be determined by evaluating the type of data, lengths of records, number of stations in a hydrologically homogeneous region, degree of correlation between stations, and other data characteristics that may affect the accuracy of the data (Bureau of Reclamation, 1999).

Table 2-2 - Data types and extrapolation ranges for flood frequency analysis
(Bureau of Reclamation, 1999)

Type of data used for flood frequency analysis	Range of credible extrapolation for annual exceedance probability	
	Typical	Best Possible
At-site streamflow data	1 in 100	1 in 200
Regional streamflow data	1 in 500	1 in 1,000
At-site streamflow and at-site paleoflood data	1 in 4,000	1 in 10,000
Regional precipitation data	1 in 2,000	1 in 10,000
Regional streamflow and regional paleoflood data	1 in 15,000	1 in 40,000
Combinations of regional data sets and extrapolation	1 in 40,000	1 in 100,000

2.4 Analysis Methods

Many different analysis approaches are available for developing a design flood. The choice of a particular method usually depends on the type of hydrologic information needed, availability of data, time and budget constraints for the analysis, and prior experience of the analyst. Most of the approaches use some type of frequency analysis for evaluating the probability of occurrence of the design flood. The analysis methods that follow are not intended to be exhaustive in nature. Different countries have different but suitable models available for use. Therefore, the modeling approaches presented deal more with generalised types of models rather than specific ones. Several approaches are presented including flood frequency analysis, rainfall-runoff modeling, and probable maximum flood development.

2.4.1 Flood Frequency Analysis

Flood frequency analysis is conducted at a particular location by fitting a distribution to the data using either at-site statistical parameters or regional parameters to estimate flood quantiles. An “at-site” frequency analysis uses statistical parameters that are derived from streamflow records at a single location. This approach is the easiest and is usually sufficient for estimating large floods at a site that has a very long record length. A “regional” analysis is more complex and time consuming because the statistical parameters are derived from not only streamflow records at the site but at many sites in a hydrologically similar region. A regional frequency analysis is probably more suitable for estimating rare and extreme floods because many more years of record are used in the analysis, which should reduce uncertainty in the estimates.

When dealing with streamflow records, the data set usually consists of a mixed population with floods originating from events generated by different hydro-meteorological causes (e.g. extra-tropical storms, tropical storms, convective events such as thunderstorms, frontal precipitation or snowmelt), or upstream tributaries with markedly different flood response, including ice-jam floods. Some of the streamflow records may be those from a station which is located downstream of a dam, thus subject to regulation by the operations of the reservoir. Ideally, these floods would be re-computed for their unimpaired conditions or separated according to causal factors and analysed separately; then, the individual flood frequency curves would be combined to form the flood frequency relationship for the location of interest. In practice, a mixed population analysis is usually conducted, due to the difficulty and cost of separating the floods according to their causal mechanisms. To avoid these problems a seasonal differentiation can be applied if the flood generating processes differ significantly between seasons. Accuracy is often sacrificed when using a mixed population analysis, as the statistical weighting of the individual distributions, which have to be combined, is uncertain.

Several approaches are available for estimating the statistical parameters for fitting a distribution to a data set – the method of moments, probability weighted moments (PWM), expected moments algorithm

(EMA), and maximum likelihood estimators (MLE). The advantage of using the EMA or MLE approaches is the ability to incorporate historical and paleoflood data into the flood frequency analysis. The method of moments is generally the easiest to use, and computer programs for this type of analysis are more widely available.

In the United States, the method of moments is thoroughly described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). These guidelines recommend fitting a Pearson type 3 distribution to the common base 10 logarithms of the peak discharges (LP-III distribution). To determine the three statistical parameters used to fit the distribution, the sample mean and variance are determined from the logarithms of the at-site flood flows, and the skewness is determined from a combination of at-site and regional data. Adjustments are made to treat high and low outliers.

Probability Weighted Moments (Hosking, 1990) are based on L moments which are linear combinations of ranked observations. This differs from product-moments in that no squaring or cubing is applied to derive these moments. Often the variability of product-moments is high if an occasional event which is several times larger than other values dominates the other events. If logarithms of sample values are used to estimate product moments, small values are overemphasised. These effects can be avoided if L-moments are applied. By linear combinations of L- moments, probability weighted moments (PWM) can be estimated which specify several distributions which are usually applied in flood statistics (Stedinger et al., 1993)

The EMA (Lane and Cohn, 1996; Cohn et al., 1997) is a moments-based parameter estimation procedure that improved upon the method of moments procedure by incorporating different types of systematic, historical, and paleoflood data into flood frequency analysis. EMA is philosophically consistent with the method of moments approach (Cohn et al., 1997 and England, 1998), and it is a natural extension to the method of moments that produces identical results when no high or low outliers are present. The EMA approach operates in a censored data framework by explicitly recognising the number of known and unknown values above and below a threshold. An example peak-flow frequency curve with EMA is shown in figure 2-3.

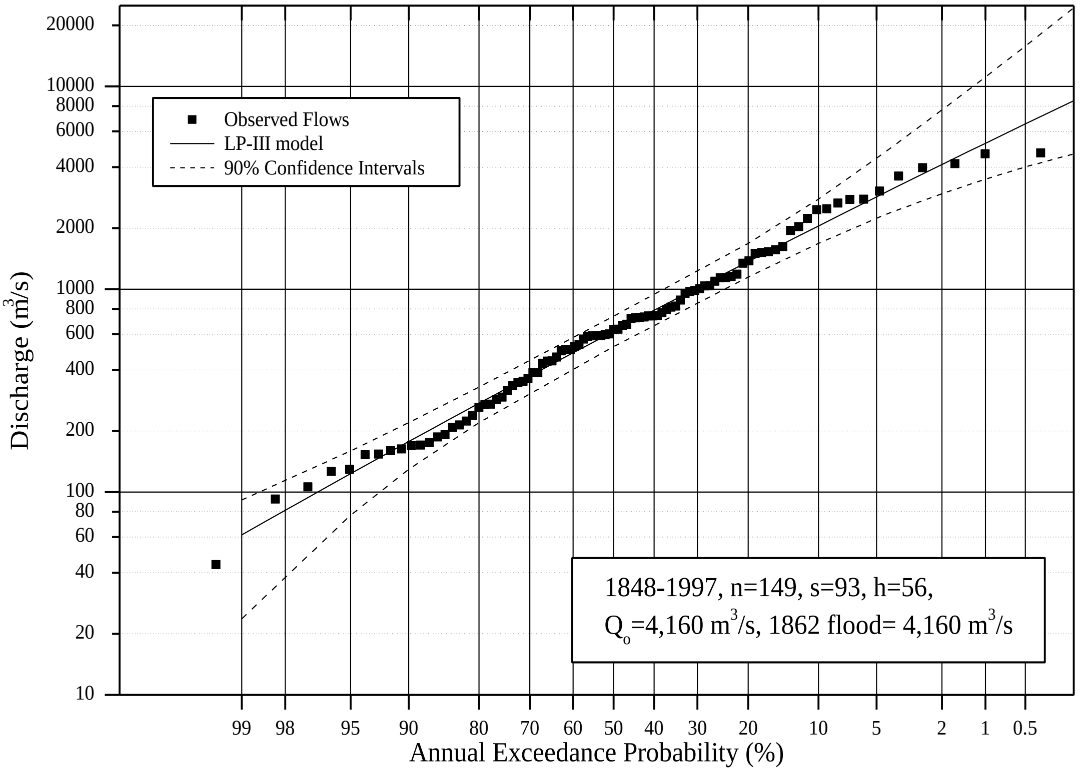


Figure 2-3. - Example application of EMA for American River annual maximum 3-day mean discharge frequency analysis (National Research Council, 1999).

A flood frequency relationship can also be developed using a Bayesian approach with the method of maximum likelihood (O'Connell, 1999). The approach incorporates systematic, historical, and paleoflood information, and data and model uncertainties. MLEs incorporate different types of systematic, historical, and paleoflood data into flood frequency analysis. O'Connell (1999) has developed a computer program, FLDFRQ3, which fits several types of distributions to flood data and accounts for data uncertainties with Bayesian techniques. MLEs have been shown to be superior to the method of moments for estimating statistical parameters when incorporating historical and paleoflood information (Stedinger and Cohn, 1986). An example peak-flow frequency curve with MLEs is shown in figure 2-4.

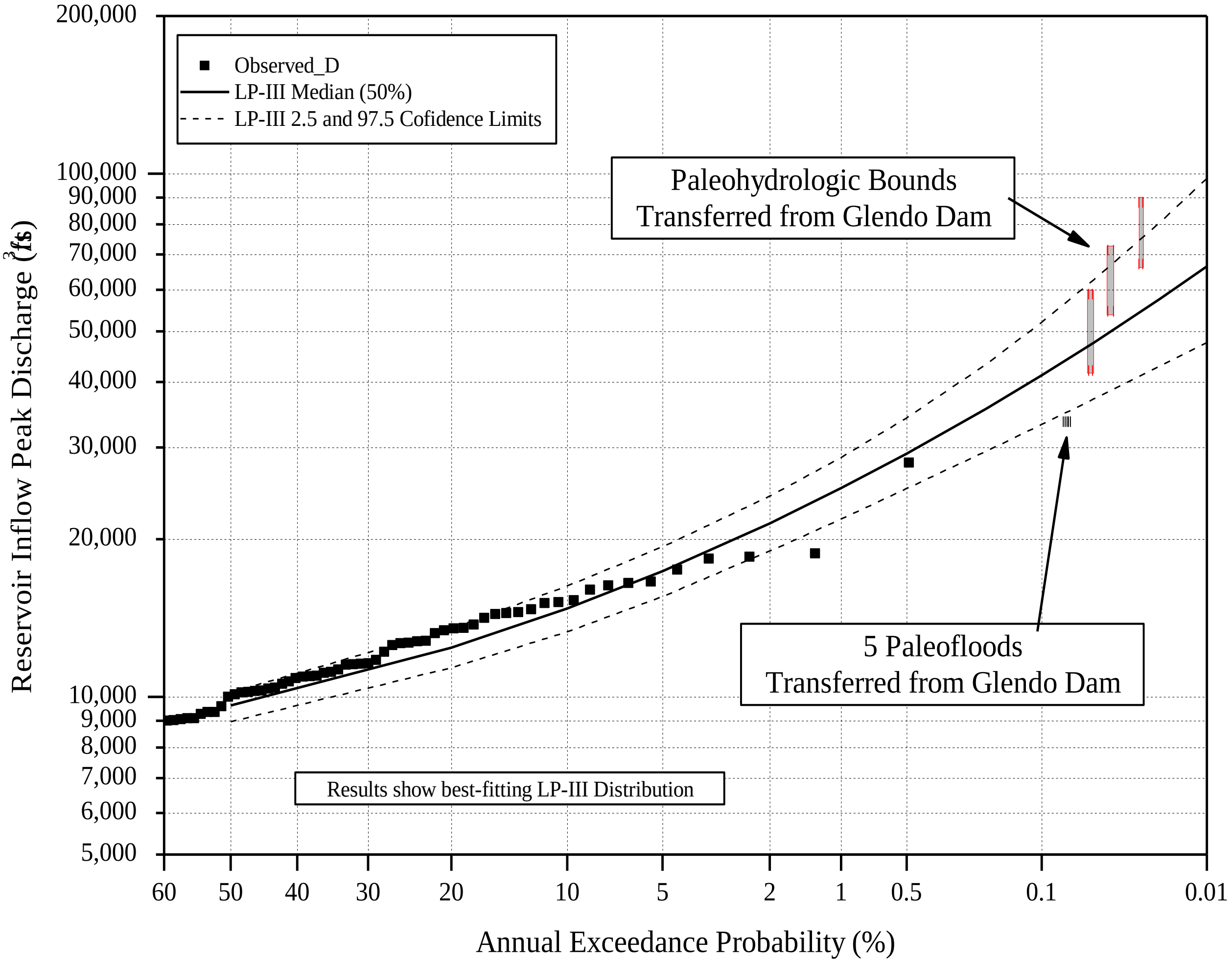


Figure 2-4 - Annual peak-discharge frequency inflows to Pathfinder Dam, Wyoming, from best-fitting LP-III distribution using FLDFRQ3 (England, 2003).

2.4.2 Rainfall-Runoff Modeling

The choice of a particular analysis method depends on the type of hydrological information needed and availability of data. By generating complete flood hydrographs, rainfall-runoff modeling provides information about many flood parameters that flood frequency analysis alone cannot. Conceptually, the method involves transforming a design rainfall into a design flood that is assumed to have the same probability of occurrence as the storm. A very thorough description of this approach was written by the

Australian Institution of Engineers (2001). Applications of hydrological models are useful if hydrologically relevant characteristics were changed (e.g. by reservoirs) or in cases where the existing hydrological time series of the past cannot be extrapolated into the future.

Rainfall-runoff models simulate hydrological processes with varying degrees of complexity. At one end of the spectrum are simple transfer functions that relate climatic inputs to runoff. At the other end, the most complex models attempt to solve equations related to known physical hydrologic processes. Most rainfall-runoff models are somewhere between these extremes. The accuracy of the model depends on the accuracy of the input data and the ability of the model to correctly represent the hydrologic processes. Complex models require lots of detailed spatially varying data. If the necessary data is not available or is too expensive to collect, it may make more sense to use a less complex model.

Rainfall-runoff models need several types of data to make the transformation from rainfall to runoff. Climate data needs include spatially averaged rainfall, the rainfall temporal distribution, snowpack depths, snowmelt parameters and air temperature during snowmelt season. Physical properties of the catchment that are needed include the sub-basin drainage areas, channel and catchment slopes, watercourse lengths, lag times or times of concentration, antecedent conditions, and information about physical structures that divert or store runoff. Soils and land use data are needed to determine spatially averaged soil infiltration rates and other losses. In addition, many other types of data are needed to run the model, including reservoir and stream routing parameters, evaporation and other parameters used in the transfer equations that are generally determined through calibration.

A hydrologic model may either be characterised as a single-event rainfall-runoff model or as a continuous streamflow simulation model. Either of these types of model will produce flood hydrographs. However, continuous streamflow simulation models require additional data. Since these models continuously account for all of the rainfall and the location of water in the catchment, unsaturated and saturated flow data and evapotranspiration information are necessary to account for soil moisture changes and subsurface water movement. Nevertheless, the application of stochastic-deterministic simulation systems is an option to increase the data base of flood analyses. Based on a stochastic rainfall generator, which provides spatial distributed rainfall fields over long time series, a deterministic hydrological model can be applied to generate long term series of runoff data within river basins. The stochastic characteristics of precipitation, with regard to the spatial and temporal distribution, can be considered, as well as the statistical uncertainties of initial wetness of watersheds. By comparing the statistical characteristics of generated flood series with characteristics from observed series, it is possible to validate the efficacy of data generation and to adapt the statistical parameters as necessary. With application of stochastic-deterministic runoff generators, a large amount of runoff data can be simulated by considering changes in the physical characteristics of flood processes including flood retention facilities. If the time intervals of simulation are small enough multi-variate statistical analyses of the generated time series are possible.

Model inputs can be either deterministic or stochastic. Deterministic models use single values of the required inputs to derive a single flood hydrograph. Conversely, stochastic models use probability distributions to characterise the observed range and variability of the required model inputs and develop multiple flood hydrographs. Examples of deterministic models include HEC-HMS (U.S. Army Corps of Engineers, 1998), RORB (Laurenson and Mein, 1995), and PRMS (Leavesley et. al, 1983). Examples of stochastic single event flood models that use Monte-Carlo techniques to sample from distributions of the main flood producing factors include SEFM developed by MGS Engineering Consultants, Inc., in conjunction with the U.S. Bureau of Reclamation (Schaefer and Barker, 2002), and version 6 of RORB (Laurenson et al, 2010).

2.4.3 Probable Maximum Flood Development

The development of the probable maximum flood (PMF) is a specialized case of rainfall-runoff modeling. The PMF is usually selected for design when catastrophic consequences are possible and structural failure cannot be tolerated. The PMF is “the maximum runoff condition resulting from the most severe combination of hydrological and meteorological conditions that are considered reasonably possible for the drainage basin under study" (FEMA, 2004). No realistic probability can be attached to the PMF. When the designer selects the PMF as the design flood, it is because the consequences of failure are very severe. If a lesser design flood is selected, it is done with the knowledge that some risk of failure is acceptable. By its very conservative nature, the AEP of the PMF is less than that of the PMP, which from figure 2-2 usually ranges from 10^{-4} to 10^{-7}.

The PMF is determined using a deterministic procedure rather than a probabilistic one. In calculating the PMF, the same models discussed in Section 2.4.2 are used, but with more conservative design parameters input to the models. Approaches used for determining the PMF vary from country to country and even from agency to agency within each country. Each of the approaches has one thing in common – a desire to choose conservative input parameters to produce the largest PMF for the study site. The degree of conservatism varies because the objective is to compute a flood that is reasonably possible but still representative of the maximum runoff potential. Detailed procedures for computing the PMF are well documented in FERC (2001), Cudworth (1989), and Australian Institution of Engineers (2001). Therefore, PMF computational procedures are not presented in this report, only generalized concepts are discussed.

The most important input to determining the PMF is usually the PMP. The calculation of the PMF uses the PMP storm which is centered over the watershed to produce the most critical combination of peak discharge and flood volume. The temporal distribution of the storm is selected to produce the largest peak discharge and the maximum distribution of flow about the peak. To determine the most critical flood, several spatial and temporal arrangements may need consideration.

To produce the largest PMF, losses are minimized. Losses take many forms, but the largest are from infiltration into the ground. Other losses come from interception by vegetation, evapotranspiration, and retention in surface depressions.

Antecedent conditions prior to the PMP also play a major role in determining the PMF. The PMP storm is typically a seasonal event. Therefore, the watershed may have snow on the ground during the winter, or may already be very wet from a prior storm. Concurrent snowmelt with PMP may also be an important consideration. Reservoirs may be full. The stream probably contains base flow which is contributed by water flowing underground considerable distances as ground water. Each of these conditions are considered in combination with the PMP storm to determine those that could be reasonably expected to occur at the time of the storm while maximizing the flood potential of the watershed.

Additional decisions are made with regard to converting rainfall to runoff and flood routing parameters. Unit hydrographs are the most common method used to convert excess rainfall to runoff. Many approaches are available to route flood runoff through reservoirs, detention storage, and stream channels. The key to having a representative flood model is calibration and verification to large historic floods.

2.5 Evaluating uncertainty margins

It is important to highlight here the numerous causes of uncertainty involved in flood magnitude evaluation. These causes may be related to the flow measurement, data handling or statistical evaluation. These include, but are not limited to, the following:

Flow measurement and data handling

- uncertainty in establishing the rating curve for flood flows;
- uncertainty in the transposition of records from a gauging station to an ungauged area;
- errors introduced in data handling (usually a severe limitation in several countries);

Statistical evaluation

- uncertainty in the selection of a statistical distribution;
- uncertainty arising from the limited sample of observations available;
- non-homogeneity of flood sample (changes in water management during the period of record, with the construction of reservoir(s) upstream of the gauging sites, change in location and type of gauging station, different flood generation processes, such as snowmelt flood, ice-jam floods, etc.); and,
- uncertainty in the calibration and structure of the rainfall-runoff model that is used to estimate the design flood hydrograph.

The evaluation of uncertainty introduced by flow measurement methods and data handling must be carried out on a case by case basis. This uncertainty may sometimes be very significant; however it remains undetected most of the time, unless the data user visits the gauging site and inquires about gauging and data handling methods.

Several methodologies can be applied for the assessment of uncertainty introduced by statistical evaluation,. Confidence intervals or limits are commonly used to assist engineers in the assessment of the accuracy of estimates and in the determination of the proper flood peak discharge which should be used for the design. The associated confidence interval of the estimate is a function of the length of record available for the analysis, the assumed probability relationships (frequency distribution), and the way the sample statistics are estimated.

As the length of the record increases, the reliability of the estimate also increases. Approximate values of reliability (percent chance) can be calculated for different return periods. As an example for infrequent events, Table 2-3 summarises approximate reliabilities as a function of confidence limit, annual exceedance probability, and record length (Wanielista et al, 1997). For example, with 25 years of historical data there is a high degree of certainty that the estimate for the 1 in 10 year flood will fall within plus and minus 50% of the actual value, but the likelihood that this estimated value falls within plus and minus 10% of the actual is only about 50%. Table 2-3 also shows the likelihood that a flood of a given annual exceedance probability occurs within a specific planning period. For example, it is seen that the likelihood of a 1 in 50 year flood occurring within a 30 year period is 45%. Techniques that can be used to estimate confidence intervals in flood frequency analysis are described by Stedinger et al. (1993).

Table 2-3 – Approximate Reliabilities as a Function of Confidence Limit

Return Period (years)	Record Length (years)	Confidence Limits (% error)			Likelihood that a flood of given return period occurs within N years	
		±10%	±25%	±50%	N = 30	N = 50
2	10	47	88	99	100%	100%
	25	68	99	100		
	100	96	100	100		
10	10	46	77	97	95%	99%
	25	50	93	99		
	100	85	100	100		
50	10	37	70	91	45%	63%
	25	46	91	97		
	100	73	99	100		
100	10	35	66	90	26%	39%
	25	45	89	98		
	100	64	99	100		

Monte-Carlo simulation techniques are well suited to capturing the stochastic variability of flood producing factors, though such frameworks can also be extended to characterise the uncertainty involved in the transformation of rainfall to floods. The information required to do this rigorously is increasingly difficult to obtain as the magnitude of floods approach the credible limit of extrapolation. However, the uncertainties associated with key design inputs can be notionally represented (such as the large uncertainty involved in assigning an annual exceedance probability to the Probable Maximum Precipitation) and then used to assess the impact on the design objective of interest. An example application of this is provided in Figure 2-5, where it is seen that the uncertainty in the exceedance probability of the dam overtopping is almost an order of magnitude either side of the best estimate.

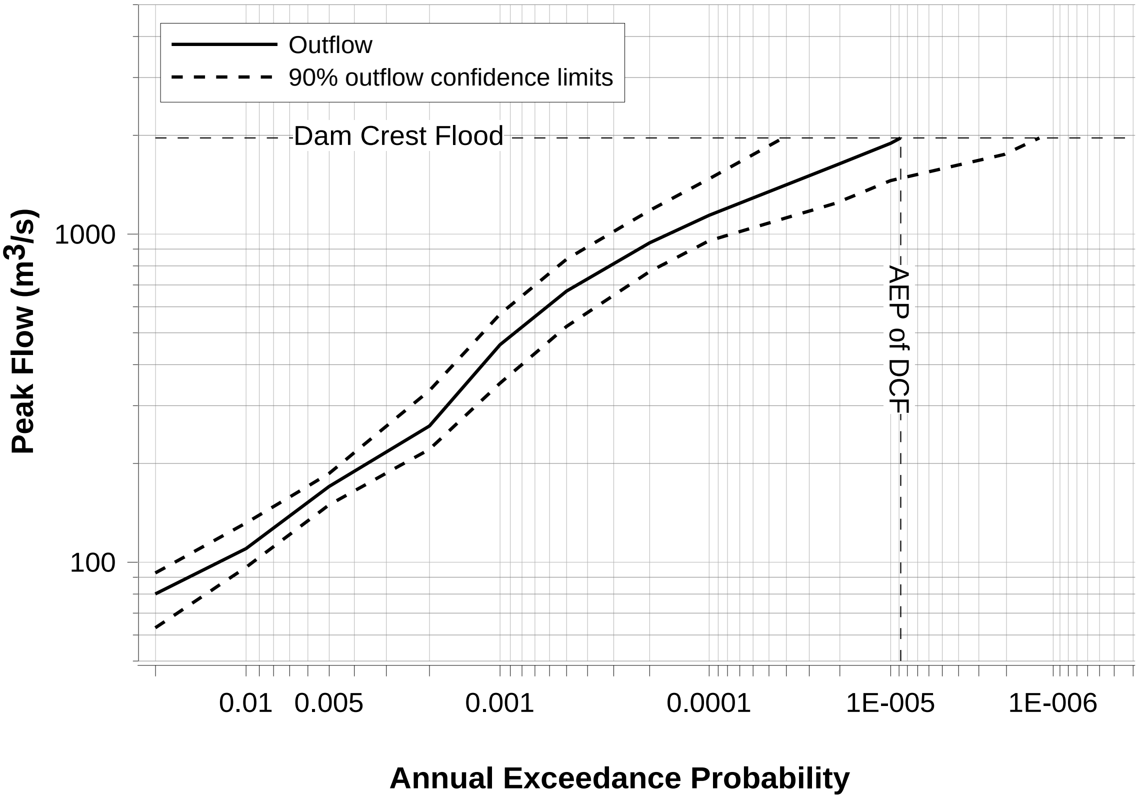


Figure 2-5: Example outflow frequency curves from a dam with confidence limits (Mittiga et al, 2007).

2.6 Floods and Climate Change

The influence of climate change on flood risk is receiving increasing attention. This interest arises primarily for two reasons, namely (i) the causal relationship between rising temperatures and the severity and frequency of large to extreme rainfalls, which result in an increase in hydrologic floods, and (ii) the increase in flood damages associated with sea level rise and societal factors. These two themes are briefly discussed below.

Firstly, however, it is worth noting that the evidence for temperature increase is widespread over the globe. Examples are given in IPCC (2007) including: eleven of the twelve years from 1995 to 2006 rank in the twelve warmest years in the instrumental record of global surface temperature (since 1950); increases in sea levels with the global average sea level rising at an average rate of about 3.1 mm per year from 1993 to 2003; and, observed decreases in snow and ice extent with the maximum areal extent of seasonally frozen ground decreasing by about 7% in the Northern Hemisphere since 1900.

The known causes of these changes are a mixture of natural and anthropogenic, but generally centre around the concentration of greenhouse gases present in the atmosphere. Greenhouse gases in the atmosphere reduce the loss of heat into space and are essential in maintaining the temperature of the earth. Carbon Dioxide (CO_2) is believed to be the most important anthropogenic greenhouse gas in the atmosphere. The global atmospheric concentration of CO_2 has increased from pre-industrial value of about 280 ppm to 379 ppm in 2005 (IPCC, 2007). Additionally, concentrations of other long-lived greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) and halocarbons have increased during industrial times.

The IPCC (2007) states that it is very likely (i.e. there is a greater than 90% probability) that the increase in the global average temperatures since the mid-20th century is due to observed increases in greenhouse gas emissions due to humans. During this period, the sum of solar and volcanic forcings would likely have produced cooling rather than warming.

With higher temperatures, the water-holding capacity of the atmosphere and evaporation into the atmosphere increase, and this favours more intense precipitation. Trenberth et al. (2003) argue that increasing the moisture content of the atmosphere should increase the rate of precipitation locally by stimulating the storm through latent heat release and further by supplying more moisture. They do, however, question what happens to the total volume of water as the duration of the storm may be shortened through this process.

Multi-model simulations, with nine global climate models, support this hypothesis by showing that precipitation intensity (annual precipitation divided by number of wet days) will increase to different degrees depending upon the climate change scenario being modelled (Kundzewicz et al., 2007). Already, there are various cases of recorded increases in the intensity of rainfall over the 20th century, such as:

- A clear increasing trend in intensity of winter and autumn heavy precipitation in Switzerland (Schmidli and Frei, 2005);
- Increase in precipitation intensity in Italy, although a decrease in the number of wet days (Brunetti et al., 2004);
- Significant increase in the number of wet days and two-day precipitation extremes in the United States based on an analysis of contiguous states over the period 1932-97 (Pielke and Downton, 2000);

- An increase in the frequency of large precipitation events over the period 1910 to 2000 in India (Roy and Balling, 2004);

- Increasing trend in six out of seven precipitation extremes averaged across Europe (Klein Tank and Konnen, 2003); and,

- Increase in extreme rainfall despite a decrease in total rainfall in Italy and Spain (Alpert et al., 2002).

The assessment of the influence of climate change on floods is somewhat more complicated than for rainfalls. While it can be expected that an increase in the frequency of high intensity rainfalls will result in an increase in the frequency and severity of floods, there are additional factors to be considered that control the conversion of rainfall excess to flood hydrograph. For example Kundzewicz et al. (2006) suggest that snowmelt is likely to be earlier and less abundant, and as such the likelihood of spring floods in susceptible locations may decrease. They also note that increased temperatures will result in ice-jams being less prevalent, and the associated increase in river conveyance may decrease the risk of flooding during spring. It can also be expected that longer periods of dry weather will result in lower reservoir storage levels, and hence outflows may reduce due to the increased availability of flood storage. Conversely, the increased sea levels predicted by the IPCC (2007) will cause increased flooding in low lying coastal areas, which represent the most densely populated regions of the world.

As most reservoirs are used for multiple objectives, the need for improved flood protection which could derive from climate change has to be balanced with other targets of operation. Here especially the increased risks of droughts and changing water quality conditions have to be considered.

The influence of global warming on flood damages is dependent on factors other than hydrological floods (Pielke and Downton, 2000; Evans et al, 2004a). Of perhaps most relevance to flood management downstream of dams is the need to consider the influence of rising sea levels on upstream flood conditions. The expected concurrence of higher sea levels with dam flood outflows will result in increased inundation levels and hence greater threat to life and property. The lead times required to mitigate the attendant risks, either through policy changes or the construction of dams and other flood control structures, are long and in some cases may take many decades to come to fruition. Flood control dams provide one means of mitigating these risks, though it is clear (e.g. Evans et al, 2004b) that a portfolio of flood response measures will be needed that span public policy, landscape management, river and coastal engineering, and loss reduction initiatives. This is the purpose of flood risk management, which is described in more details in Chapter 4.

3. FLOOD IMPACTS

3 FLOOD IMPACTS

3.1 Flood damages and flood benefits

Large or extreme floods have been considered a nuisance since the beginning of civilization, because they are phenomena of abnormal magnitude, which disrupt human activities and cause damages to human settlements, in addition to loss of life. That is the reason why "flood impacts" have always been perceived in a negative sense and the principle of flood protection has always been straightforward: the cost of flood protection works is balanced with the corresponding reduction in flood damages (whether physical or intangible, like loss of life). Implicit to this way of thinking was the belief that nature has an infinite capacity of resilience and that it would eventually recover from the consequences of any occasional/limited disruption of natural processes caused by flood control measures.

Since the end of the last century, a new concept has emerged which introduces the natural processes in the balancing equation between flood control measures and flood damage reduction. It is recognised that floods are an integral part of the natural hydrological and biological processes on a watershed, and that disrupting the flood regime affects these processes in a more or less significant manner. Therefore, flood impacts are now divided in two categories:

- The negative impacts, which are mainly the impacts on human activities and lives and on man-made structures. Those aspects are dealt with in the following sections 3.2 to 3.4; and

- The positive impacts, which are their contribution to natural processes, are dealt with in section 3.5.

3.2 Physical Damages

3.2.1 Magnitude of flooding

In order to formulate and carry out a degree of flood management, it is necessary to define, in one way or another, the magnitude of flooding, as well as the extent of physical damages and to find a relationship between the two. Following Chapter 2, it is suggested that the magnitude of a flood be defined on the basis of a flood parameter. A flood parameter, which is most appropriate to the local situation, should be selected. Subsequently, the various values this selected flood parameter has attained or attains during a range of (possibly historical) floods of different magnitude would be analysed and processed. This would result in a frequency curve (also called non-exceedance curve).

But, apart from flood parameters one can also define flooding parameters, or, may be more clearly, one may call these inundation parameters. The various parameters applicable to floods and inundations are discussed in detail in (ICID, 2005) to which reference is made. Here, only the aspects relevant to the purpose of this Bulletin are summarised. The difference between the two is illustrated in Figure 3-1. The upper graph shows the non-exceedance curve for the volume of a range of floods, while the lower graph demonstrates the non-exceedance curve for actual flooding, where "magnitude" is expressed here by the inundation parameter "bank overspill".

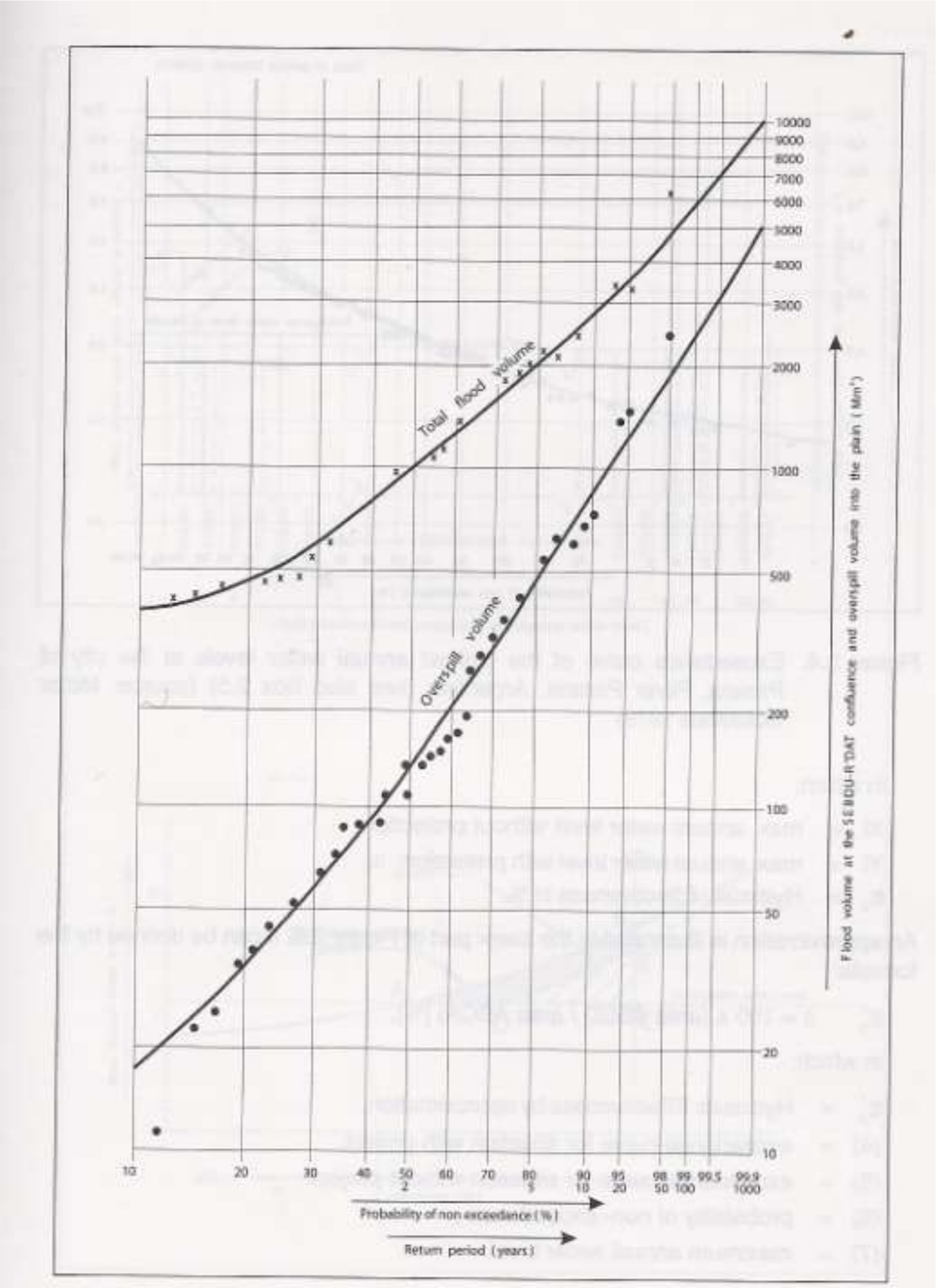
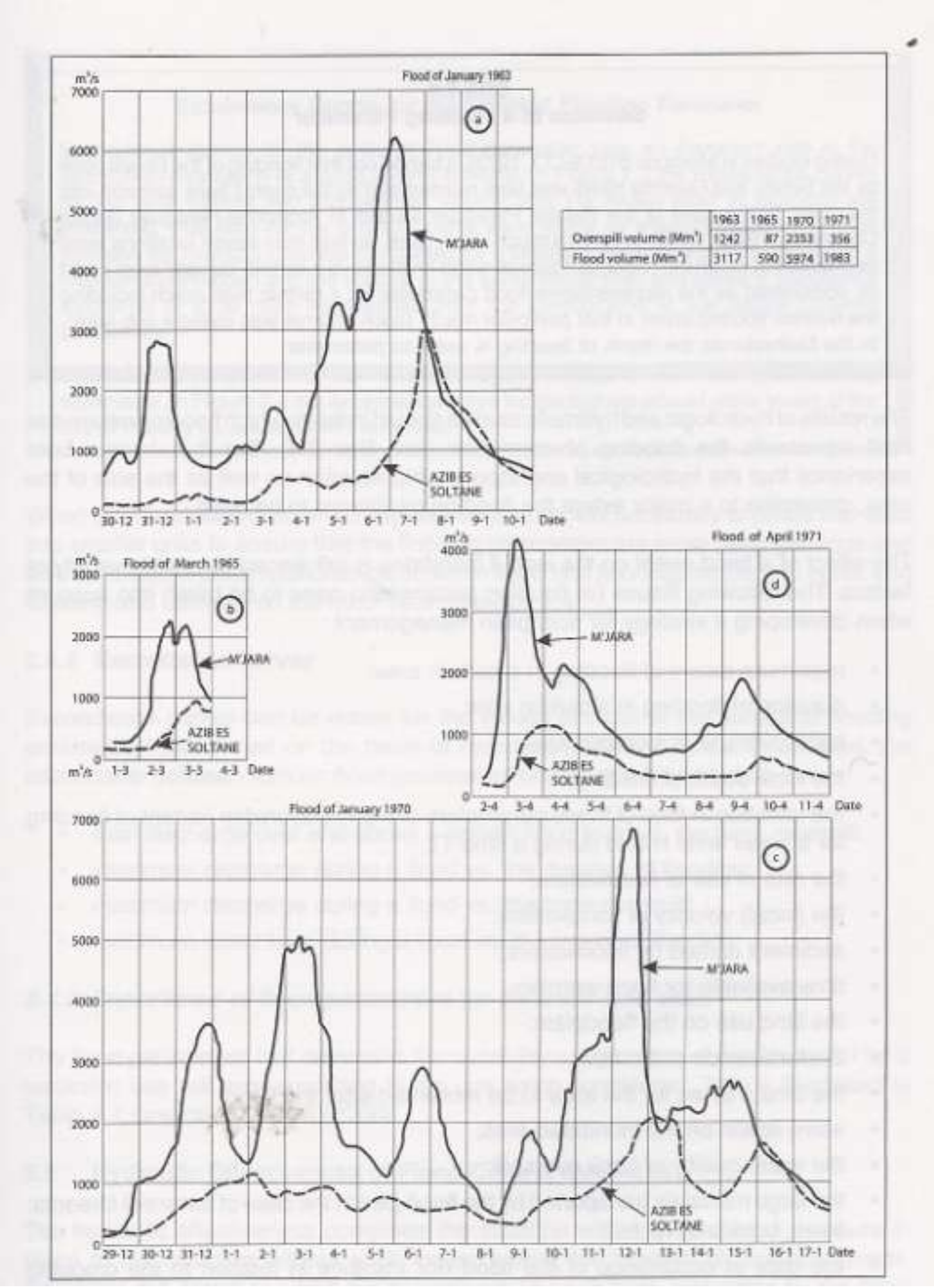


Figure 3-1 – Non-exceedance curve for flood and overspill volumes for the river Lower Sebou in Morocco - See also Box 3.3 (NEDECO, 1975)

A flood parameter should represent a flood in such manner that the different values of the parameter, valid for different floods travelling down a river in a certain catchment at a given point (for instance at the point of entry of the reservoir or the flood prone area), reflect the magnitude of these floods in relation to each other.

Obviously, a flood at a certain point of a river basin and watercourse can best be characterised by its hydrograph and the related return period. But there are many situations where hydrographs of different size for the same river and the same location have completely different shapes (Figure 3-2).



	1963	1965	1970	1971
Overspill volume (Mm³)	1242	87	2353	356
Flood volume (Mm³)	3117	590	5974	1983

Figure 3-2 - Four different size floods originating from the rivers Ouerrha and Sebou, Morocco (NEDECO 1973)

In that case a carefully selected unambiguous parameter of a flood wave travelling along a river may, at a certain location, characterise a flood quite satisfactorily as well. Such flood parameters are:

- maximum discharge during flood;
- maximum water level during flood;

- maximum average daily discharge during flood;
- volume of the actual flood wave above a given discharge;
- duration of the actual flood wave above a given discharge or water level.

As the form of a flood of a given peak discharge, at a given geographic location, will, very generally, be a function of the catchment, a single parameter can be used to describe the flood[1].

As already stated one can also define inundation parameters. Inundation is a complex phenomenon; it depends on stochastic features (the flood) and the characteristics of the flood prone area. But physical, man-made structures (dams, flood embankments) also play a role. The latter, in turn, can modify the relationship between flood and inundation, in a deterministic or stochastic (dam break for instance) manner.

The results of topographic, hydrologic and hydraulic studies should indicate which inundation parameter best represents the flooding phenomenon (see Box 3-1).

Box 3-1 - Selection of an inundation parameter

During studies in Morocco (NEDECO, 1973), it turned out that inundation of the Rharb plain by the Sebou and Ouerrha rivers was best represented by the overall bank overspill into the plain. In the case of the Parana-Paraguay studies in Argentina-Paraguay (Motor Columbus, 1979), which covered a much larger area, no less than seven locations were earmarked at which the maximum annual water level above a certain ”danger” level could be considered as the representative flood parameter. In this case this was also the inundation parameter for a certain river reach; as it included the riverine flooded areas in that particular reach.

In the Netherlands and in many other countries the depth of flooding is used as the inundation parameter. However, it is known from experience that the hydrological and topographical situations, as well as the size of the area, determine to a major extent the inundation parameter to be used.

Given the fact that a flood is basically characterised by its hydrograph and return period and the flooding it causes by an inundation parameter, there is still the need to translate flood hydrographs into flooding events. A few comments about the method normally used are given in Box 3-2.

Box 3-2 - The Relationship between a Flood and the Inundation it causes

The method preferred to establish the relationship between the hydrograph representing a flood and the typical inundation parameters is hydraulic modelling.

Except for the inundations, which are complicated by their conveyance system (especially valid in urban areas), one can state in general that physical modelling (scale models) is not required. Nowadays, mathematical models of flooding events, as for instance discussed in (ICID, 2005), are able to solve most problems. Moreover, many models also incorporate sediment transport or water quality parameters and are therefore able to represent all parameters, which characterise the inundation.

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[1] For instance, the parameter used in Australia for planning purposes is almost always the annual exceedance probability (AEP) of a flood of a given maximum height or maximum flow rate.

Obviously, it is preferable to have data available about reference floods (i.e. recorded historical floods) for calibration of the model parameters. Also, an accurate topographical description of the flooded area as well as the bathymetry of watercourse(s) and its banks must be available.

Whether one has to apply one- or two-dimensional models will depend on the size of the flood prone area, on the complexity of the water movements inside that area and on the interchange between the flows in the river and in the flood prone areas.

The advantage of hydraulic models is that they quite easily enable the simulation of levee break or breach growth, either by means of “dam break” models or on the basis of schematisations following from theoretical considerations on development of dam failures and breach growth in embankments.

In the absence of modelling of the flood prone area one has to fall back on the analysis of as many floods and recorded inundations as possible. In that case, one has to rely inter alia (for instance by correlation methods) on the most representative flood and inundation parameters.

An exhaustive list of models used in hydrologic and hydraulic studies for floods is given in (SEPIC, 2004).

The impact of a flood event on the area it inundates, its inhabitants, its infrastructure, buildings and other assets is influenced by a wide variety of factors (i.e. flooding parameters), such as:

- maximum extent of inundation in a certain area;
- duration of inundation in a certain area;
- bank overspill in a certain area;
- the local depth of inundation;
- the variation in time of these parameters or their relationship (extent of inundation for a water level H and during a time T);
- the rate of rise of floodwaters;
- the (local) velocity of floodwaters;
- sediment carried by floodwaters;
- time available for flood warning;
- the land use on the floodplain;
- the turbulence of the flow;
- the time it takes for the area to be reclaimed after the flood;
- wave action on the inundated area;
- the water quality of bank overspill;
- the large materials transported by the flood (like in the case of torrential streams: trees, boulders, rocks);

- the season of occurrence of the flood (e.g. in relation to the cropping season or camping grounds on river banks);
- the time of the day or day of the week when flood happens (i.e. people at home or at work).

All these issues (or: inundation parameters) need to be taken into account when developing a strategy for flood management.

When the inundation concerned covers a large area, it is necessary to divide the area into smaller units to ensure that the inundation parameters are more homogeneous (see also Box 3-1). It is then also possible to establish a close relationship between flood and inundation, on the one hand, and inundation and damage on the other.

One may say that, in general, a flood parameter has a regional significance while an inundation parameter bears on the local situation.

Also for a selected inundation parameter an exceedance curve can be drawn (Box 3-3). As this requires quantitative data, which can be collected in a simple straightforward manner, only a limited number of items from the list of inundation parameters given above can be used for this purpose. Though the first four items of the list (maximum extent of flooding, duration of inundation, bank over spill, depth of inundation) are all inundation parameters having certain merits, it is the fourth one, average or maximum depth of inundation in a certain area, which is most frequently used.

Box 3-3 - Exceedance curves for the selected inundation parameter

Exceedance curves for the selected inundation parameter play an important role in the (economic) evaluation of a flood control scheme (see Section 3.6). In Figure 3-1 the exceedance curves for the total volume and the overspill volume into the Rharb plain in Morocco are presented. The data for the overspill curve were found by establishing a correlation between the overspill volumes (calculated for a limited number of floods by means of a mathematical model) and the volume of the same floods over and above a continuous discharge of 2,100 m^3/s as obtained from the hydrographs at the Sebou-Ouerrha confluence.

The selected parameter for the Parana-Paraguay studies for each sub-area was the water level. In Figure 3-3 the exceedance curve for a particular sub-area is shown for the highest annual water levels at the city of Parana.

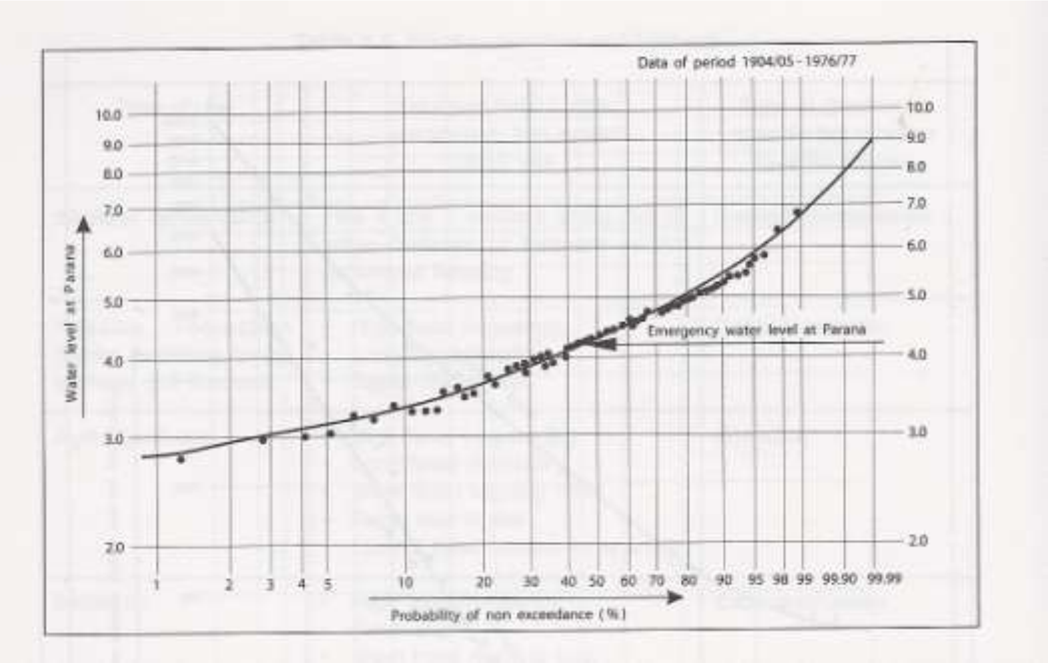

Figure 3-3 - Exceedance curve of the highest annual water levels at the city of Parana, River Parana, Argentina - See also Box 3-3. (Motor Columbus, 1979).

3.2.2 Type and nature of damages

The grouping of damages normally applied is very much a function of the particulars of the area concerned (land use, economic and social aspects) and of the magnitude of damage in each group. Various sub-distinctions can also be made. Table 3-1 presents an overview of such distinctions. Each country will develop its own groupings and therefore this table can by no means be considered to provide the final picture. It only shows the general trend.

Table 3-1 - Type and nature of damages due to floods

Main distinction	Sub-distinction	Nature of damage	Remarks
Direct damages	Residents and visitors	• Loss of life • Injury, severe trauma	
	Accommodation and related private property	• Structural damage to buildings • Damage to contents of buildings, cars • Internal clean-up	
	Public buildings and utilities	• Structural damage to buildings and infrastructure • Damage to contents of buildings • internal clean-up • Damage to public and private vehicles • Loss and disruption of essential services • Displacement of vulnerable groups, e.g. patients from hospitals	Buildings: administrative, hospitals, schools, sports accommodation, community centers; Utilities: roads, rail-ways, telecomm., electricity, gas, water supply, sewerage, storm water drainage, etc.
	Commercial and industrial enterprises	• Structural damage to shops, buildings, storage • Loss of equipment, transport, plant • Damage to stock and equipment • Internal clean-up	
	Agriculture and livestock	• Loss of harvest • Decrease in crop quality • Delays in production • Removal of sediment and related leveling works • Additional chemical treatment of plants, fertilizer to mitigate negative effects of inundation • Loss of cattle and their production	Losses in the agricultural sector can persist for several years (e.g. loss of mature orchards)
Indirect damages	Physical and psychological effects	Ill-health caused by flooding, stress, epidemics and related health recovery costs	In the Netherlands a further distinction is made of indirect damage inside the flood-prone area and outside (disturbance of industrial production)
	Damage to the economy	Loss of wages, production, business income	
	Opportunity costs	Reduced level of services (schools closed, interrupted communications)	
	Emergency measures	• Evacuation expenses • Cost of relief and rescue operations • Flood fighting	

An illustration of possible subdivision of flood damages is provided in Figure 3-4, where damages are subdivided into direct and indirect damages, then further sub-divided into tangible (which can be associated with a financial cost) and intangible (which cannot be associated with a financial cost) damages, and further into primary damages (which are felt mainly during flood occurrence) and secondary damages (which are felt after flood is past).

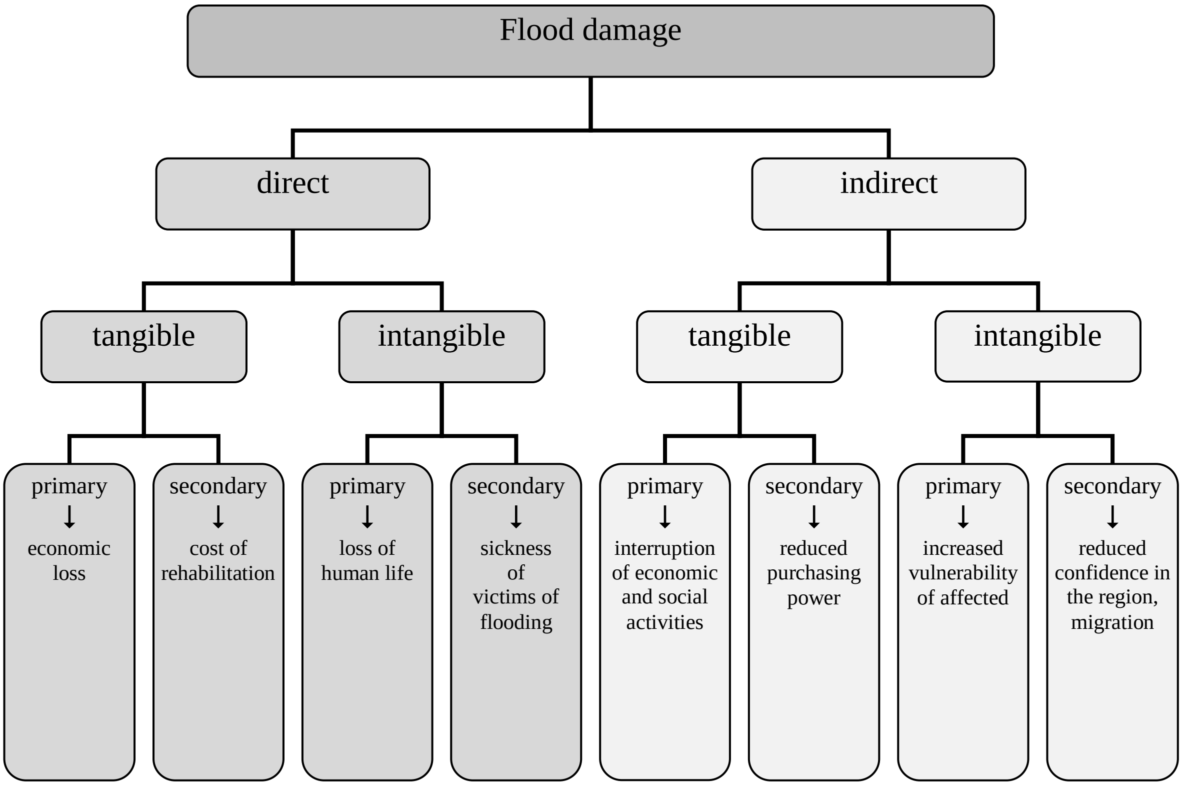

Figure 3-4 – Subdivision of flood damages (Parker, 2001)

3.2.3 Extent of physical damage

Damages caused by floods (or better: inundation) include loss of life, damages to buildings and infrastructure, environmental, social and other types of damages.

Many flood plains are subject to intensive agricultural activities. Urban and industrial developments, as well as telecommunication and transportation services, are also situated in flood plains. This penetration of human activities into the flood plains causes economic and community disruptions, with sometimes even wider national implications, when flooding occurs. Moreover, a diversity of economic and physical characteristics in different river reaches complicates evaluating potential flood damage for policy purposes. The degree to which a specific reach in a river is prone to flood damage will inter alia be determined by the occupational pattern, as well as the topographical, geological and hydrological characteristics of the reaches.

In order to decide on an optimum degree of flood management it is necessary to know the extent of damage caused by floods of different magnitudes/probabilities. Damage assessment must therefore be seen as a necessary step used for carrying out flood management. In this respect, it is noted that inundation maps, as mentioned in Section 4.4.2, can be very useful in carrying out the assessment.

Flood impacts concern social, technical, financial and economic aspects of human life. However, there are also impacts on the natural environment: flora, fauna, wet lands, ground water, forests, etc. In general, the first four impacts mentioned are well known; though the distinction between financial and economic impacts is not always clear (Box 3-4). The fifth group of impacts, however, has only been recognised in recent times (see Section 3.5).

Box 3-4 - Distinction between financial and economic costs

In the context of the cost of flood impacts, financial costs could be defined as costs to an individual, group of individuals, government agency or business establishment. For example, the loss of net revenue to an individual business enterprise as a result of flooding would be considered a financial loss - but not an economic loss - as it is assumed that customers, who would otherwise have purchased goods or services from the flooded business, can readily secure their needs from competing enterprises in the nearby area, and so the loss suffered by the first business is offset by the windfall gain of the second. However, there may be social impacts as a result of changing suppliers and reduced choice.

On the other hand, economic costs are costs measured in terms of consumption of human or natural resources for the community as a whole. Economic costs are a measure of change in communal welfare, and do not include financial losses to a segment of the community which then become a gain to another segment. The distinction between these two types of costs can be important with multiple stakeholders - such as described in Appendix 4 where the costs/benefits of flood operations between different owners needs to be analysed in an economic framework.

The first category of impacts comprises:

- loss of human lives;
- direct material damages to private and public property;
- health problems (stress included);
- indirect or induced impacts related to difficulties in the normal functioning of the communication system of the community (a standstill of activities and services, severed road links, disruption of economic and commercial activities, exceptional emergency measures, evacuation and re-establishment of people).

Box 3-5 Damage caused in New Orleans (USA) by flooding due to Hurricane Katrina

In 2005, the city of New Orleans and its surroundings were hit by Hurricane Katrina. The magnitude of the material (i.e. physical) damage due to flooding was estimated at US$ 30 billion. The overall damage, however, was much larger. In this respect one must think about immaterial damage, like damage to or loss of unique products made by artists, loss of one’s well-known and beloved habitat, the cost and effort which went into flood relief provided by the authorities and societal organisations, loss of students, who continued their studies at universities elsewhere, bankruptcy of enterprises, which had to stop operating during and after the flooding, etc.

It is not possible to give a reliable estimate of these immaterial costs but it could well be that the sum of all damage costs claimed in court against the US Federal Government (some US$ 650 billion) gives a good indication of this overall damage costs. Nearly 50 % of this amount is claimed by regional authorities (State of Louisiana US$ 200 billion, city of New Orleans US$ 80 billion).

Not all impacts are necessarily expressed in monetary “values”. The values can be ethical, moral, social, religious or be of a psychological nature (anxiousness and concern in view of the flood event and its associated risk, isolation of persons, disruption of the social fabric, loss of cherished, unrecoverable goods, damages to the historical and cultural heritage, etc.). It could well be that the last mentioned damages are a few times higher than the material damages (Box 3-5).

The extent of physical damages is dependent, both on the exposure to flooding and on the type and extent of human activities in the flood prone area.

The exposure to flooding, in turn, is a function of, on the one hand, the conditions present in the flood prone area and, on the other, the characteristics of a particular flood. In this respect, the following can be mentioned:

- the speed of rise to flood peak, e.g. summer storm events tend to have a higher peak factor in relation to the duration of the overall flood event; alternatively, snowmelt runoff provides for a much slower rise unless of course occurring in combination with an ice jam;
- depth of inundation with respect to existing development;
- velocity of flood waters;
- flood warning and evacuation measures in place;
- effects of inundation on transportation access;
- extent and condition of flood defence assets.

The type and extent of human activities present in the flood-prone area is another factor determining the physical damage. In this respect, it is noted that a substantial degree of protection against flooding practically always results in more human activities, more development in the still (to a certain extent) flood prone area and, last but not least, in a general attitude of carelessness and denial towards the possibility of a flooding event.

How damages are distributed over the various sectors of society and the economy will depend on the population density in the flood prone area, on land use and on the degree of economic development. In Table 3-2 the distributions of physical damages are given as percentages of the total damage caused by specific floods in the areas indicated. One can, for instance, observe that, as far as the relative magnitude of agricultural damage is concerned, there is indeed a significant difference between Argentina, Paraguay and The Netherlands, on the one side, and USA and Morocco, on the other.

Petraschek (2001) argued that the nature of the damage changes with society and illustrated this with the distribution of overall damages caused by floods in Switzerland in both 1868 and 1987 (Table 3-3).

Table 3-2 - Distribution of damages as a percentage of total damages caused by a certain flood

Sector	Argentina	Paraguay	Morocco	U.S.A.	Netherlands
	Sub-Area A 7	Sub-Area P 4	Rharb plain	Missouri – Mississippi	Meuse
Reference flood	Average flood	Average flood	Average flood	1993	1993
Private and public property	56	32	7	38	58
Infrastructure /services	18	23	11		-
Industry and commerce	7	20	14		33
Evacuation expenses	14	22	-		-
Agriculture and livestock	5	3	68	62	9
TOTAL	100	100	100	100	100

Table 3-3 - Nature of Damage Changes with Society (Petraschek, 2001)

Sector	In 1868	In 1987
River training	17.0 %	22.9 %
Roads and bridges	8.2 %	32.7 %
Agriculture (land & crops)	56.5 %	8.8 %
Buildings and contents	18.3 %	21.7 %
Utilities	---	13.8 %

3.2.4 Damage parameters and damage curves

The extent of physical damage, due to an observed flood event has, to be assessed in monetary terms and in a methodical manner. Such assessments form the basis of the damage curves to be developed for a certain flood prone area. Damage curves show the relationship between the magnitude of inundation and the physical damage caused by it. In order to find this relationship both aspects have to be related to a common inundation parameter (also called damage parameter). More details can be found in (ICID, 2005). Box 3-6 is copied from the latter.

A set of damage curves for a flood plain in South Africa is shown in Figure 3-5.

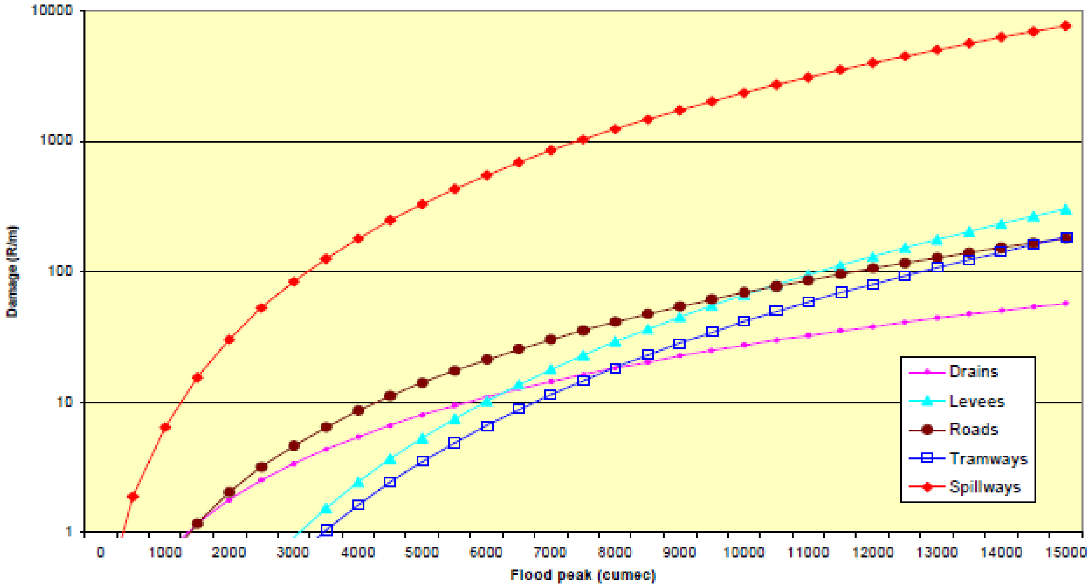

Figure 3-5 - Stage damage curves for different infrastructure categories in the Mfolozi flood plain, South Africa -1995 values (Viljoen et al, 2000).

Damage curves are used in the economic evaluation of flood control schemes (ICID, 2005), but are also an efficient tool for the determination on non-structural measures to be used in flood management. In most cases these measures cost only a fraction of the damage which can be avoided thanks to their implementation. Mentioned in this respect are: flood forecasting and warning, control of floodplain development (e.g. zoning on the basis of inundation maps), flood proofing, flood emergency response planning, flood fighting, etc. Details about these measures can be found in (ICID, 1999) and in Section 4.4.3 of this Bulletin.

Box 3-6 - Application of damage parameters in various countries

Morocco

In the Rharb plain in Morocco it was found that the volume of "bank overspill" into the (large) flood-prone area was an overall parameter which, more or less, could be considered to be representative for other relevant damage parameters such as: depth of inundation (accommodation, crops), duration of inundation (most crops), current velocity (infrastructure, sugar cane), sediment deposition (citrus plantations) (NEDECO, 1975).

By modelling four historical floods of different magnitude the duration of flooding for "units" having a certain land use, cropping pattern and topography could be established. By using the damage curves, developed on the basis of "duration of flooding", as well as figures from past-flood surveys, one could then determine the agricultural and other damage for each unit and, subsequently, for the whole flooded area for each of the four floods. The correlation thus found between the overall flood parameter "bank overspill" and the overall damage and "damage by type" enabled the preparation of damage curves.

Netherlands

In The Netherlands all damage functions are based on "depth of flooding" but, in addition, the flood parameters 'waves' (as caused by storm surges), and current velocity (between 3 to 8 m/s) are taken into account for damage to buildings.

For calculating the number of deaths the "depth of flooding", the current velocity, the rate of rise of the water level (in m/h) and waves have been incorporated in the damage function.

Australia

In Australia it is recognised that urban damage depends on "depth of flooding" while rural damage depends on both duration and depth of flooding.

As far as flood proofing is concerned it is worthwhile to quote the statement made in (Black, 1975):

"……Houses are basically light structures with potentially very great buoyant forces and they are not particularly strong. Flood proofing is an idea that developed to protect large corporate structures (factories, banks, etc.) and would appear to have little promise as conventionally applied to a house. Individual levees around a house or a small group of houses may work if a means of removing seepage can be effected or seepage is so slow that the flood waters have receded before sufficient seepage occurs to cause excessive damage. Other ideas may emerge but one should be careful to evaluate the forces and hazards involved."

It has to be admitted that economic evaluation of flood control schemes tends to focus on the prevention of direct damages (Table 3-2). The important item "loss of human life" is thus ignored.

In a recent thesis (Jonkman, 2007) an effort has been made to formulate a general approach for the estimation of loss of life due to floods. Subsequently, the limited information regarding loss of life in historical flood events was evaluated. It was found that large-scale coastal and river floods, that affect low-lying areas protected by flood defences, can cause many fatalities. In this respect it is mentioned that 1 % of the exposed population will not survive the event. However, this, relatively high, mortality rate does definitely not apply to most flooding due to river floods[2].

In the recent paper (Hill et al, 2007), an overview is given of the various studies aimed at the determination of the potential loss of life (LOL) due to floods. However, it appeared that in most cases the currently available empirical models developed are estimating LOL due to dam-break and they are not suitable for estimating LOL for the case without dam failure. In fact data concerning extreme natural floods are limited.

The most relevant information from flood events comes from the databases of Dartmouth Flood Observatory (DFO) in New Hampshire, USA, which collates information on large floods from around the world, with an archive extending back to 1985 (www.dartmouth.edu/~floods). The analysis is described in (Hill et al, 2007):

"The most extreme events were selected from the dataset which had average recurrence intervals in excess of notionally 100 years. This resulted in reducing the data set from 2,861 to 76 floods. The selected floods were then examined to ensure that they were representative of the natural flooding resulting from rainfall and that the loss of life was a direct result of the flood. A final list of 26 events was selected, once events were rejected which had the following characteristics:

- associated with landslides, as some of the loss of life could be a result of the landslide;
- dam or levee failure;
- flash floods;
- tsunamis;
- Hurricane Katrina because some of the fatalities were due to wind;
- displaced persons in excess of 100,000, as these are likely to represent flooding on large river systems with long warning times.

In Figure 3-5 the fatality rate for each event is plotted against the number of displaced persons. As expected, there is a relationship between the fatality rate and the number of displaced persons. This reflects that the events with a smaller number of persons displaced are likely to represent smaller catchments where the warning time is reduced and conversely, where there are a very large number of persons displaced, then the catchment is likely to be large with a corresponding longer warning time and hence lower fatality rate. It may also be a function of the generally flatter topography associated with very large populations at risk. [Graham 1999] also notes this inverse relationship between PAR (persons at risk) and fatality rate and that the databases of flood events: 'probably contain many cases demonstrating that there is an inverse relation between population at risk and flood lethality. This means that as the population at risk increased, the flood lethality (or flood severity) decreased. Large populations do not fit into narrow canyons—hence larger populations are situated in the flatter areas where the lethality is usually reduced.'

A simple approach to estimate the loss of life for natural floods would be to adopt the median fatality rates (0.0015) from the 26 events from the Dartmouth Flood Observatory database. However, from Figure 3-5 it is clear that this would underestimate the fatality rate for smaller catchments, where there is reduced warning time, and overestimate the fatality rates for very large catchments, where there are long warning times. Another approach is to adopt the best fit line shown in Figure 3-6. However, there is still much of the variability in the fatality rate that is not explained by the simple relationship.

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[2] Obviously, this statement does not apply to dam-break floods and non-anticipated (i.e by the population living in the flood plains) large spilling from the reservoir.

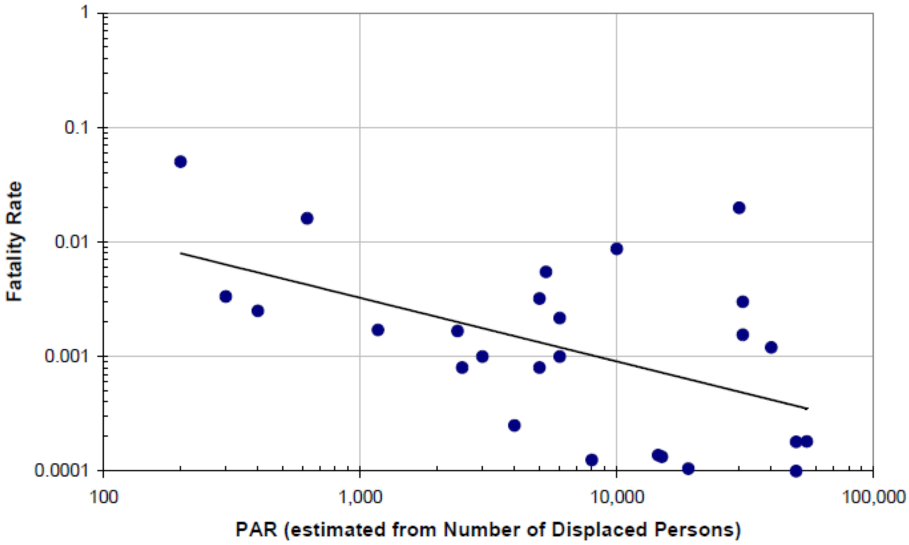

Figure 3-6 - Fatality rates for large flood events from the Dartmouth Flood Observatory database

Based upon the consistency of the low end of the range fatality rates from (Graham, 1999[3]) with those from the Dartmouth Flood Observatory events, it is proposed that they form the basis for estimating loss of life from natural flooding. The recommended indicative fatality rates are summarised in Table 3-4.

Table 3-4 - Recommended indicative fatality rates for natural flooding adapted from (Graham, 1999) by Hill et al (2007)

Flood Severity	Warning Time (minutes)	Flood Severity Understanding	Fatality Rate
Medium	No warning	Not applicable	0.03
	15 to 60	vague	0.01
		precise	0.005
	More than 60	vague	0.005
		precise	0.002
Low	All	All	0.0002

For Medium flood severity the fatality rates have been taken from the low end of the range recommended by Graham (1999). For the Low flood severity a fatality rate of 0.0002 (1 in 5,000) has been included, based upon the median fatality rates for large populations in the Dartmouth Flood Observatory events (PARs between 1,000 and 100,000). This fatality rate corresponds to the fatality rate recommended by Graham (1999) for Low severity dam break flooding, with a warning time in excess of 1 hour and a precise understanding of the flood severity. It should be noted that it is expected that, for the majority of cases, the flood severity of the non-failure floods would be Low and hence the fatality rate would be approximately 0.0002. However, there will be some cases, such as confined valleys or flash floods, where the non-failure floods would give rise to Medium flood severity conditions, and in these cases it is recommended that the fatality rates outlined in Table 3-4 are applied."

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[3] It should be highlighted that the empirical method developed by Graham (1999) has been developed for the estimation of loss of life from dam failure.

3.3 Floods and land use

The various aspects relating to land use in flood plains are quite well described in (Green et al, 2000). The following has been copied from Chapter 2.2 of their Paper:

“Floodplains were amongst the areas first developed for human settlements: the soils are often rich, alluvial deposits; the land is flat; rivers were the best routes for transport; water was plentiful; and the local wetlands provided good sources of material for building and domestic uses such as baskets.

Thus, floodplains have major competitive advantages for human settlement and people from early history chose the advantages of arable farming on the floodplains over a poorer life hunting-gathering in the hills above the floods. Whilst settling on the floodplains exposed them to the risk of flooding, the quality of life that could be achieved was greater; that greater prosperity also reduced their vulnerability to other hazards. Maddison (1998) reports that in C8th China, 3/4s of the population lived in north China from dry land farming; by the end of the C13th, 3/4s of the population lived south of the Yangtze from rice farming. This shift allowed an immediate doubling of the population together with a 30% rise in per capita income.

This competitive advantage has continued to the present day. The Wentlooge Levels are a coastal polder in South Wales (UK); since the offshore mudflats are a Ramsar site, it looked like an ideal candidate for managed retreat. Closer examination revealed that the reason why large new investments are being attracted to the area are exactly the same as the reasons why the area was first reclaimed in Romano-British times and was a centre for industrial activity in the C19th: the only alternative land is either steep hillside or narrow river floodplain (Chatterton et al, 1993).”

“In most of the world, the floodplains are already part of the web of the socio-economic system; few are untouched by human activity. From this catchment perspective, the term “floodplain encroachment” is highly misleading and also carries an essentially ideological message: the real decision is whether it is better to develop on the floodplain than elsewhere. The answer may be yes for one of two reasons: it is better to develop on the floodplain than anywhere else or there is nowhere else to develop. Once other planning constraints are taken into account, such as designations as areas of landscape value, of archaeological significance or “Green Belt”, the floodplain may be the least damaging place for intensified development. For instance in the UK, the municipal government decided to undertake flood alleviation works on the Black Brook near Loughborough and then to develop the area because the alternative was intrusion into Charnwood Forest (Parker, 1995). In relative terms, the costs of flood alleviation are often much lower than the infrastructure and other costs of intensifying development elsewhere.”

The constraints on flood management and the use of floodplains vary significantly between different countries. Consequently, what is an appropriate policy in one country may be quite inappropriate in another. Three measures of the pressures and constraints under which an appropriate flood management policy must be developed are:

- Gross Domestic Product (GDP)/km^2
- population density; and
- arable land per capita.

The first is a joint measure of the availability of natural resources and the intensity with which they are already being used; the second is a measure of the intensity of demand for those resources; and the third a measure of the availability of a key resource (Table 3-5 and Table 3-6). Thus, the lower the values of the first two measures and the higher the value of the third, the fewer will be the likely constraints in developing a flood management strategy.

In particular, where arable land is scarce, and in food terms arable land is much more productive than grazing land, it is less likely to be possible to consider abandoning some of that arable land or converting it to grazing. Similarly, resettling people who live on the floodplain is a more practical option in those countries, particularly those of C19th settlement, where population densities are, in global terms, very low. To bring the population density of the USA to that of France, a not-particularly-densely-populated country, the population of the USA would have to increase to the equivalent of ¾ of the population of China. Conversely, 100 million people inhabit the floodplain of the Yellow River in China (World Bank, 1997).

Table 3-5 - Gross Domestic Product and Population Density per Square Kilometer

Country or State	GDP/km^2	Population/km^2
New Jersey	10 010 810	371
Connecticut	6 685 702	228
The Netherlands	6 423 100	443
Japan	5 644 387	331
United Kingdom	3 552 713	238
Germany	3 310 826	231
Illinois	1 859 901	78
France	1 600 902	104
United States	596 186	28
Missouri	587 108	29
Bangladesh	152 341	871
South Dakota	70 090	4
China	46 535	120
Montana	36 760	2
Australia	33 095	2
Nepal	21 930	143
Mali	1 639	7

Precisely because they were settled early, floodplains are typically integrated into existing agricultural and economic activities. Floodplains are used for flood recession farming and seasonal livestock grazing; they also provide fish and materials for construction and everyday use (Acreman and Hollis, 1996; Drijver et al, 1985).

Table 3-6 - Arable Land Availability per Capita

Country	Arable land per capita (hectares)
Algeria	0.27
Australia	2.68
China	0.10
Germany	0.14
India	0.17
Japan	0.03
Thailand	0.29
UK	0.10
USA	0.67
World average	0.24

Source: World Bank Selected World Development Indicators 1999/2000

At the same time, the occupiers of the floodplains have adapted to the risk of flooding so as to cope with the flood hazard. These adaptations vary from the raised earth mounds constructed in the Netherlands as flood refuge areas, to raising housing on stilts in Malaysia, to the practice of taking refuge in roof areas in Bangladesh. In Setubal, in Portugal, residents have adapted to frequent flooding by closing off their front door with either a steel door or a concrete wall. In some cases, a similar wall has been constructed across the door between the living area and the bathroom so that when the toilet overflows in a flood, the living area is protected (Penning-Rowsell and Fordham, 1994). The most extreme form of adaptation is perhaps that of the char dwellers of Bangladesh. Here, the rivers are constantly changing their courses, creating and eroding islands and the char dwellers retain title to land whether or not it is currently part of the river channel (Schmuck-Widmann, 1996). Thus, many populations are highly adapted to the routine pattern of flooding."

3.4 Degree of Protection

3.4.1 The traditional approach of establishing a set of standards for flood protection

As discussed above, the different types of land use, together with the density of population in a particular flood prone area, will result in the degree of protection which is considered justified in the circumstances. In (ICID, 2005) it is stated that:

"…society will ask for more and better protection against floods if (a) human life is in danger, and (b) flooding, as experienced, disturbs daily life in an unacceptable manner."

What level of protection is actually achieved is, first of all (for the lower levels of protection, say, up to a return period of 50 years), a matter of economics: will the costs be borne by the benefits.

After such protection has been established on an economic basis, any additional protection (which, from an economic point of view, will only render low additional material benefits) is a "luxury": the society concerned can afford to spend part of its affluence on such additional flood control[4]. This approach is not new: a rich person will also buy a more expensive larger car than a person having a moderate income. This can be illustrated by a comparison of return periods valid for the Netherlands and Bangladesh respectively (Table 3-7). In both cases it concerns a densely populated country situated in the delta of a number of large rivers. And in both cases the danger for loss of human life originates predominantly from the sea rather than from these rivers. But GNP[5] of the Netherlands amounts to US$ 27 000 per capita and that of Bangladesh to US$ 360 per capita!

As in many other countries, the people in Bangladesh have learnt "to live with floods", while in the Netherlands they do not want to any longer and (much more importantly) so far, they can afford to maintain this principle. Obviously, the above greatly simplifies the situation in both countries:

- in Bangladesh, the combination of inflow into the country by rivers and heavy rainfall during the wet season, renders it impossible to ever attain the level of (river-) flood control achieved in The Netherlands;

- the size of the estuary and the average low level of densely populated islands and mud flats in Bangladesh render it impossible to fight against the high water levels of cyclones by constructing a 'Delta Project', as was done in The Netherlands after the storm surges in 1953."

"From the above it can be concluded that it is not possible to give firm recommendations regarding the desired level of protection. There are too many aspects to be taken into account and the situation

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[4] Like having a second house somewhere else or a second car in the family.

[5] Nowadays GNP is also called GNI (gross national income)

differs too much from country to country and from river basin to river basin, to enable the drawing up of a table with firm figures.

Table 3-7 - Return periods of peak water levels / floods used for design of flood protection works in various countries[6]

Country	Condition or item	Agricultural areas	Residential/ industrial areas
Australia (Victoria)			100
Bangladesh		10 to 25	Not known
Canada	Residential development ”life line” structures “vital life line” structures		100 500 1000
Germany		15-25	50 to 200
Hungary		100	1000
Netherlands	Flooding from sea Flooding from rivers Flooding in trans. zone	4000 1250 2000	10,000 1250 2000
Spain	roads	25 to 50	100 to 500
Switzerland		5 to 20 10 to 50	50 to EHQ[7] 100 to EHQ
United Kingdom			Less than 100
USA			Up to 500

However, based on the figures in Table 3-7 and what has been said earlier, it can be safely concluded that:

- Economic considerations[8] and potential for loss of life in first instance will determine the return period of the design flood;
- Rural areas will normally be protected up to the design flood having a return period in the range of 10 to 25 or 100 years;
- Residential and industrial development areas will generally be protected taking account of return periods of 100 to 500 years;
- If the reliability of basic data is dubious and/or flooding will result in a substantial loss of human life, the return period taken is much higher. In the Netherlands 10,000 years is taken as return period for its low-lying densely populated areas. In fact for major dams in most countries also a design flood having a return period of 10,000 years or the PMF is taken into account.”

3.4.2 The risk based approach to flood management

In recent years guidelines have been developed in various countries which advocate the use of risk analysis for floodplain management decisions such as the determination of flood planning levels. Minimum standards such as the ubiquitous “100 year flood” level are rejected in favour of a framework which aims to balance the risk from rare floods against the economic and social advantages of using the floodplain. This approach is elaborated upon in Chapter 4.

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[6] Figures given are partly based on non-confirmed information, implicitly given in various publications

[7] EHQ stands for extremely high flood’, which is supposed to have a return period somewhere between 100 years and that of the PMF (1,000 to 10,000 years).

[8] But insurers may also have firm ideas in this respect: (Parker, 2001) stated that any area having a risk of flooding of more than 0.5 % (i.e. a return period of 200 years) should be considered ‘high risk’. If building is permitted within these areas, in his opinion a return period for flooding of 200 years should be adopted.

3.5 Flood impact on natural processes

The impact of floods on natural processes (and thus on the environment) can only be discussed in the wider context of the river basin as a whole and the impact of man-made actions on the environment like the construction of large dams, flood management, flood embankments, river training and river diversion.

First of all one should realise that floods as such may generate benefits on their own without any interference by mankind. Floods replenish wetlands; recharge the aquifer and support agriculture and fisheries. In the long term, the benefits of the latter can only be known by carrying out socio-economic studies to analyse and measure the effects of floods. The positive effects of floods on the environment are known but so far the quantification of these effects is lacking, particularly in monetary terms.

Still one should bear these effects in mind when selecting and evaluating flood control projects. The effects of man-made actions to prevent and/or limit the impact of floods have been studied and discussed by many different organisations and individuals. In this respect reference is made first of all to the Technical Bulletins published so far by ICOLD’s Committee on the Environment. (ICOLD, 1981, 1982, 1985, 1988a, 1988b, 1992a, 1993, 1994, 1995, 1999). More bulletins are under preparation and are about to be released shortly. Also the present activities of that Committee and that of the Committee on the Role of Dams in the Development and Management of River Basins need to be mentioned here.

The subjects “River Basin Ecosystems” and “Ecosystem Impacts of Large Dams” have also extensively been elaborated upon by the World Commission on Dams (Bergkamp et al, 2000). Mention should also be made of (Drijver et al, 1985) and (Hill et al, 2000). When looking through these publications one cannot but conclude that most of their authors like the natural catchment and its rivers to stay free from any intervention whatsoever. Obviously, this is not a realistic idea. There are more and more people living in these floodplains and these inhabitants will induce economic development. The settlements, the related infrastructure and the economic development (farms, irrigation infrastructure, industries, tourist facilities, etc.) demand the restriction and, if possible, the complete prevention of flooding. However, it stands to reason that any intervention aimed at flood management should be subject of an ‘Environmental Impact Assessment’, in order to arrive at mitigative measures in relation to the disturbance of the ecosystem by the proposed flood management project.

Sometimes, the floodplains are not yet inhabited and this, for instance, can be the case when lowland floodplains are wetlands. In Green et al (2000) it is argued that: “… (these wetlands) are amongst the richest habitats in the world and the strongest argument against intensifying development of the floodplains is usually the ecological value of the existing wetlands. When the functional values of wetlands (de Groot, 1987; Maltby, 1986) are added to this equation, it can be more efficient to leave the wetlands alone. The value of wetlands in terms of providing fisheries and other functional values have now been extensively reported (Dixon et al, 1994; Maltby, 1986).”

Last but not least it is noted that ICOLD, being aware of this situation full of potential conflict, recently (February 2010) published the draft of a position paper on an improved planning process for water resources infrastructure called “Comprehensive Vision Based Planning (CVBP)”. In this position paper, flood management is placed in the wider context of water resources development. CVBP is accomplished on a watershed basis that addresses the domestic, agricultural, industrial and environmental needs in the watershed. To produce sustainable water resources projects, the process needs to also address water quality and quantity, groundwater management, sedimentation, land use, and maintaining the natural habitat and the environment by ensuring adequate downstream discharges.

3.6 Economic Analysis of Benefits and Cost of a Flood Protection Project

This section presents a simple example illustrating the evaluation of the benefits and costs of a flood protection project using exceedance curves and a damage curve. This type of calculation is necessary for defining the magnitude of a flood protection system, prior to undertaking more comprehensive analyses.

3.6.1 Calculation of the average annual damage without Flood Protection Project

In column [1] of Table 3-8 a range of values is given for the 'volume of bank overspill', which, in this case is the selected inundation parameter (or 'damage' parameter). These values follow from the exceedance curves in Figure 3-8 (curve most to the left). For the same values of the damage parameter, damage costs are given in column [2]. These values are derived from Figure 3-7.

An 'exceedance' curve implies that, for instance, the increase in bank overspill of 300 hm^3 between the 200 and 500 values (column [1] of Table 3-8) will result in an increase in damages from US$ 46 to 82 million (see Figure 3-6 and column [2]), i.e. US$ 36 million (column [3]). Following from Figure 3-7, the probabilities of exceedance of bank overspills of 200 and 500 hm^3 will be 0.33 per annum and 0.15 per annum respectively (column [4]). The probability of exceedance of the said additional 300 hm3 of bank overspill will be on 'average' 0.225 p.a. (column [5]).

The remainder of the calculations in Table 3-8 are straightforward. Note that damages caused by floods having a return period of more than 20 years (probability 5 % per annum) contribute only 6 % to the average annual damage (AAD).

3.6.2 Calculation of the average annual damage with a Flood protection Project

The calculation is repeated for the situation that flood control projects are introduced.

In that situation the exceedance curve of bank overspill changes: there is less bank overspill and, consequently, less damage. Flood control, by means of higher flood embankments leading to increased river discharges, implies in the case of a discharge of 3000 m3/s that the AAD reduces from US$ 41.1 million to US$ 19,7 million (Table 3-8). Thus, the average annual damages 'avoided' amount to US$ 21.4 million. The same Table 3-8 shows that a discharge of 5000 m^3/s brings the remaining AAD down to US$ 5.9 million and the corresponding average annual damage avoided becomes US$ 35.2 million.

3.6.3 Benefit – Cost Analysis

When the so-called 'tangible' benefits and costs have been determined on an annual basis for the economic life[9] of the project a benefit-cost analysis can be made. Reference is made to Tables 3-9 and 3-10 for further details. The calculation enables determination for various discount rates of the 'net present value' (NPV), the benefit-cost ratio (B/C) and, by approximation, the Economic Internal Rate of Return (EIRR).

When carrying out these calculations on tangible benefits and costs of floodplain management measures, one must realise that there is no 'cookbook' way to do so. It requires estimation for each possible strategy (option), as well as sound engineering judgement. This applies, for instance, to the

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[9] The economic life of a project depends very much on the discount rate applied in the economic evaluation. The higher the discount rate the shorter the economic life. This is demonstrated in Box 3-7: at a discount rate of 15 % the present day value of the AAD after 30 years is only 4 % of its original value (sum of column [9] of Table 3-8). The technical life of a project can be considerably longer.

maintenance to be expected, to the expected growth rate of the investment in the protected area and to the reliability of the hydrological database.

In the examples given one can see that, solely from an economic point of view, the increase in discharge to 3,000 m^3/s is more attractive than the solution with an increase of discharge to 5,000 m3/s, though in the latter case the remaining AAD is much less. But the differences are small and the economic optimum is probably somewhere around 4,000 m^3/s.

In this respect, note also that ‘flood control’ includes both structural and non-structural solutions. In general, it has been found that non-structural solutions (appropriate zoning, flood warning arrangements, acquisition of flood prone properties, evacuation arrangements) tend to be more economically attractive than structural solutions. Of the possible structural measures, the only common ones are flood embankments and waterway improvements. Reservoir dams tend to be only economically justified if they are operated on a multipurpose basis.

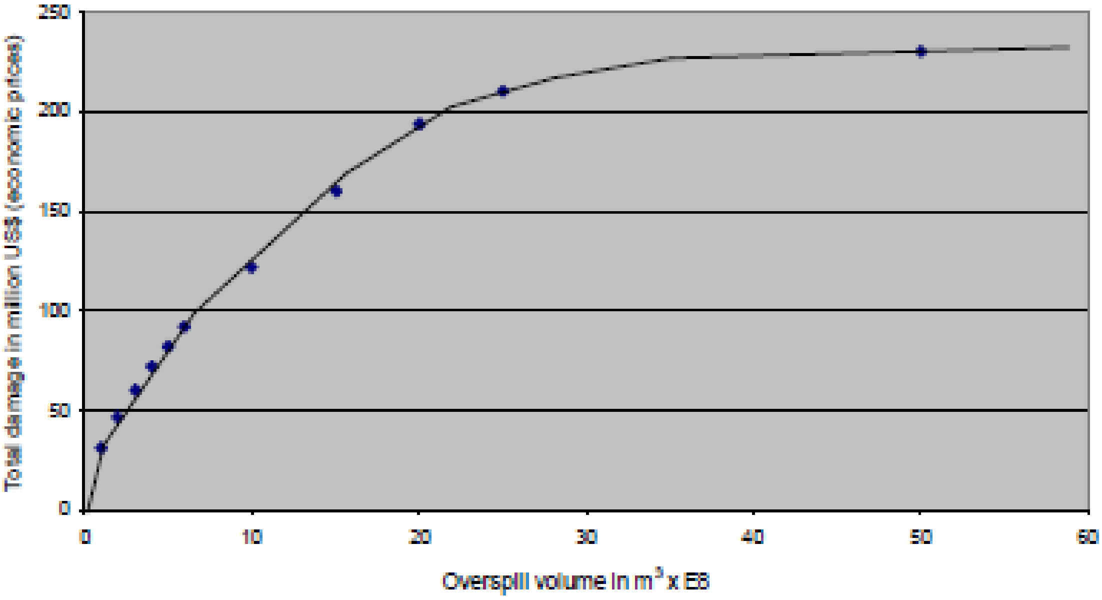

Figure 3-7 - Damage curve for the selected inundation parameter ‘overspill volume’.

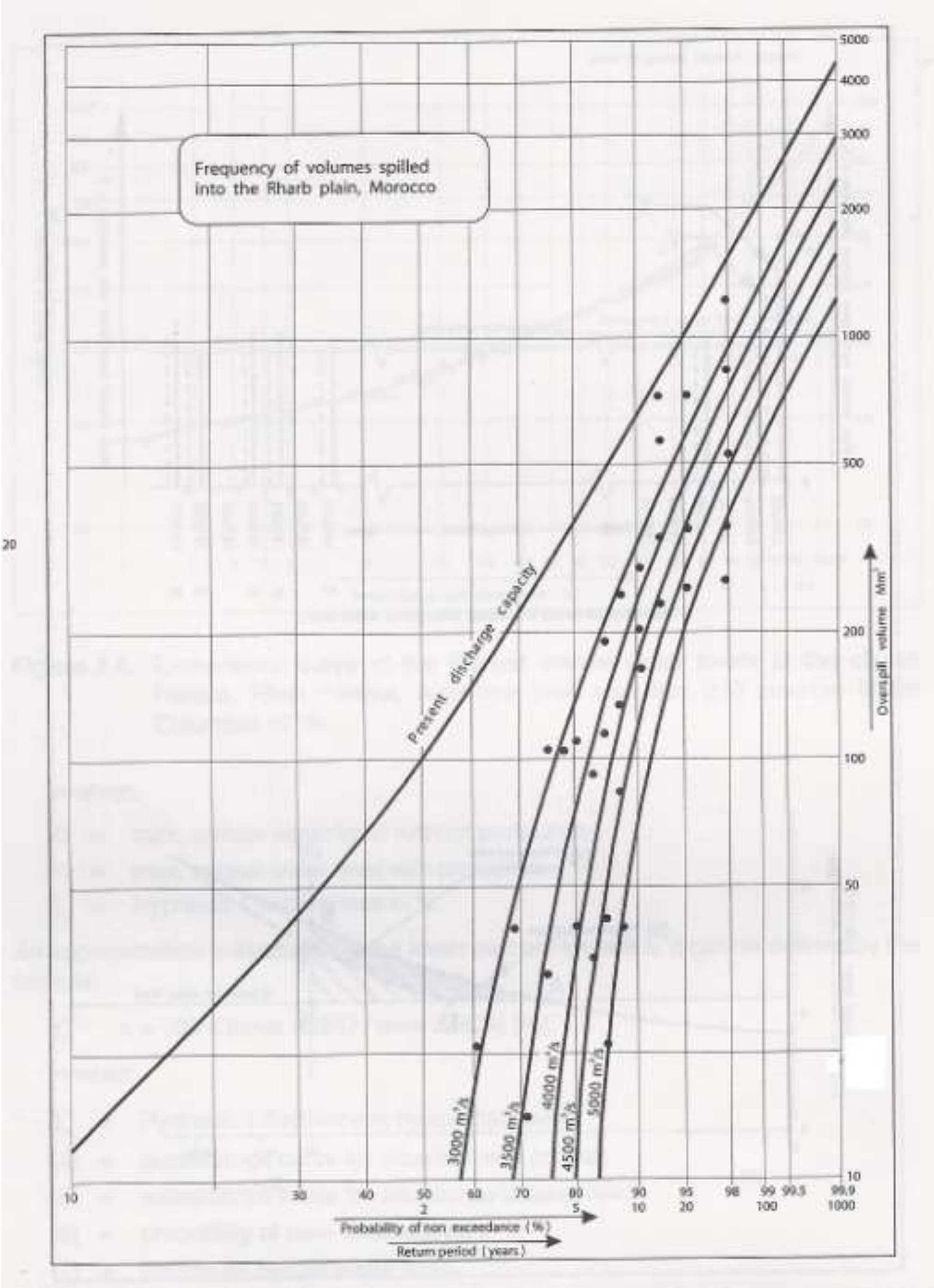

Figure 3-8 - Exceedance curves for remaining bank overspill after introduction of alternative options for flood protection.

Table 3-8 **-** Calculation of average annual benefits (= AAD avoided)

			damage without project			damage with project discharge = 3000 m^3/s			damage with project discharge = 5000 m^3/s		
volume of bank overspill in million m3 (hm3)	damage related to bank over spill in million US$ (coll.1)	increase in damage due to incr. in bank over spill (million US $)	prob. of exceed-ance of vol. of bank over spill (coll.1)	average prob. of exceed-ance of increase in bank over spill	damage corresponding with increase in bank over spill and prob. of exceed-ance	prob. of exceed-ance of vol. of bank over spill (coll.1)	average prob. of exceed-ance of increase in bank over spill	damage corresponding with increase in bank over spill and prob. of exceed-ance	prob. of exceed-ance of vol. of bank over spill (coll.1)	average prob. of exceed-ance of increase in bank over spill	damage corresponding with increase in bank over spill and prob. of exceedance
[1]	[2]	[3]	[4]	[5]	[6]= [3]x[5]	[7]	[8]	[9]= [3]x[8]	[10]	[11]	[12] = [10]x[11]
10	3		0,95			0,42			0,17		
		3		0,9	2,7		0,4	1,2		0,16	0,48
20	6		0,85			0,38			0,15		
		14		0,755	10,57		0,34	4,76		0,14	1,89
50	20		0,66			0,30			0,12		
		12		0,58	6,96		0,32	3,78		0,10	1,14
100	32		0,50			0,33			0,07		
		14		0,415	5,81		0,245	3,43		0,06	0,84
200	46		0,33			0,16			0,05		
		36		0,24	8,64		0,11	3,96		0,0315	1,134
500	82		0,15			0,06			0,013		
		41		0,10	4,1		0,04	1,64		0,008	0,328
1000	123		0,05			0,02			0,003		
		71		0,03	2,13		0,0125	0,8875		0,0015	0,1065
2000	194		0,01			0,005			0		
		36		0,0055	0,198		0,0025	0,09		0	0
5000	230		0,001			0			0		
Math. Expectation Value of (remaining) damages p.a.:					41,108			19,7475			5,9185
Benefits due to Project (I.e. avoided damages) per year:						21,3605			35,1895		

Table 3-9 - Economic evaluation of flood protection by means of an **increased river discharge of 3000 m^3/s** (all figures in US$ ‘000, except for B/C ratio)

Cost of construction			benefits = avoided damages due to		Discounted Costs and benefits					
					costs	benefits	costs	benefits	costs	benefits
year n	investment	maintenance	avoided damages per annum	avoided damages, incl investments1)	costs and benefits are discounted at 6 % per annum		Ditto at 8 %		Ditto at 15 %	
[1]	[2]	[3]	[4]	$[5]= [4]x(1+p)^n$	(coll.2+3) $(1+0.06)^n$	(coll 5) $(1+0.06)^n$	(coll.2+3) $(1+0.08)^n$	(coll 5) $(1+0.08)^n$	(coll.2+3) $(1+0.15)^n$	(coll 5) $(1+0.15)^n$
0 (2000)										
1	80.000		0	0	75.472	-	74.074	-	69.565	-
2	80.000		0	0	71.200	-	68.587	-	60.491	-
3	80.000		0	0	67.170	-	63.507	-	52.601	-
4		800	21.360	24.041	634	19.043	588	17.671	457	13.745
5		800	21.360	24.762	598	18.504	544	16.853	398	12.311
6		800	21.360	25.505	564	17.980	504	16.072	346	11.026
7		800	21.360	26.270	532	17.471	467	15.328	301	9.876
8		800	21.360	27.058	502	16.977	432	14.619	262	8.845
9		800	21.360	27.870	474	16.496	400	13.942	227	7.922
10		800	21.360	28.706	447	16.029	371	13.296	198	7.096
11		800	21.360	29.567	421	15.576	343	12.681	172	6.355
12		800	21.360	30.454	398	15.135	318	12.094	150	5.692
13		800	21.360	31.368	375	14.706	294	11.534	130	5.098
14		800	21.360	32.309	354	14.290	272	11.000	113	4.566
15		800	21.360	33.278	334	13.886	252	10.491	98	4.090
16		800	21.360	34.277	315	13.493	234	10.005	85	3.663
17		800	21.360	35.305	297	13.111	216	9.542	74	3.281
18		800	21.360	36.364	280	12.740	200	9.100	65	2.938
19		800	21.360	37.455	264	12.379	185	8.679	56	2.632
20		800	21.360	38.579	249	12.029	172	8.277	49	2.357
21		800	21.360	39.736	235	11.689	159	7.894	43	2.111
22		800	21.360	40.928	222	11.358	147	7.528	37	1.891
23		800	21.360	42.156	209	11.036	136	7.180	32	1.694
24		800	21.360	43.420	198	10.724	126	6.847	28	1.517
25		800	21.360	44.723	186	10.420	117	6.530	24	1.359
26		800	21.360	46.065	176	10.126	108	6.228	21	1.217
27		800	21.360	47.447	166	9.839	100	5.940	18	1.090
28		800	21.360	48.870	157	9.560	93	5.665	16	976
29		800	21.360	50.336	148	9.290	86	5.402	14	874
30		800	21.360	51.846	139	9.027	80	5.152	12	783
31		800	21.360	53.402	131	8.771	74	4.914	11	701
32		800	21.360	55.004	124	8.523	68	4.686	9	628
					222.970	380.208	213.254	285.150	186.104	126.336
				Net Present Value		157.238		71.896	-	59.768
				Benefit-Cost ratio	1,71		1,34		0,68	

1) p is the rate of investment in the area protected against floods estimated at 3 % per annum

Table 3-10 - Economic evaluation of flood protection by means of **an increased discharge of 5000 m^3/s** (all figures in US$ ‘000, except for B/C ratio)

Cost of construction			benefits = avoided damages due to		Discounted Costs and benefits					
					costs	benefits	costs	benefits	costs	benefits
year n	investment	maintenance	avoided damages per annum	avoided damages, incl investments[1])	costs and benefits are discounted at 6 % per annum		Ditto at 8 %		Ditto at 15 %	
[1]	[2]	[3]	[4]	[5]= [4]x$(1+p)^n$	$\frac{(coll.2+3)}{(1+0.06)^n}$	$\frac{(coll\ 5)}{(1+0.06)^n}$	$\frac{(coll.2+3)}{(1+0.08)^n}$	$\frac{(coll\ 5)}{(1+0.08)^n}$	$\frac{(coll.2+3)}{(1+0.15)^n}$	$\frac{(coll\ 5)}{(1+0.15)^n}$
0 (2000)										
1	100.000		0	0	94.340	-	92.593	-	86.957	-
2	100.000		0	0	89.000	-	85.734	-	75.614	-
3	100.000		0	0	83.962	-	79.383	-	65.752	-
4	100.000		0	0	79.209	-	73.503	-	57.175	-
5		1.500	35.189	40.794	1.121	30.483	1.021	27.764	746	20.282
6		1.500	35.189	42.018	1.057	29.621	945	26.478	648	18.165
7		1.500	35.189	43.278	998	28.782	875	25.252	564	16.270
8		1.500	35.189	44.576	941	27.968	810	24.083	490	14.572
9		1.500	35.189	45.914	888	27.176	750	22.968	426	13.052
10		1.500	35.189	47.291	838	26.407	695	21.905	371	11.690
11		1.500	35.189	48.710	790	25.660	643	20.891	322	10.470
12		1.500	35.189	50.171	745	24.933	596	19.924	280	9.377
13		1.500	35.189	51.676	703	24.228	552	19.001	244	8.399
14		1.500	35.189	53.227	663	23.542	511	18.122	212	7.522
15		1.500	35.189	54.823	626	22.876	473	17.283	184	6.737
16		1.500	35.189	56.468	590	22.228	438	16.482	160	6.034
17		1.500	35.189	58.162	557	21.599	405	15.719	139	5.405
18		1.500	35.189	59.907	526	20.988	375	14.992	121	4.841
19		1.500	35.189	61.704	496	20.394	348	14.298	105	4.336
20		1.500	35.189	63.555	468	19.817	322	13.636	92	3.883
21		1.500	35.189	65.462	441	19.256	298	13.004	80	3.478
22		1.500	35.189	67.426	416	18.711	276	12.402	69	3.115
23		1.500	35.189	69.449	393	18.181	255	11.828	60	2.790
24		1.500	35.189	71.532	370	17.667	237	11.281	52	2.499
25		1.500	35.189	73.678	349	17.167	219	10.758	46	2.238
26		1.500	35.189	75.888	330	16.681	203	10.260	40	2.005
27		1.500	35.189	78.165	311	16.209	188	9.785	34	1.795
28		1.500	35.189	80.510	293	15.750	174	9.332	30	1.608
29		1.500	35.189	82.925	277	15.304	161	8.900	26	1.440
30		1.500	35.189	85.413	261	14.871	149	8.488	23	1.290
31		1.500	35.189	87.975	246	14.450	138	8.095	20	1.155
32		1.500	35.189	90.615	232	14.041	128	7.720	17	1.035
					362.439	594.993	343.397	440.652	291.101	185.484
				Net Present Value		232.554		97.255	-	105.617
				Benefit-Cost ratio	1,64		1,28		0,64	

1) p is the rate of investment in the area protected against floods estimated at 3 % per annum

4. PRACTICE OF INTEGRATED FLOOD RISK MANAGEMENT

4 PRACTICE OF INTEGRATED FLOOD RISK MANAGEMENT

4.1 New challenges in flood management

Flood management has a long history and much literature has been published on the subject. The focus of flood management, which most of the literature deals with, is how to reduce flooding and/or damage caused by floods. Methods for flood management have often been developed as a result of major flooding events that had large human or economic losses, which triggered awareness and made funds and political will available. Flood management has thus been mostly problem driven, often on an ad hoc basis, and based on flood control.

During recent decades, a new type of challenge has, however, been emerging with regard to flooding, namely how to maintain the long-term positive effects on environment and socio-economic activities that are the result of regular floods. In parallel with the development of flood control measures it has increasingly emerged that:

- Floodplains, as created through the centuries by regular floods depositing clay, silt and sand, are essential for food production and industrial development and thus the livelihood of a large part of the population of the world; and

- wetlands and estuaries, for which floods are essential for preserving high biodiversity, are important for economic activities such as tourism and fisheries.

Therefore, it has been understood that flood control, if developed too far, often has a trade-off both environmentally and economically. Extensive flood mitigation measures that give very large security against floods may cause large negative environmental or social impacts. Conversely, it may be more beneficial to accept a higher risk for floods, which would require fewer mitigation measures and thus cause less negative impacts on environment and people who are dependent on flood consequences for their livelihood. The challenge is, therefore, to balance flood impact mitigation with harnessing the benefits of the floods.

This emerging new challenge in flood management has followed the development of Integrated Water Resources Management (IWRM) that today is implemented in many river basins of the world. IWRM implies an interdisciplinary and collective approach that promotes a process of cross-sectoral coordination in water management. It, therefore, brings in the importance of looking at the effects of water management on other disciplines such as environment, agriculture and socio-economics. One of the central parts of IWRM is stakeholder participation.

A new concept has therefore surfaced as part of the IWRM: Integrated Flood Management (IFM). The generally accepted definition of IFM is the one made by APFM (2004):

"The integrated flood management approach aims to maximise the net benefit from floodplains and at the same time reduce loss of life as a result of flooding, flood vulnerability and risk, and preserve ecosystems and their associated biodiversity, within the overall framework of IWRM."

Fundamental parts of IWRM and IFM are as expressed by GWP (2000) and APFM (2004):

- River basins should be seen as integrated systems, acknowledging that water and environment is an economic good;

- Cooperation and coordination across institutional boundaries;

- Participatory and transparent approach including a representative range of stakeholders in the decision-making process.

Although, in many parts of the world, the main focus of flood management will be on reduction of flood damages the concepts of IFM will be increasingly important for land and city planners as well as for organisations and stakeholders developing and managing large hydraulic infrastructure. For policy makers, planning engineers, dam owners and other stakeholders it is essential to accept the concept of IFM and work proactively. Currently in many countries, IWRM and IFM are vested in the water law and policies and therefore, it is important to be part of the process, rather than being a passive observer.

Distinction should be made here between projects implemented for the almost single purpose of flood control and projects which are basically implemented for developing water resources (hydroelectricity, water supply, navigation, etc.,). In the second case, project benefits used in the comparison should include all the benefits, not only flood control benefits.

4.2 Introducing risk management

4.2.1 Concept

In parallel with the notion of the positive effects of floods, it has also been realised that, in many cases, flood control measures are designed rather conservatively, mainly focusing on preventing as high a flood as is financially possible.

Risk is defined as: Risk = Function (Probability, Consequence).

Figure 4-1 illustrates the concept of risk management.

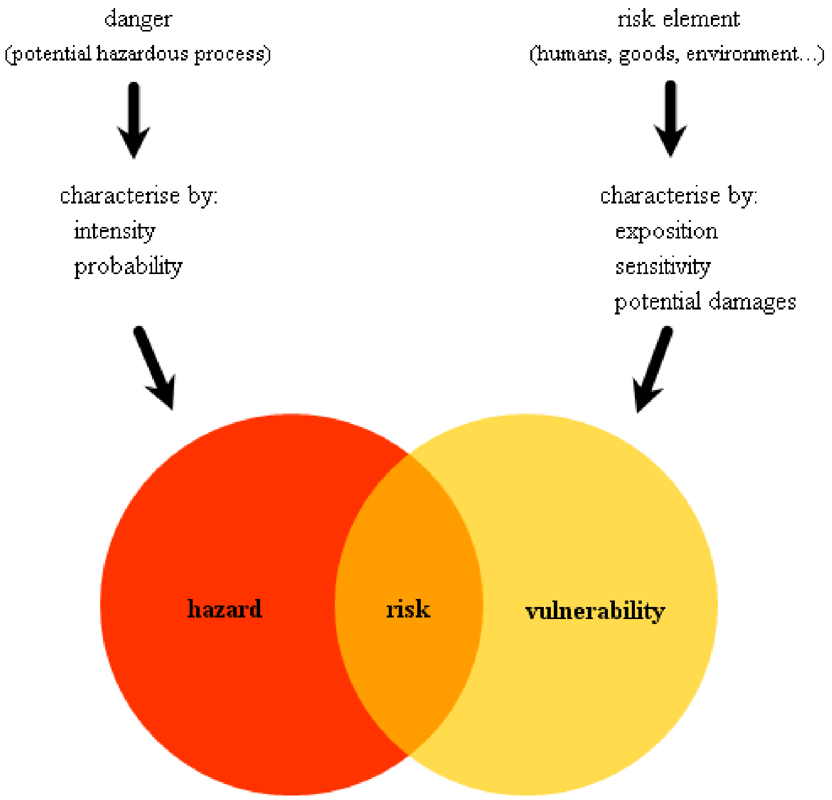

Figure 4-1 - Risk Concept (Grünewald, 2003)

In line with the development of understanding of both flood probabilities and flood damages, based on longer records and documented flood impacts, it is natural to introduce risk management into the flood control process. By accepting and learning to live with large floods, flood control measures can be optimised, giving room for utilising the floodplains and allowing for more efficient positive effects of floods. The basic idea is that areas prone to flooding should be utilised in the best way possible in the periods between floods. By further introducing flood management measures, such as flood warning systems, public awareness and preparedness, etc., the flood damages and, thereby, the costs can be limited.

The introduction of risk management has, therefore, initiated the term Integrated Flood Risk Management (IFRM), which is now the common expression used for flood management. IFRM can basically be divided into two major parts:

- Flood risk assessment that has the main purpose of quantifying the impacts of floods with different recurrence periods;

- Risk mitigation, which has the purpose of selecting measures to alleviate the impacts of floods.

By further linking risk and vulnerability, in accordance with Figure 4-2, the risk mitigation can be divided into either reducing the risk of floods or reducing the vulnerability of the society to floods, or a combination of both.

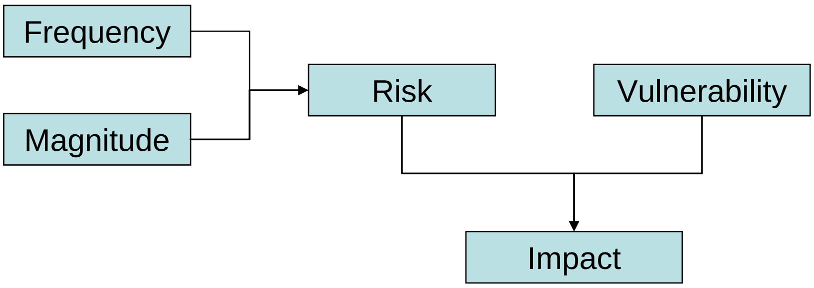

Figure 4.2 - Determining factors for flood impact.

The main measure for reducing risk has been infrastructure, such as dams and dykes. However, recently, non-structural measures, such as giving "room for the river" by providing retention areas along the river or by retaining water in the landscape through changing the land use, have also been used. Reducing vulnerability of society to floods includes typical flood management measures such as early warnings, information and preparedness. As such, the IFRM concept combines both traditional flood control through structural measures and flood management through non-structural measures.

A fundamental part of reducing vulnerability is also loss-sharing mechanisms, in which the victims of a disaster are compensated for the damages by the state or community. Linking mitigation and loss-sharing is key to the success of IFRM, since it would be difficult for stakeholders to live with the risk of flood without such insurance (Linnerooth-Bayer and Vari, 2002). Without loss-sharing the purpose of IFRM to utilise the floodplains and benefits of floods to a larger degree would thus be in vain.

Therefore, IFRM gives the possibility of combining the accumulated knowledge of more than one century's flood control, the recent decades of development in flood and risk management technology and the concept of IWRM, where water and environment are economic goods. Through economic assessments of different alternative mitigation measures, the best long-term solution can, therefore (at least in theory), be found for flood management.

4.2.2 Pragmatic and balanced approach

While recognising the IFRM principles, it should be noted that no river basins have the same susceptibility to floods, and that, in many cases, the damages caused by floods far exceed the benefits of the floods. In many developing countries, the destructive force of water still causes significant drops of the GDP growth and floods are one of the reasons for sustained poverty in large parts of the world (Grey and Sadoff, 2007).

Implementation of IFRM requires a large amount of data and knowledge on flood characteristics and flood impacts, as well as capable authorities and institutions. The concept of IFRM has, to a large degree, been developed in the industrialised world, where the general economic standard gives opportunity for optimised solutions and where knowledge and data availability is high.

Lack of data causes uncertainties in the risk assessment and reduces the possibility of optimised solutions. A developing economy, typically based greatly on subsistence agriculture, normally lacks the structures for either risk management or loss-sharing, which are essential parts for successful IFRM. Therefore, in many situations, the IFRM concept is an over ambitious and unnecessarily cumbersome process. In these situations, it is important to focus on the most essential parts of flood management and to limit the extent of system analysis and participatory approach to avoid extended lead times before implementation.

The lessons learnt, in the decade-long debate on infrastructural development, have shown that over high demands on preparatory studies and participatory involvement, for ensuring a wide participation and minimised environmental and social impacts, such as proposed by the World Commission on Dams (WCD, 2000), may lead to a standstill in investments in infrastructure. While investment in infrastructure is needed in many developing countries for water security (both as a source of production and prevention of floods), Grey and Sadoff (2007) emphasise that the previously unforeseen consequences of environmental change and social displacement have now been well documented and therefore, cannot be ignored. However, continue Grey and Sadoff, setting the environmental and social standards so high that they constrain or even prevent achieving water security is equally unacceptable.

ICOLD is actively participating in these developments. It has recently published (February 2010) the draft of a position paper on an improved planning process for water resources infrastructure called “Comprehensive Vision Based Planning (CVBP)” (see Section 3.5).

The need for investments in infrastructure, as a basis for IFRM, must be emphasised. Non-structural measures have little effect if not combined with flood control structures, simply because the degree of regulation is limited. Likewise, infrastructural investments in an already well regulated river give limited extra benefits. Figure 4-3 illustrates the return on investments in infrastructure and managerial measures, which shows the importance of keeping a balance of structural and non-structural measures for efficient flood management. An example of a detailed calculation of the economic optimisation of a flood protection project is presented in Section 3.6. This example applies for the case where only the only significant damages caused by floods can be financially evaluated.

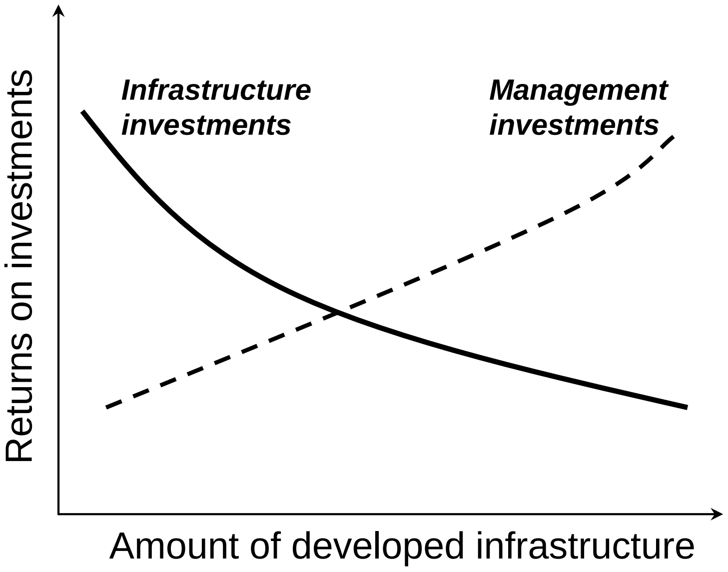

Figure 4-3 - Balancing investment in water infrastructure and management (Grey and Sadoff, 2007).

One of the most important steps for any policy maker, planner or engineer, involved in the design of a flood management strategy is, therefore, to put flood management into the overall development framework, to focus on the essential issues and, thereby, limit the system boundaries to ensure that the strategy can be implemented in a reasonable time perspective. In simple words the IFRM concept must be conducted in a pragmatic way.

4.2.3 Nature of risk

One of the most challenging issues when dealing with the control of hazards, whether natural or man-made, is related to the nature of the vulnerability. Experience shows that the ability of Society to deal with the risk greatly depends on the nature of the risk. Three broad categories can be identified (refer to Section 3.2.2 for more detail):

1. Risk limited to economic losses;
2. Risk to intangible or non-monetary values praised by the Society (environment, archaeology, social well-being, etc.);
3. Risk to human life.

The Society's response varies greatly with the kind of risk.

- Well-accepted straightforward techniques exist for economic risk (see Section 3.6)
- Protection against the risk to intangible or non-monetary values is so far left to the appreciation of individuals.
- In some Societies, laws and regulations specify the acceptable level of risk to human life

It can be seen that, until recently, Societies have not adopted a systematic and comprehensive approach to risk mitigation, and measures adopted reflect in each case what the political class perceives as the best interest of the Society.

The originality of the new trend in integrated flood risk management consists of a participatory approach where all key players are consulted and where the adopted solution is reached by consensus amongst those players.

This approach is described in the next Section.

4.3 Step-wise approach

Because of the different pre-conditions found in different river basins and countries of the world there is no blue-print for implementing IFRM. Therefore, the message of this bulletin is to acknowledge the principles of IFRM, which are all well motivated and sound, and to adapt these principles in accordance with what is reasonable and implementable in every specific case.

The Dams and Flood Committee of ICOLD thus proposes a number of basic steps to follow when designing a flood management strategy. These steps are not the exact solution for all river basins but force the person or institution in charge of the flood management task to consider all aspects of IFRM and to implement them as is judged best possible under the specific circumstances.

The overall recommendations for the process of developing an effective flood management strategy are to be transparent in your actions, to take the time to listen to and to explain the alternative solutions to stakeholders, but to aim for a maximum time period of 2-4 year (depending on the magnitude of the problem) for the whole procedure prior to implementation.

All proposed steps are associated with recommendations on relevant literature for the reader to get more details and background. In this way the reader can establish his/her own basic knowledge and interpretation of IFRM and how it can be implemented.

4.3.1 1st Step: Identifying system boundaries and key players

Recommended reading:

- Water – a shared responsibility, The United Nations World Water Development Report 2 (UNESCO, 2006)
- Integrated Water Resources Management (GWP, 2000)
- Integrated Flood Management – Concept paper (APFM, 2004 and 2009a)
- Sink or Swim? Water Security for growth and development (Grey and Sadoff, 2007)
- Social Aspects and stakeholder involvement in integrated flood management (WMO, 2006b)
- Water management, water security and climate change adaptation: Early impacts and essential responses (Sadoff and Muller, 2009)

As explained in the section above, integrated flood risk management is closely linked to IWRM and to land management (Figure 4-4). The first step for anyone dealing with IFRM is to get an overview of IWRM and its main concepts and relation to flood management (GWP, 2000; Green, 2003; APFM, 2004; UNESCO, 2006; APFM, 2007a; APFM, 2009a; APFM, 2009b). It is also essential to acknowledge the difference in development level in different parts of our world, which guides the focus of water management and development (see e.g. Grey and Sadoff, 2007).

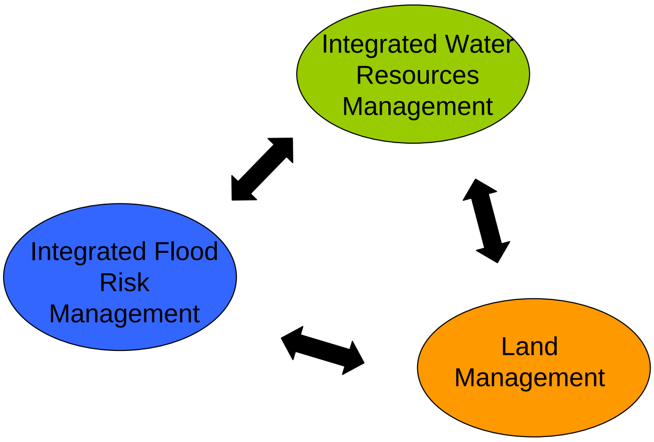

Figure 4-4 - IFRM is closely linked to IWRM and land management.

One of the corner stones of IWRM is that the boundaries for a river basin, the catchment divides set by topography, provide a natural unit for water management. A river basin is a closed region, where water management directly affects the inhabitants and other stakeholders of the basin. Although the river basin covers different administrative units, there are incentives for these to cooperate.

The experience of implementing IWRM on the basin scale, and especially in transboundary rivers, has shown that this is a difficult process. While many countries of the world have developed water governance on the national scale, its implementation on a basin scale is still very limited (UN-Water, 2008). Most countries try to localise water management by distributing powers and resources. The reason is that local organisations and communities have strong local hydrological, environmental and socio-economic knowledge and also have the largest stakes in decisions taken on how to manage the resources. Centralised national or regional governments have difficulties in regulating water in a river basin, as they are unaware of local interests and priorities.

4.3.1.1 Geographical boundaries for flood management.

One of the first decisions in IFRM is to limit the geographical boundaries for flood management. APFM (2004) and WMO (2006b) follow the IWRM concept and recommend the river basin scale as the natural unit for flood management. They argue that the acceptance of the fact that any form of abstraction, transfer, storage or other influence causes effects in the entire downstream river system and for its inhabitants, is fundamental for IWRM and for flood management. That is also why stakeholder fora should be created with the river basin unit as a basis.

The choice of the river basin as the geographical boundary for flood management is therefore motivated and should be the preference if found applicable. However, many river basins are very large and may be shared by many countries or regional administrations. Furthermore, the river sections prone to floods may be naturally limited by topography or the degree of economic development. Choosing a very large geographic area, especially if it covers legally different bodies, such as in the transboundary case, significantly increases the time and effort for stakeholder participation. Therefore, it may be appropriate in the first place to choose a limited area, focused around the flood problem area, to ensure that an effective IFRM strategy is developed in reasonable time. At a later stage, this strategy can be integrated in larger basin-wide perspective, if found beneficial.

It should, however, be noted that in most transboundary river basins there is a Joint Water Commission or similar, which normally requires each state to inform the other states on water management measures. Also in the case of different regional administration responsibilities there is a national coordinating body that needs to be informed. Thus, it is essential, even if a limited area is chosen for IFRM, to have a transparent process and to make information available to everyone that may be remotely affected or involved.

4.3.1.2 Key players for the participatory process.

Following the decision on geographical area, it is essential to identify the key players for the participatory process. One of the main duties of an organisation dealing with IFRM is to identify the flood impacts and to establish a planning process. The integrated approach implies that this should be made in a holistic way considering both negative and positive impacts, as well as short- and long-term effects. It is important, through a participatory process, to identify the specific problems and benefits of floods in the river basin, taking into account as many views as reasonably possible.

In almost all cases, the regulatory function of flood management lies with the regional water authority or river basin organisation. However, following the integrated concepts of IFRM, there may be many institutions, in addition to the water authorities, that must be involved in conducting the flood management (Figure 4-5). Examples of such institutions are Local Governments and regional organisations under line ministries. Regulatory responsibilities related to the flood management functions may even have been given to other institutions, rather than to the regional water authorities. Examples are housing and infrastructural development and general disaster management that is often the responsibility of the Local Governments.

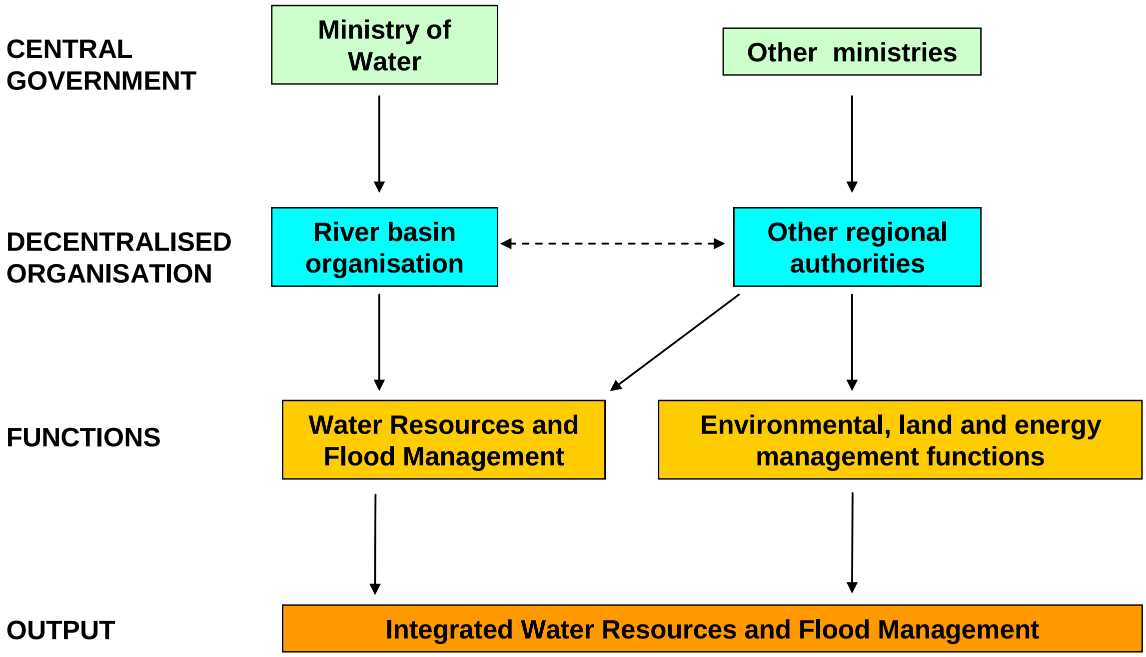

Figure 4-5 - The normal organisational framework related to water and flood management.

An important step for the institution responsible for IFRM is, therefore, to identify all organisations that should be involved, as well as all stakeholders in a river basin that may be negatively or positively affected by floods. Water laws in many countries already state that stakeholder fora should be established on the river basin scale. Representatives for large dams or river regulating organisations are part of these fora. Therefore, in many cases, especially if the river basin has been chosen as the geographical area,, there is no need to establish a special forum to deal only with IFRM. Which stakeholders should take part in the IFRM vary from country to country and between different river basins. Similarly the legal power of the stakeholder forum is normally given by national laws and policies and varies between countries.

As with the choice of geographical area, it is important to choose the key players, with care to avoid a never-ending process that does not lead to any implemented flood management at all. It should be noted that different groups of stakeholders have different needs and that there is a distinction between stakeholder participation and public participation. The public, representing the wide range of stakeholders, have the right to be informed of what is happening and to make its voice heard. The key players or stakeholders, that will be part of the implementation and operation of the IFRM, have a much more central role since they are pre-requisites for its success. An acceptance and ownership of the IFRM strategy is essential and if the key players do not agree on the main process and methodology, it will be very difficult to have a functioning flood management in place (see e.g. WMO 2006b). Therefore, the choice of key stakeholders should preferably be limited to a few bodies, which will drive the participatory process and take the necessary decisions, while at the same time keeping an open ear to the public.

Here lies probably the most challenging part of preparing and implementing a successful IFRM process. It is implicitly assumed that all participants strive towards reaching a reasonable consensus with all the other participants. Experience proves that this is not always the case, and that stakeholders sometimes look more towards self-interest. The key stakeholders must therefore diplomatically balance the seriousness of the arguments put forward by all parties and dare to take final decisions, although complete consensus is not achieved.

4.3.1.3 Degree of detail on which the IFRM should be based.

The geographical area and which stakeholders to be involved are probably the most essential system boundaries for IFRM. However, the system boundaries also include the degree of detail to which the IFRM will be based on. The introduction of risk assessments into flood management, which to a large degree, is dealing with non-exact sciences, implicitly means that studies can go on endlessly until absolutely the best option can be found.

Therefore, it is essential at the beginning of the IFRM process to set up goals for what scientific methods and what confidence levels are reasonable for taking decisions on flood mitigation measures. Setting up the goals does not mean that these cannot be reconsidered at a later stage, if found appropriate, but without defining this framework at an early stage, the process risks being very long and complicated.

One of the main decisions related to the degree of detail is whether to take climate change into account. The answer to this is probably yes, according to most policy makers and engineers dealing with water management. However, in many countries of the world, particularly developing countries, the data and knowledge of the effects of climate change are almost non-existent. In these cases, the only available projections are from the Global Climate Models (GCM) as e.g. presented in the IPCC (2007), which are generally too broad and uncertain to adopt on the local scale. Furthermore, the projections on the effect of climate change on matters related to floods, such as flood frequencies and magnitudes, are still very large. Therefore, it is recommended to seriously consider if locally detailed studies (e.g. application of Regional Climate Models – RCM) should be part of the IFRM process, which risks extending the lead time although giving uncertain results. However, climate change should not be forgotten as one of the factors that motivate flood management just by its projected risk of increased variability. For countries that have not achieved water security, climate change will most probably make it harder and require increased investments in infrastructure and risk management to manage the higher variability (Sadoff and Muller, 2009).

Another main decision to take is what level of topographical detail the flood impacts should be based on. Topographical data are fundamental for both inundation mapping and hydraulic calculations to assess flood impacts. Despite this, topographical data are still insufficient in many parts of the world, especially for flood plains with very low gradients. Topographical surveys are both, similar to local studies on climate change, time demanding and costly. Therefore, it is important, at an early stage of the IFRM, to acknowledge the difficulties of topographical data and to choose a level of detail that is possible to obtain within a reasonable budget and time frame.

4.3.2 2nd Step: Preparatory studies

Recommended reading:

- Sections 2 and 3 of this bulletin on Flood Magnitudes and Flood Impacts
- The Benefits of Flood and Coastal Risk Management - A Manual of Assessment Techniques (Penning-Rowsell et al, 2006)
- Conducting flood loss assessments – a tool for Integrated Flood Management (APFM, 2007b)
- Applying environmental assessment for flood management (APFM, 2007c)

The prerequisites for any kind of strategy or planning process are the knowledge of the current situation and what scenarios can be expected. After having identified the key stakeholders that should be involved in the process, the second step of implementing IFRM is to conduct the necessary studies to assess the impacts of floods in the river basin. As with IWRM the importance of doing these studies in a transparent way is fundamental for the ownership and acceptance of the results.

4.3.2.1 Assessment of flood characteristics

The understanding of the flood characteristics of the river basin is primary for the assessment of flood impacts. Therefore, the flood characteristics of the rivers in the basin should be defined according to the methods described in Chapter 2 of this bulletin. Parameters such as peak discharge, peak volume, hydrograph shape and frequency are necessary inputs to the preparatory studies of flood impacts in a river basin.

An important consideration in the flood assessment is to acknowledge the uncertainty in raw data and respect the statistical laws of the methods applied (see Section 2.4). Uncertainties cannot be avoided in the assessment of flood characteristics. However, the uncertainties must not be hidden but should be transparently reported to the key players in the IFRM process. If impossible to compute a single value, the flood characteristics should be presented as a range and it should be left to the risk assessment to choose if a conservative or a most probable flood parameter should be used for the choice and design of flood mitigation measures.

4.3.2.2 Flood inundation mapping

One of the most obvious first studies to conduct to assess flood impacts is inundation or flood risk mapping. In short, inundation mapping is to combine the natural flood characteristics with topographical data and the effects of man-made structures to determine the extent of flooding along the river basin. As pointed out in Chapter 3 the inundated area is only one parameter of interest. Other parameters such as duration of flooding, depth of flooding, speed of inundation, material carried by the water, surge waves, etc. are also of interest in assessing the full impacts of floods.

Normally inundation mapping involves hydraulic modelling and the use of geographic information systems (GIS). For many floodplains and lower areas 2-dimensional models need to be applied. This makes the inundation mapping very cumbersome and very expensive, which is a reason why this is one of the first large obstacles for IFRM. The responsible water authorities of most developing countries lack the funding for such detailed studies.

Another obstacle is often that topographical data are not available for the river reaches in the river basin. Topographical sheets at 1:50 000 are the most detailed maps in several parts of the world. These maps typically have contours at spacings of 20 metres, which is far too coarse for inundation mapping on floodplains. Therefore, inundation mapping most often means that a detailed topographical survey must be conducted. This activity is often overlooked in planning and budgeting. The recent development of airborne surveying techniques is very promising and some countries (e.g. USGS in the USA) have already taken steps to introduce regular surveys using this technique. The laser technique has the advantage that it can survey down to a very detailed horizontal level and also has the ability to estimate the depth of inundated areas.

A further difficulty of inundation mapping is that during extreme flooding events the risk of unexpected incidents is large. Examples are dam gates that cannot be opened or debris damming the discharge channels. Experience from real flood events often shows that because of this the hydraulic models underestimate the water levels and the inundated areas. It is therefore important that inundation modeling is conducted by experienced engineers and in collaboration with stakeholders that have the local knowledge and experience.

4.3.2.3 Socio-economic studies

The knowledge of the inundation parameters is by itself extremely important for disaster management and evacuation planning. However, for strategic planning for IFRM, the flood inundation must be converted to socio-economic and environmental impacts.

A fundamental pre-requisite for assessing the socio-economic impacts is to quantify the areas affected by floods. Flood inundation mapping should, therefore, be combined with an inventory of the affected areas in terms of residential, commercial, industrial and agricultural activities (ICID, 1999). This inventory will provide the basis for the estimation of flood damages at different flood magnitudes.

Section 3.2 summarises the methods of determining the extent of physical damage and losses of floods. A recent report, available on the internet, on how to conduct flood loss assessments has also been published by APFM (2007b). Although this report focuses on loss assessment of actual flood events, it gives a good summary of the fundamental parts of flood loss estimation in IFRM. A more comprehensive manual for assessment of losses for flood risk assessment is given in Penning-Rowsell et al (2006).

The fundamental difference between traditional flood management and IFRM is that the socio-economic consequences of floods should also include benefits. The effects of floods on floodplains in the lower areas of river basins are more complicated from a socio-economic view than to limit them to flood damages. Although WMO (2007) states that, particularly in developing countries, disasters have the potential to put development back by 5-10 years, it also stresses the importance of floods for economic development. Floods replenish the wetlands, recharging groundwater and support agricultural and fishery for millions of people living in the floodplains and the estuarine areas of river basins. Therefore, socio-economic analyses of the long-term effects of floods must also be a part of flood impact assessment on the river basin scale.

APFM (2007b) defines the net-benefit from floodplains as the overall benefit of exploitable land for various economic activities minus the expected flood losses. However, as mentioned in Section 3.2 of this bulletin, care should be taken with this definition, since the value of the floodplains is not more than the net gain, if these activities have to be done elsewhere. It is essential when introducing both positive and negative effects of floods, to use comparable parameters and avoid ideological views to skew the totally estimated benefits/losses.

For many flood prone areas of the world, the socio-economic consequences from flood damages are prominent compared to the positive effects of floods and people may have little option than to live in these areas. The comprehensive assessments of both direct and indirect damages (see Section 3.2) of floods are, therefore, in most cases, the core of the socio-economic studies in IFRM, although consideration should always be given to investigating the long-term positive effects and including them in the analysis.

Intangible losses, such as loss of lives, injuries, heritage items, etc. are special cases that are challenging. To make these losses comparable with flood damages, they should be given a monetary value, which is always controversial. There is thus no blue-print on this and this issue must be handled in participation and with transparency. FLOODsite (2009b) provides one of the latest contributions and Section 3.1 of this bulletin lists other methods used in various countries. Notable is that all methods have been developed in the industrialised world and none based on the conditions in developing countries, where vulnerability to floods is normally large. Care should therefore be taken before transferring these methods from developed countries to conditions in the less developed countries.

4.3.2.4 Environmental studies

The prevention of regular floods in river basins has led to loss of habitats and, biological diversity and has reduced ecosystem productivity (WMO, 2006c). Flooding and floodplain inundation allow aquatic organisms to move out of or into main river channel and create new habitats and breeding grounds. Floods also deposit silts and fertile organic material that are essential for both the biological life, as well as the productivity of subsistence agriculture. Therefore, equally important as the socio-economic analysis of flood impacts, is the assessment of the effects of floods on the natural environment in a river basin.

In the preparatory phase of designing IFRM, the emphasis is on Strategic Environmental Assessments (SEA). The purpose of a SEA is to generally assess and predict the environmental impacts of policies, plans and programmes and to provide early warnings of environmental impacts during the decision-making process. APFM (2007c) gives a good overview of the SEA methods with regard to flooding. SEA for flood management in the preparatory phase is normally based on a general qualitative description of environmental issues on the basis of expert judgment. It normally involves the steps of

- Screening
- Scoping
- Identification, prediction and evaluation of impacts
- Identification of possible mitigation

An essential part of the SEA is to make a qualitative comparison between the zero-alternative, that is to have no flood management at all, and the proposed IFRM. The purpose of this is to put the IFRM into the overall perspective of the positive effects of floods on environment and especially biodiversity.

The SEA is followed by Environmental Impact Assessments (EIA) when more concrete plans and flood mitigations measures have been identified (see Step 3 below). The EIA is based more on quantitative assessments and guides the choice of different flood mitigation measures.

4.3.3 3rd step: Identifying flood mitigation measures

Recommended reading:

- Manual on Non-structural Approaches to Flood Management, International Commission on Irrigation and Drainage (ICID, 1999)
- Dams and Floods, ICOLD Bulletin 125 (ICOLD, 2003)
- Manual on Planning of Structural Approaches to Flood Management, International Commission on Irrigation and Drainage (ICID 2005)

- Integrated Flood Risk Management in Asia – a Primer (ADPC, 2005)
- Role of Dams in Flood Mitigation, ICOLD Bulletin 131 (ICOLD, 2006)

IFRM aims to find a balance of providing economic development of floodplains, sustainable ecosystems and flood control. Many river basins in the developed world have succeeded to find this balance and have a situation with large economic activities combined with good control of floods. Examples of such river basins are the Rhine and the Mississippi (WMO, 2007).

Successful examples of flood control all show that a mixture of different measures is needed. Non-structural solutions are often less costly and relatively better from a social and environmental perspective. However, as indicated in Figure 4-3, non-structural mitigation measures have limited effects in a situation where infrastructure development is low. But in combination with flood control measures that give regulation possibilities, many typical non-structural measures, such as flood forecasting, give a significantly higher return.

The choice of flood mitigation measures may, however, mostly be determined by the available options. Financially reasonable flood control structures are dependent on favorable topography and are not always possible. Also many non-structural measures, such as changes in flood-plain development, may not be options since they are politically or practically difficult to implement. For the responsible person dealing with IFRM it is important to have basic knowledge of the possible options and to have an open mind. The recommended literatures give a good description of non-structural and structural flood mitigation measures, including many examples from real cases. The literatures together with the brief description below thus give a basis for the possible mitigation options in IFRM.

Also in this step it is essential to remember the close relationship with IWRM. Many flood mitigation measures, not the least dams, may have multipurpose benefits. It is therefore important to acknowledge the joint benefits also for uses other than solely flood mitigation. The participatory approach involving the key players in water management gives opportunity for finding such mutual solutions.

4.3.3.1 Structural methods

ICID (2005) list the five classic structural methods for flood control as

- Storage in reservoirs in the upstream rivers
- Storage in parts of the floodplain
- Improvement of river channels
- Creation of additional flood ways (bypasses)
- Flood embankments (levees, dykes)

Storage in reservoirs, together with dykes, is amongst the most efficient flood control measures. However, construction of new dams, in some cases, may have relatively significant environmental and socio-economic effects. Reservoirs reduce the flood peak by storing parts of it and delaying and attenuating the peak, while it is routed through the water body.

The roles of dams for flood mitigation are well described in ICOLD (2003) and (2006). Prominent case studies, where multipurpose dams are essential tools for flood mitigation, are the Tone River in Japan, Kairouan Plain in Tunisia, Mississippi River in USA and the Yangtze River in China. Many metropolitan cities of the world are protected by large dams for flood control, e.g. Hanoi in Vietnam, where the upstream Hoa Bin reservoir protects against large floods in the Red River. The case studies from Japan, Morocco and Germany, presented in this bulletin (Appendices 2, 3 and 5), provide further examples of good practices of dams for flood mitigation.

Possibilities of storage in floodplains to mitigate large floods are normally very limited. However, assigning areas of less use and economic value to be flooded may give temporary relief in a flood situation. An example of this practice is the lower Rhine, in which the room-for-the-river concept has guided the authorities to identify areas, which can be flooded on purpose (e.g. by breaching a dyke) to temporary alleviate downstream high water levels. This practice is also adopted in the middle reach of the Yangtze River, between Yichang and Wuhan.

Levees or dykes have been the standard solution for local protection against flooding through-out the world (ICID 2005). A key for this solution is the maintenance and regular inspections of the structures. Levees are most often constructed as earth embankments and structural deficiencies or overtopping will cause very rapid breaches of the flood protection measures, causing extensive damage to the people, houses and infrastructure behind it.

ICOLD (2003) gives general guidelines for the design of flood mitigation dams and levees. Much emphasis must be given to guarantee the safety of the structures. ICOLD bulletins and congress/conference proceedings provide a comprehensive source for all aspects of dam safety and good practice for planning, construction and operation of dams.

Improvement of river channels and creation of additional flood ways both aim to increase the conveyance capacity. Relatively simple methods, such as removal of local bends and clearing of obstacles and bushes, are cheap and contribute to reducing the flood levels. Larger measures such as deepening or widening of the flood channel or digging new channels are all very costly and therefore, are normally not considered, unless very large assets, such a large city, need to be protected. This is the case for the city of Winnipeg in Canada. The exception is when floodwater can be diverted through an old river course to a point downstream or directly into the sea (ICID, 2005).

What is essential to consider, in association with structural flood control, is that these measures will never give more protection than they have been designed for. A reservoir or levee is designed to mitigate a flood of a certain magnitude, often determined based on its probability (e.g. a 100-year flood), but if the flood is larger the structure will fail to provide the full protection. People and economic activities have a tendency to move to the areas, which are protected by the flood control measures, with the assumption that these areas are now safe (ADPC 2005). Structural flood mitigation measures must therefore always be part of general flood risk management, in which policy makers and the public are made aware of the risks involved and have the means to cope with them.

4.3.3.2 Non-structural methods

ICID (1999) lists a number of non-structural approaches to flood management of which the most important are:

- Control of floodplain development
- Flood proofing
- Land use management
- Flood insurance
- Flood forecasting and warnings
- Flood emergency response planning
- Evacuation and emergency assistance and relief

Non-structural approaches to flood management are closely linked to risk management, which is further discussed in Section 4.4.4 below. These chapters should therefore be read in conjunction.

The essential idea of non-structural flood mitigation measures is to learn to live with floods instead of, or in combination with, flood control measures. Therefore, the emphasis is on reducing vulnerability of society to floods and on being prepared when floods occur. As mentioned above there is no conflict between non-structural and structural measures, and their combination creates higher efficiency of both types of intervention.

The more long-term solutions to flood mitigation include control of flood plain development and flood proofing. They aim to reduce the vulnerability to floods by good planning and by applying practices to ensure flood secure houses, infrastructure and agriculture. Flood plain development can be controlled by governments or local authorities by legislation. Normally flooding is taken into account in the city plans, where the boundaries for various land use zones can be designed (ICID, 1999). Bye-laws are used to further regulate the type of permissible types of buildings, structures and agriculture practices inside these zones. Besides regulations, it is also possible for authorities to apply economic means of control, such as tax and insurance policies promoting movements of people and activities away from flood prone areas.

In many areas development has, however, already occurred that limits the possibilities of steering settlements and economic activities from the flood prone areas, at least in the short-term. Flood proofing is an option in these cases. This aims to modify buildings and structures to reduce flood damage (ICID 1999, ADPC 2005). Historically this is nothing new. Building of houses, and sometimes entire villages, on raised lands or on stilts is a common, ingenious method of protecting against flooding, especially in Asia. Flood proofing can be either permanent (e.g. raising the building platform above flood levels) or temporary (e.g. providing refugee areas for people and livestock during a flood situation). What makes flood proofing differ from structural flood protection are its small-scale and the reliance on being driven by the local people and communities. Governments and authorities responsible for flood management can contribute with information, planning, training and financial support. Both ICID (1999) and ADPC (2005) provide excellent guidelines on the aspects of flood proofing.

Another long-term flood mitigation measure is land use management, which aims to reduce flooding by providing natural storage of rainfall in the soil in the catchment (ICID 1999). The major role of land use management, in relation to flood management, is to restore nature’s ability to reduce flood peaks. Deforestation and bad cultivation practices have, in many places, led to erosion and flash floods since rainfall is prevented from entering the ground or the unsaturated storage in the soil has been decreased to a minimum. Especially in smaller and mountainous catchments, reforestation and soil conservation practices can, therefore, be efficient flood mitigation measures.

Flood insurance is in a way similar to flood proofing in that it reduces the vulnerability of the public to flood damages. Introducing the risk aspect into flood management implicitly raises the idea that, if floods occur with a relatively low frequency, it may be advantageous to accept the costs when it happens rather than investing money on preventive measures. Flood insurance and loss-sharing are the tools, which make this management approach possible. If flood damage can be limited to economic consequences and if the stakeholders can be guaranteed to be reimbursed for most of their losses, the effects of floods are considerably reduced. Disaster insurance is, therefore, a key for IFRM but it is also a complicated matter. To develop an insurance scheme, in an equitable way and without encouraging inappropriate investments, is difficult and may differ very much depending on the political ideology and economic development in a country. Chapter 5 in ICID (1999) gives a good description of the different aspects of flood insurance and what to consider when and if a flood insurance scheme should be introduced.

The other major type of non-structural flood management relates to being prepared when a flood occurs. It includes flood forecasting, warnings, emergency planning and response. These measures all aim at minimising the damage of a flood by being prepared and introducing temporary solutions. Again ICID (1999) and ADPC (2005) give good overviews of flood disaster preparedness.

The development of computers, IT and the internet has continuously improved the possibilities for forecasting extreme weather related disasters. Hydrological and hydraulic models, linked to information from real-time stations, often distributed via the web, today provide good tools for predicting floods. It should, however, be noted that the performance of the forecasting systems depends heavily on the reliability of data and the skills of the personnel setting them up and operating them. Many developing countries are challenged with poor institutional capacity in the meteorological and water authorities, which prevents functioning systems from being implemented. A further problem associated with flood forecasting is false alarms, which may induce a lack of trust from the public. Again, proper operation of such systems by skilled personnel is essential to avoid unnecessary alarms being issued.

Flood forecasting is only one of the tools needed to be prepared for floods. Very little is gained if the forecasts are not distributed and the relevant authorities and the public do not know what to do with the information. Awareness, communication, clear roles and responsibilities, training, demonstrations and drills are essential components for flood preparedness and emergency response. Participation and transfer of knowledge and experience from general disaster management authorities are key to the success of good flood preparedness.

An overall important aspect to consider when planning non-structural measures is to fully understand the roles and responsibilities of different authorities. In many cases, long term planning required for flood plain and land use development involves many and sometimes overlapping authorities. For example, in North America (USA and Canada) flood protection is a federal responsibility in which the federal authority sets the rules and pays for the damages in case of large flood. But flood plain development is a municipal responsibility, in which the cities collect taxes and benefit from industrial and commercial development. The municipalities are in this case not very keen to strictly apply flood plain development limitations. The participation of all relevant authorities is, therefore, key for successful long-term planning of non-structural flood mitigation measures.

4.3.3.3 Environmental and Social Impact Assessment and environmental flows

All flood mitigation measures will always create negative consequences to some degree for people or for the environment. These consequences need to be considered for analysis and selection of flood mitigation measures.

The standard tool for assessing impacts of any intervention is to conduct an Environmental and Social Impact Assessment (ESIA). APFM (2007c) gives guidance for environmental impacts assessments in relation to floods. The procedures for ESIA are often regulated in the national environmental laws and are quite strict. In a situation where a large number of options are considered as alternative flood mitigation measures, proper ESIA are therefore most often not applicable. In these cases it is recommended to make an environmental and social screening of the consequences of the different alternatives, based on qualitative judgments by experts. The screening procedure can help in selecting a few main alternatives that can be further analysed with a proper ESIA, resulting in monetary values for any negative consequences.

A special case of environmental assessment, especially for dams, is to assess environmental flow requirements, to mitigate any negative impacts because of the changed flow regime. Environmental flow requirements have traditionally been the release of a minimum flow from reservoirs, to provide the prerequisite for aquatic life in the downstream reaches. During recent years, the importance of flood events for the ecological systems have, however, been emphasised. In some countries, the definition of environmental flows has, therefore, been changed to also include flood releases, e.g. South Africa (Hughes and Münster 2000). Therefore, the possibilities or legal requirements of environmental flow releases must be conducted as part of the environmental and social assessment of flood mitigation measures.

4.3.4 4th Step: Risk analysis and economic assessment

Recommended reading:

- Risk and Integrated Water Management (Rees, 2002)
- Application of quantitative risk analysis to floodplain management (Mannix et al, 2003)
- Economic Aspects of Integrated Flood Management (WMO, 2007)
- Developing methodological foundations for GIS-based multi-criteria evaluation of flood damage and risk (FLOODsite, 2009a)

The core part of IFRM, and maybe the most complicated part, is how to design and how to prioritise flood mitigation measures. In recent years, guidelines have been developed in many countries, which advocate the use of risk analysis for floodplain management decisions, such as the determination of flood planning levels. Minimum standards, such as the ubiquitous “100 year flood” level, are rejected in favour of a framework, which aims to balance the risk from rare floods against the economic and social advantages of using the floodplain. But to date, there has been little opportunity to apply risk-based procedures to practical floodplain management problems, and accordingly there is little associated literature that explores the practical issues involved. In the recommended literature above, the application of risk analysis to flood management is promoted and elaborated upon. For example, Mannix et al (2003) argue that a merits-based approach provides a better means than the traditional standards-based approach of allocating scarce resources amongst competing demands by taking into consideration the costs and benefits of floodplain management measures.

A fundamental part of the risk-based approach is to acknowledge that it involves complex trade-offs and the reallocation of welfare between different interest groups. Social, political and cultural issues determine whether a risk is acceptable or not. An holistic approach, taking into account all aspects of floods, should be applied. In practice this is not an easy task but the knowledge and understanding of this holistic approach for risk and water management are essential for people dealing with flood management. Rees (2002) provides good basic reading on the subject.

After the flood impacts have been identified and quantified and the possible flood mitigation measures have been identified, a risk analysis approach should be applied to find the solution that minimises the damage from floods, while at the same time maintaining their positive impacts as far as possible. The process normally involves two steps: the selection of risk criteria and the choice of analysis method for comparison of alternatives.

4.3.4.1 Choice of risk criteria

Risk is a difficult subject that is perceived differently from person to person. What is an acceptable risk for some may not be tolerable for others. This is especially true for intangible losses, and still more for loss of life. Furthermore, often risks are acknowledged just after an incident, such as a flood, has occurred, while the perceived risk then diminishes as time passes without new incidents.

Therefore, one of the steps in IFRM is to define the risk criteria for which the flood mitigation measures should be designed. HSE (2001) outlines the three criteria used by regulators for the assessment of risks in the health, safety and environmental fields in Great Britain:

- Equity-based criterion, whereby broad standards are applied to ensure a minimum level of protection to all stakeholders.

- Utility-based criterion, whereby the benefits of a risk reduction option are compared to its costs (e.g. by use of benefit-cost ratios) for ranking purposes.

- Technology-based criterion, whereby risks are deemed acceptable if best-practice technology is used to minimise such risks.

The generally recommended criterion in IFRM is the utility-based criterion, where the net benefits of none or different flood mitigation measures are compared to find the best option from an economic efficiency perspective (e.g. Rees 2002 and WMO 2007). Mannix et al (2003), however, argue, from their experience in Australia, that stakeholders may be reluctant to accept an option which may result in human fatalities, regardless of probability. This would argue for equity-based criterion, which is more linked to the traditional design of flood management measures based on set probabilities, e.g. a 10,000-year flood or the PMF.

The choice of risk criterion for the design of flood management measures is, therefore, not straight forward and must be made with the specific cultural, social and economic situation at hand and in participation with the major stakeholders identified in step one (see section 4.4.1). Because of man’s normal behaviour to forget large disasters, it is further essential that the involved parties have a basic understanding of the concepts of probability and risk. Mannix et al (2003) states that a preferred option, on the basis of maximising utility, should only be decided once the risks associated with all options are first deemed to be tolerable, thus suggesting a combination of the equity- and utility-based criteria.

4.3.4.2 Economic assessments based on risk analysis

Whether the decision on risk criterion is based on equity or utility the most common way of choosing a flood mitigation measure is by comparing the options economically. The difference in the method is, however, in how to take non-monetary values (mainly loss of life) into account and societies’ capacity to implement the measures.

A pure equity-based criterion means that the option providing the required flood mitigation with the least cost will be chosen, taking social and environmental impacts and necessary lead time for implementation into account.

In the case where flood damages are obviously more costly than the benefits of floods and where the society has a development level to cope with floods, the preferred mitigation measures can be selected through a comparison of the cost of flood damages and the cost of the mitigation measures (Mannix et al, 2003). The key here is the calculation of average annual damages based on the definition of risks as the product of probability and consequence (i.e. Cost = Probability of event × Consequence of event). Since every mitigation measure will reduce the risk or the consequence of floods differently, the average annual cost of damages will differ and so can be compared. The most straight forward method is to apply the option with the minimum total cost of average annual damages and capital and operational costs of the mitigation measure accumulated and discounted for a set period (normally 30-50 years). This method is presented in Section 3.6. The disadvantage of this method is that it is difficult to take non-monetary issues, such as social costs, into account.

The preferred methodology for IFRM is, however, a full Cost-Benefit Analysis (CBA) taking all aspects of floods, both negative and positive into account (Rees, 2002; WMO, 2007). In the case that there are clear and quantitative benefits of floods, these can be included as “negative” costs into the average annual damage, since the different mitigation measures (and the zero-option of no mitigation) will give different reductions of the flood benefits. The major difficulty with this method is, however, to set monetary comparable values for ecosystems, social improvements, poverty alleviation, etc. However, WMO (2007) argues that different approaches to putting monetary values on social and environmental concerns are under development and describes some of them. But the utilisation of a full CBA for decision-making in flood management is still very cumbersome and time demanding and it is recommended that this method should only be applied when a few well-defined options remain.

Because of the difficulties of CBA, WMO (2007) also suggests Multi-Criteria Analysis (MCA) as an alternative method. The MCA uses factors for different issues, such as costs, environmental and social impacts or benefits, lead times for implementation, etc., to rank the different flood mitigation measures. FLOODsite (2009a) has recently developed a method for MCA in IFRM based on GIS, which is a good tool for handling spatial data and for illustrating the different options for key stakeholders. The critical part of the MCA is the subjective setting of factors and the weighting of the different issues when integrating them in a combined ranking. Therefore, MCA is normally recommended to be conducted in participation with key stakeholders.

The subjective parts of MCA and the often arguable criteria for determining monetary values for social and environmental issues, risk that the economic assessment of different flood mitigation measures may be very time consuming, especially if many stakeholders are involved. Therefore, it is essential to remember the general recommendations that IFRM must be implemented in a pragmatic and balanced way and that planning should not take more than 2-4 years. None of the economic methods consider equity between different stakeholders and it is impossible to find any flood management solution that gives fair and equal impacts for all interests (or at least perceived as such by all). Equity must, therefore, normally be solved separately in parallel with the economic assessment.

Any planning of IFRM must also consider how the flood mitigation measures should be funded. In most cases all costs must be borne by the different government levels and because of the often costly measures, with no immediate benefits (it can take years until a major flood occurs) it can be difficult to motivate such public investments. It may, therefore, in many cases, be more feasible to look into multipurpose projects, where flood mitigation measures can at least partly be paid by revenues from e.g. hydropower production or water supply.

4.3.5 5th Step: Risk management and strategy formulation

Recommended reading:

- Legal and Institutional Aspects of Integrated Flood Management (WMO, 2006a)
- Integrated Flood Control in the Czech Republic in March 2006 (Case Study, Appendix 1)
- Strategy for Flood Management for Lake Victoria Basin, Kenya (MEWRD, 2004)
- Strategy for Flood Management for Kafue River Basin, Zambia (MEWD, 2007)
- Guidance on Flash Flood Management, Recent Experiences from Central and Eastern Europe (IMGW, 2007).

The final step for IFRM is the most important one. It involves putting the flood management into action by implementing the chosen mitigation measures and make sure they are sustainable. This includes putting the flood management into the legal framework of water and disaster management and specifying roles and responsibilities. WMO (2006a) gives a good overview of the legal and institutional aspects of flood management, both on the national and international scale.

The implementation of IFRM further demands strategies to be formulated and guidelines to be written to direct the flood management and to provide instructions on its regular update. Because the inherent differences in the physical and socio-economic conditions, as well as in chosen flood mitigation measures, it is not possible to give any definitive guidelines on how such strategies or guidelines should be formulated. Instead it is recommended to learn from the experience of others and to adopt the appropriate parts that are applicable for the river basin of interest. The recommended reading therefore includes case studies from Europe and Africa to illustrate formulated strategies and guidelines for river basins in both the developed and developing world (Appendix 1; MEWRD, 2004; MEWD, 2007; IMGW, 2007). In general, however, being a fairly new concept, few references to completed IFRM projects exist and the reader is recommended to continuously search for new experiences and ideas from IFRM implementations.

4.3.5.1 Risk management cycle

The first part of implementation of IFRM is to understand the place of the steps above in the overall risk management cycle (Figure 4-6). The setting of boundaries, identification of key stakeholders, preparatory studies and assessment and choice of flood mitigation measures are only part of the flood risk management cycle (the prevention and preparation components). As flood events occur in the future more knowledge and experience will be obtained that may require changes in the studies and decisions on flood management. Even if no future major flood events occur, the inevitable changes in physical characteristics (e.g. climate change), socio-economic and legal conditions or in the institutional set up, will nevertheless generate the need for updated flood management procedures. Therefore, IFRM will result in an endless cycle of improved prevention and preparation for floods as well as intervention, recondition and reconstruction after flood events, as illustrated by Figure 4-6.

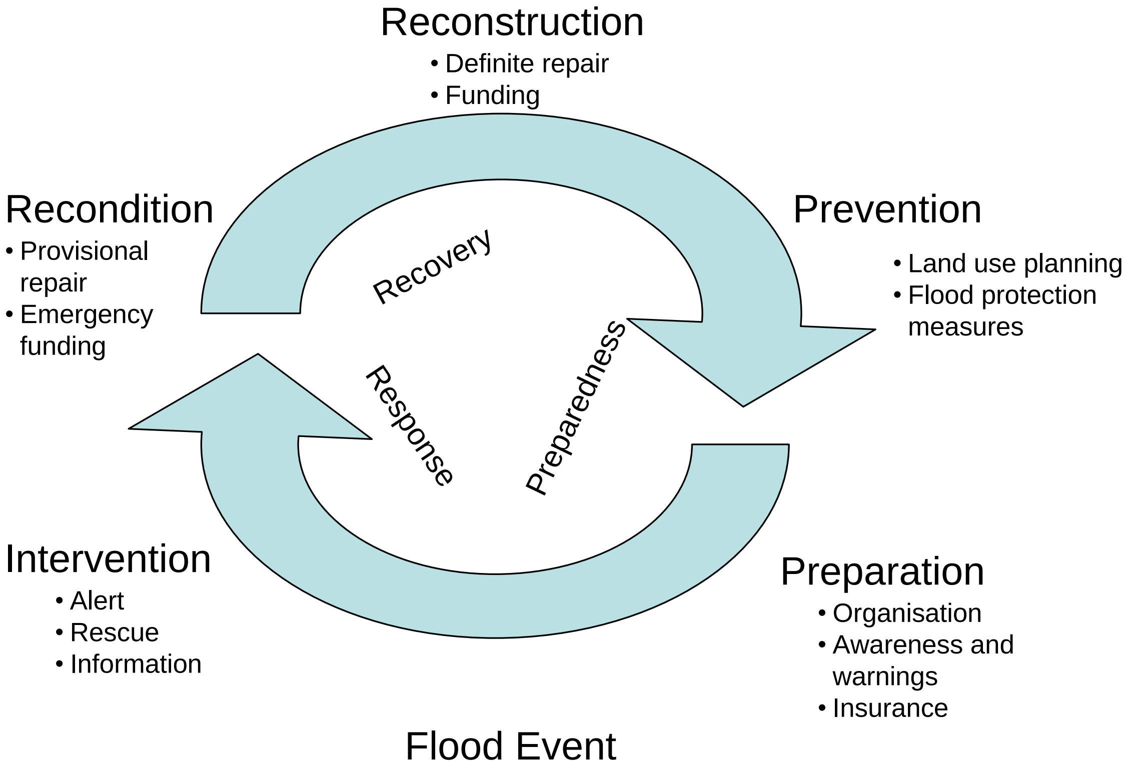

Figure 4-6 – Risk management cycle for IFRM. Modified after (UNESCO, 2006).

An example of the application of the risk management cycle is illustrated by the flood management in the Vltava River basin in the Czech Republic following the floods in 2006 (Appendix 1). Similarly, the experience from several flood events in the 20th and early 21st century in the Klodzka River in Poland, Myjava River in Slovakia and Telejaen River in Romania was used to provide general guidelines for flood management of small river basins in Eastern Europe (IMWG, 2007). In all cases fundamental parts of IFRM such as stakeholder participation, coordinated operation of flood control structures, flood forecasting, flood warnings and flood preparedness are included and discussed. The analysis and evaluation of the 2006 flood in the Czech Republic resulted in requested improvement in flood management, e.g.

- To increase the role of land use planning and building regulations in flood prone areas
- To clarify roles and power among flood protection entities
- To hold regular flood exercises and training of participants in flood protection
- To improve security surveys at smaller hydraulic structures, using the experiences and procedures in place for large dams
- To improve the meteorological and hydrological forecast
- To improve the flow monitoring stations and to equip these with real-time data transfer techniques.

This illustrates how a flood event may lead to improvements in the existing flood management, which was in place already prior to the flood, along the principles of IFRM and the steps of the flood risk management cycle.

4.3.5.2 Formulation of IFRM strategy

The goals and process of IFRM must be clearly described in a strategy document that should be made available for all key players and the public. The strategy must describe the visions and goals, system boundaries, key stakeholders, roles and responsibilities, present situation in terms of flood characteristics and flood vulnerability, as well as the suggested mitigation measures including plans and means for their implementation. The IFRM strategy shall give the playground and rules for the flood risk management process (Figure 4-6) and the actions to kick-start it if it is not already in place.

The IFRM strategy can be developed on its own, or be part of an overall IWRM strategy, since flood management essentially is one part of the general river basin management. Preferably, as previously discussed, the strategy should be made for each major river basin since this is the natural boundary for water management. An example of such river basin planning is the coordinated emergency preparedness planning in Sweden, which is presently being implemented for each major river in the country involving the local county administration boards, municipalities, rescue services, water regulating services and dam owners (Engström-Meyer et al, 2009).

The strategy, by its definition, must also be designed in such a way that flood management may evolve over time without jeopardising the anticipated results. Based on experience from the Yangtze River in China, Green (2003) emphasises that a flood management strategy must provide possibilities of transition to meet future changed socio-economic conditions. The IFRM strategy should include plans for the immediate measures to take but must, more importantly, give the strategic direction for the continuous and evolving risk management in the river basin.

The first thing an IFRM strategy must clarify is how the flood management will be integrated into the existing legal system. As WMO (2006a) points out IFRM cuts across many institutional and disciplinary boundaries and must conform to laws, policies, plans and programmes on both the national and local scale. On the other hand, equally important is the understanding that the successful implementation of IFRM may need to involve creating new policies and even new laws. The roles of the legal framework are to define institutional roles and responsibilities, to determine and protect rights and obligation and to provide mechanisms for conflict management, all of which are essential for IFRM. An IFRM strategy without clear policies is, therefore, toothless and will be difficult to implement.

Illustrations of IFRM strategies are given in (MEWRD, 2004) and (MEWD, 2007). These give the strategies for flood management in the Kafue River in Zambia and the Lake Victoria basin in Kenya. Both are typically set up with the following structure

- Physical and social description of the river basin
- Rationale for the flood strategy (flood vulnerability, climate variability)
- Strategy concepts (stakeholder involvement, integrated approach, protection of environment, institutional coordination)
- Flood management policies (institutional arrangements, non-structural and structural mitigation measures, community participation, capacity building)
- Action plans (short-, medium- and long-term measures)

The two strategies thus combine the strategic direction by the concepts and policies and the guidelines for immediate action expressed as action plans, which are essential for not losing momentum. The strategy must be associated with regularly updated and monitored action plans, to achieve actual implementation of flood management. Although, these examples may not be applicable in all river basins, they give a good illustration of the major parts to be included in an IFRM strategy.

5. CONCLUSIONS

5 CONCLUSIONS

The field of flood management has seen considerable changes during recent decades. It has been realised that, although the classic approach of controlling floods through structural measures, such as dams and levees, or a mix of structural and non-structural measures, are powerful solutions for flood control, the selection of flood management procedures should be viewed in a wider scope, taking into account the benefits of floods and, to a certain extent, the possibility of accepting floods and learning to live with them.

The reason for this change is mainly that more data and experience on floods and their impacts have led to better knowledge and understanding. Three major revelations have made us change how we manage floods:

- Longer records and better measurements of peak flows have reduced the uncertainties and documentation of flood impacts and have given quantitative estimates of flood damages; as a result we now dare to take calculated risks with floods.

- The development of technology and IT has made it much easier to predict flood magnitude than before, which has led to improved flood control and possibilities for significantly reducing flood damages by temporary mitigation measures.

- In some cases, effective flood control measures put in place during the last centuries have shown that there are also negative effects to preventing floods, proved by observed declines in local biodiversity and decreased economic return from floodplains and estuaries.

The better knowledge and understanding has given us the possibility of taking all aspects of floods, negative and positive, into account in flood management and of more precisely optimising flood mitigation measures based on risk analysis. The concept of Integrated Flood Risk Management has accordingly been proposed and presented by renowned academic and multilateral institutions, based mainly on the experience from developed countries.

The requirements for any policy maker, city planner or engineer, faced with designing a flood management strategy have, therefore, increased dramatically. Participation of a wide range of stakeholders, to make sure that all aspects have been taken into account, and extensive preparatory studies, to assess the long-term effects of floods, have considerably prolonged the period needed for even agreeing on a flood management strategy.

While acknowledging the concepts of Integrated Flood Risk Management, this bulletin promotes a balanced and pragmatic approach, where the design of a flood management strategy is conducted to a degree which is applicable and implementable in the country and river basin of interest. It suggests following a step-wise approach to formulate an IFRM strategy, based on a basic knowledge of flood characteristics, flood impacts and the aspects of integrated water management:

1. Identifying system boundaries and key players

2. Conducting preparatory studies

3. Identifying flood mitigation measures

4. Carrying out risk analyses and economic assessments of alternatives

5. Preparing strategy formulation and initiating the risk management process

The overall recommendations for the process are to be transparent in your actions and take the time to listen to and to explain the alternative solutions to stakeholders, aiming for a maximum time period of

2-4 years for the whole procedure prior to implementation. It is further essential, when considering both positive and negative effects of floods, to use comparable parameters and avoid ideological views that skew the estimated net benefits/losses of floods. Non-structural and structural flood mitigation measures are often most efficient in combination and should be assessed with an open mind, without fixed preferences.

The experiences from other countries and regions, where flood management has been implemented, are essential sources of information and guidance for the development of an IFRM strategy. Besides giving references to literature on the basic sciences and concepts of flood management, this bulletin also presents and recommends a number of documented case studies for flood management.

The need for a systematic analysis of floods/inundations from the past is emphasised. This analysis should include the relevant parameters of the floods (peak, volume, duration, shape) and of the corresponding inundations (area, depth, duration, current velocities). The damages caused by these floods should be analysed in order to arrive at a relationship between flood magnitude and damage caused. Without such knowledge, it is not possible to carry out meaningful flood risk management

6. REFERENCES

6 REFERENCES

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APPENDIX 1

CASE STUDY

INTEGRATED FLOOD CONTROL IN THE CZECH REPUBLIC IN MARCH 2006

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TABLE OF CONTENTS

1. INTRODUCTION TO THE PROBLEMS OF INTEGRATED FLOOD CONTROL

After the experience with the floods in 1997 and 2002, which came after a longer, relatively dry period of the second half of the 20th century, an integrated system of protection against floods has been constantly developing and improving in the Czech Republic. This, *inter alia*, includes the specification of all input information on the hydrological situation that has arisen, changes in the legislation in the area of flood prevention and protection, crisis management as well as the provision of state aid in the process of reconstruction of a territory after a flood, and support of the implementation of protective measures in the territory.

The process of improving the quality of the system in the sphere of prevention against floods encompasses the strengthening of the role of land-use planning and decision-making of building authorities in co-operation with water-law authorities and basin administrators in the process of permitting constructions in all territories threatened by floods, the determination of flood areas and co-ordination of the manner of utilization thereof. At the same time, background materials for flood prevention are updated. In particular, this concerns flood plans of municipalities and updating the extent of flood areas. An increase in the degree of protection in municipalities will enable increasing the limits of harmless runoffs from reservoirs above them. It is necessary to be particular about increasing the reliability of the flood warning service, including the active involvement of lower structures such as municipalities into this system. An important point is the extension and improvement of the quality of the flood forecasting service with the creation of conditions for flexible co-operation of the Czech Hydrometeorological Institute with basin administrators. Increasing the level of hydrometeorological and hydrological forecasts will bring more efficient and expeditious decision-making in utilizing the flood water retention areas of existing reservoirs. To make the activities of individual participants in the protection against floods more precise and to automate them, flood exercises are regularly organized at the level of municipalities, regions and basin area but also within the framework of the entire republic. The knowledge acquired from these exercises is evaluated and they serve retroactively to enhance the quality of the integrated system of flood protection.

The most significant measures implemented as part of the prevention against floods include mathematical flood models of the city of Prague and other big cities, where the situation is generally more complex also owing to the fact that they are directly affected by the confluence of two or more rivers. Outputs of these models are used as basic data for the execution of flood plans, the determination of flood areas and active zones of these areas, further for the assessment of flood control measures proposed and for the assessment of constructions proposed in the flood area. The correctness of the approach to prevention was attested during the flood in August 2002 by the function of flood control measures, particularly mobile barrier walls, implemented in central Prague on the basis of detailed modelling of discharge in the period of 1995–2000.

Further flood control measures are aimed at achieving an increase in the retention volume at the hydraulic structures of the Vltava Cascade, possibly at the limited use of water-supply reservoirs as well during the passage of floods. The goal is to intercept and transform flood discharge. In view of the extensive basin, the volumes of some floods are so high that their transformation is not successful even in existing reservoirs and, at the same time, it is not presently realistic to consider building new, large hydraulic structures. In spite of that it is seen that already built reservoirs have, even during such big floods, an important function because with their transformation effect they make it possible to obtain time for activities focusing on the limitation of flood damage in lower courses below them.

In the crisis situation during the floods in 2002 and 2006, thanks to the retention capacities of the reservoirs of the Vltava Cascade there was no clash of flood waves of the Vltava and the Elbe, into which the Vltava empties. At the same time, only smaller dams without a significant retention effect during major floods are on the Elbe. The Elbe river flows from the Czech Republic to Germany and, therefore, peak flows or the influence of the quality of water in the Elbe are very important for German authorities too.

This activity requires the continuous co-operation of water-management control centres of both basins, the Czech Hydrometeorological Institute as well as state administration bodies.

2 BASIC CHARACTERISTICS OF THE VLTAVA BASIN

Povodí Vltavy, a státní podnik residing in Prague is the historical successor to all the previous owners and administrators of the Vltava and its entire basin. The administration of the territory is divided among three plants – Upper Vltava, Lower Vltava, and Berounka. In a territory with a total area of 27,580 km^2 the organization administers 4,881 km of water courses.

The enterprise manages a number of water-management structures: 56 water reservoirs, 78.6 km of protective dikes, 337 weirs, 18 lock chambers, 20.7 km of navigation canals, and 31.7 km of artificial canals and conduits, a total of 17 small water power stations.

In terms of administrative division, the Vltava basin lies in the territory of five regions; in terms of its area it covers approximately one third of the Czech Republic.

The Vltava basin drains an extensive south-western and partly also a central part of the Bohemian Highlands. The headwater areas are located in mountain ranges forming the European watershed of the Elbe – Danube. The highest altitude is reached by the Vltava basin with the Bohemian Forest peak of Plechý (1,378 m). The altogether regular hydrographic network of the Vltava basin drains water from mountainous country and uplands via hilly country down to the lowlands in the central Elbe valley. The lowest altitude in the basin mouth on the confluence of the Elbe and the Vltava is 156 m. The backbone course is formed by the Vltava, fed by significant tributaries, which include the Malše, the Lužnice and the Otava in the southern part, and the Sázava and the Berounka in the central part. The Vltava empties into the Elbe, which is characterized by approximately the same water bearing as the Vltava, and flows from the Czech Republic to Germany.

3 COURSE OF FLOODS – GENERAL PROCEDURES

3.1 Hydrometeorological Situation during Floods

Information on the meteorological situation as part of the flood forecasting service is provided, by law, for the basin administrator and other participants in the protection against floods by the Czech Hydrometeorological Institute. By means of numerical forecasting models and experienced forecasters, the Czech Hydrometeorological Institute creates weather forecasts (short-range and medium-range as well as long-range) on which basin administrators rely when making decisions on the management in reservoirs of hydraulic structures. The process of perfecting the forecasting models, increasing the time advance of forecasts and their more prompt issuance belongs among the long-term tasks of the development of flood protection in the Czech Republic.

The Czech Hydrometeorological Institute in collaboration with basin administrators also provides a forecasting and flood warning service, which includes monitoring the hydrometeorological situation, precipitation, water stages and discharges in selected profiles and the evaluation of precipitation-runoff models. The system further consists in the timely and reliable transfer of such information to the flood control authorities of state administration and to self-governments of municipalities. The transfer of data from observation and warning profiles, information, notices, warnings and reports is of strategic significance to flood protection.

For effective utilization of the flood warning service it is necessary to build a system of reporting profiles with the determination of decisive limits for declaring degrees of flood activity. Water stage gauging stations in reporting profiles of A categories were equipped, one by one, with automatic transfers of data to the operating centres of the Czech Hydrometeorological Institute and basin administrators.

Also, it is necessary to pay attention to the presentation of information from the warning and forecasting service on the internet including information on precipitation and flood forecasts. Presented information is for example: discharges and water levels in reporting profiles, inflows and outflows from the dam reservoirs, water levels in reservoirs, available storage volume in reservoirs, relation all of these data to the degrees of flood activity and to the flood intensity.

3.2 Influence on the Situation of Hydraulic Structures, Decisive Handling Operations, Security Survey and Supervision

All the hydraulic structures managed by Povodí Vltavy, státní podnik (dams, weirs, dikes) are maintained in working order thanks to a sophisticated system of security survey and supervision, maintenance, renovations and repairs. Following previous flood situations, all the hydraulic structures undergo inspections and all defects and deficiencies ascertained are removed in such a way as to ensure the safe operation of all the hydraulic structures. All the hydraulic structures have executed handling and operating regulations and programmes of security survey and supervision. Most of the #hydraulic structures are operated as multi-purpose hydraulic structures. Their purpose is mainly securing the requirements for water supply in dry periods, including the securing of minimum ecological discharges in the course below reservoirs. Decreasing flood flows is only one of the benefits provided by the reservoirs. Discharging water from a storage space in advance of the arrival of a flood can only be permitted in the event that a reliable forecasting hydrological service is secured, guaranteeing that the storage space will be refilled at the end of the flood. Where a retention space is reserved in a reservoir it is, of course, permanently available for the transformation of the flood. Handling operations before a flood are managed on the basis of a forecasting service in accordance with handling regulations; in the course of the flood on the basis of the evaluation of the hydrological situation and proposals and requirements from discussions of flood commissions, also within the framework of the handling regulations of the hydraulic structures. Emergency handling actions are only permissible in the event that a state of emergency is declared.

The Czech Hydrometeorological Institute controls the state monitoring network of monitoring the quality of water in courses and underground water. At the time of a flood a regime of emergency monitoring is set in which the enterprises of Povodí also take part; it monitors fundamental consumption profiles near sources of drinking water, below possible sources of contamination and in the basin mouth, and a system of warning measures arising therefrom, including the determination of entities responsible for timely warning and the provision of corrective actions.

3.3 Activity of Water-Management Control Centres and Flood Commissions

Forecasting the occurrence of possible flood danger and subsequent timely awareness of flood control authorities on the part of the Czech Hydrometeorological Institute and administrators of water courses have a great influence on the management and implementation of preventive and expedient actions to mitigate the consequences of a flood. Flood control and crisis bodies respond to the occurrence of a flood situation in all areas affected by a flood; they hold regular meetings, sessions and communication takes place with units of the Integrated Rescue System, which leads to a successful solution for situations that arise.

Compared to the floods from previous years, the consequences for health and lives are decreasing; the numbers of persons being rescued are lower thanks to better awareness of the inhabitants, the use of the internet and the willingness of the inhabitants to adapt themselves to the requirements and recommendations of units of both crisis and rescue systems.

In response to the development of a flood threat, flood commissions of municipalities and regions are activated to fulfil tasks arising from flood plans. In view of an escalation of the flood situation in the territory of some regions and the need to handle it by means of crisis measures, the commissioners of such regions may declare, one by one, states of danger in the threatened area of the region, in accordance with the provisions of Act No. 240/2000 Coll., on crisis management. The government of the Czech Republic subsequently declares a state of emergency for the territory of more regions.

3.4 Impacts on the Population and Flood Damage

Summaries of declared degrees of flood activity and crisis states processed by individual bodies contribute to the description and evaluation of the activity of the integrated control system. The overall picture necessary for evaluating the functionality of the integrated control system is supplemented by an overview of main events and crisis situations that were dealt with in the course of the flood.

The final evaluation of the course of a particular flood situation and the efficiency of the activities of individual flood protection entities is dealt with by a summary report on the flood. The summary report on the flood is a document that deals comprehensively with the causes, course, implications and consequences of a specific flood. The report on the flood is elaborated in conformity with the provisions of Act No. 254/2001 Coll., on water. The said act regulates the duty of flood control authorities to evaluate the flood situation within one month of the end of the flood.

The administrator of the Vltava basin executes a summary report using background documents of the state enterprise Povodí Vltavy, other administrators of minor water courses, the Czech Hydrometeorological Institute and flood control authorities of municipalities in the process. The report is submitted to the individual flood control authorities of regions and to the Ministry of the Environment.

Subsequently, a summary evaluation report of flood control authorities of regions is executed on the basis of background documents of individual participants in protection against floods (owners of land and constructions that are situated in a flood area, flood control authorities of municipalities, municipalities with extended competence, owners of hydraulic structures, administrators of water courses and basin administrators). This report also contains an analysis of the extent and amount of flood damage and the purposefulness of measures taken.

An important activity after floods is recording the maximum levels of high water reached in the territory and their permanent marking directly on structures in the landscape. This leads, among other things, to heightened awareness of the population of the possibility of flood danger even in a period when the hydrological conditions are average to below average and the vigilance and responsibility of the population decreases.

In the period immediately after the culmination of a flood all entities concerned conduct inspections and record flood damage. In the event that an extraordinary flood occurs, whether in terms of the intensity of the discharge or the extent of the territory affected, state grant titles are activated for removal of the consequences of the floods for affected areas or possibly grant titles for new measures of flood protection.

More detailed and systemically interlinked legislative regulations of the process of the preparation of permanent preventive protective actions must serve for more entities. The responsibility for the preparation of preventive protective actions is imposed on municipalities and regions but with the direct responsibility of threatened entities for their own protection and for its funding being observed and emphasized. Also, it is necessary to adapt budgetary rules for financing municipalities and regions to duties thus imposed.

4 FLOOD IN MARCH 2006

4.1 Hydrometeorological Situation during the Flood

Following a long cold period of the winter of 2005/2006 with relatively high snow cover, which kept up until March, there was melting of snow at the end of March 2006, which was accompanied by heavy rains. The snow-water content recorded in mountainous areas was not record-breaking but in combination with often the highest observed values at medium altitudes, virtually in the entire territory of the Czech Republic, the total reserves of snow were the highest in 50 years. The total amount of water in snow was about 2 milliards m3 in the catchment area above the city Prague when the intensive melting of snow started. The retention volume of Vltava cascade reservoir is less than 100 milion m3..Water, not only from melting snow but also from rainfall flowed into streams, namely in conditions where particularly at medium altitudes frozen ground was still present in some places. In addition, a fresh breeze accelerated the melting of the snow and a high amount of clouds preventing heat radiation maintained rapid melting even at night. Almost 40–60 mm of precipitation fell on the surface in the period from 25 March 2006 to 3 April 2006.

As a consequence of intensive rainfall and snow melting, there were increases in the levels of water courses, namely in the area of the basin of the Upper Vltava and the basin of the Sázava. Of the basin of the Upper Vltava, the most marked progress of the flood was on the Lužnice and its tributaries (roughly fifty-year flood discharge). The progress of the flood was also affected by the heavy overflowing of the Sázava throughout the area, where peak discharges were reached with a recurrence interval of more than 50 years. The character of this flood differed markedly from a number of past floods by the fact that the peak discharges on water courses did not reach, with the exception of upper sections, maximum values in terms of n-year occurrence but the volumes of the flood waves were huge thanks to gradual intensive melting of the snow cover at medium and upper altitudes.

Only a two-year to five-year discharge was recorded in the city of Prague on the Vltava with a discharge of 1,500 m^3/s not being exceeded; this is a limit for flood activity to reach the third degree and related considerable restrictions in the running of the city. Flood protect measures can protect the city till the discharge almost 5 000 m^3/s , but they restrict and complicate the operation not only in the centre of town, but in all Prague. This was contributed to, to a great extent, by the transformation effect of the Vltava Cascade, which was managed throughout the winter considering the measured height of snow cover. This manner of handling and control of the flood on lower courses below larger dams also influenced the progress of the flood on the Elbe downstream of the confluence with the Vltava, and the recurrence interval of the peak discharge did not reach 10 years. The fairly moderate progress of the flood was a result of the co-operation of the control centres of individual basins, which influenced within their possibilities the times of flow of the peak discharge into the mouth of the Vltava. This handling also showed favourably in neighbouring Germany, mainly in Dresden and other towns near the border.

4.2 Influence on the Situation by Hydraulic Structures, Decisive Handling Operations, Security Survey and Supervision

In connection with the course of the winter, water management staff began to lower water levels in the dam reservoirs of the Vltava Cascade sufficiently in advance and to vacate parts of the storage spaces for potential spring floods as well. In view of the considerable snow cover even at medium altitudes it was also decided to partly lower the level in the most significant water-supply reservoir, Želivka on the Sázava, so that the supply of water was not threatened in quantity or quality. The prerequisite condition for this decision was a reliable forecasting service, and thus the certainty that the vacated spaces would be reliably filled.

Handling operations were taking place in mutual co-operation on all the hydraulic structures of the Vltava Cascade during the flood in order that the free capacity in the reservoirs was utilized to a maximum extent for the transformation of flood tributaries. The biggest influence was exerted by the hydraulic structures Lipno I and Orlík, which have a significant retention capacity reserved. Handling operations on the hydraulic structures led to the runoff being increased gradually until it reached culmination in the lower sections of the courses below the reservoir, thereby favourably influencing the course of the flood wave. Harmless runoff was kept below the hydraulic structures of the Vltava Cascade and thus the consequences of the flood and flood damage were reduced not only on the Vltava but also on the Elbe in the Czech Republic and Germany.

A normal operating situation occurred on all movable weirs of the Vltava waterway before the arrival of the flood, and all handling operations were taking place according to valid handling regulations. After the limits determined in the flood plans were reached, navigation in the navigation route on the Vltava was stopped and, as part of flood control measures, workers of Povodí Vltavy, státní podnik closed four floodgates. All the weirs were tilted in a timely and reliable manner.

During the flood of 2006, security survey and supervision was performed continuously on hydraulic structures that were highly stressed in transferring flood discharges, in accordance with valid programmes of security survey and supervision and according to the current instructions of chief workers of security survey and supervision depending upon the development of the hydrological situation. The period of the highest load of the hydraulic structures lasted five to ten days; the design parameters were neither reached nor exceeded in any of them. However, at several of them the maximum level for the period of their existence was reached (for example: Želivka water-supply reservoir). Competent chief workers of security survey and supervision conducted, according to an expeditious agreement, check inspections at selected hydraulic structures after the flood in conformity with Act No. 254/2001 Coll., on water. It was stated that both during and after the passage of the flood the hydraulic structures affected by the flood were operational and in a safe condition.

4.3 Activity of Water-Management Control Centres and Flood Commissions

Workers of the central water-management control centre of Povodí Vltava in Prague and of regional control centres in Plzeň and České Budějovice participated in the control of the flood situation. Based on the forecasts of the CHMI and the progress of the flood situation, measures were taken for heightened monitoring of the current hydrological situation and, simultaneously, all operating staff and attendants of hydraulic structures were warned of the possibility of the occurrence of a flood situation. Concurrently, on the basis of forecasts of precipitation, temperatures, hydrological situation and the level of filling of individual reservoirs, handling operations were commenced on hydraulic structures so as to utilize their free space to the maximum extent. Then in the course of the flood, information was received at all control centres of Povodí Vltavy from the whole Vltava basin and information reports were issued daily on schedule, which were sent to flood control authorities and state administration institutions. These information reports were continuously published also on the website of Povodí Vltavy, státní podnik. 103 regular information reports were issued in total during the flood.

After 2nd degrees of flood activity were reached in most gauging sections, the flood commissions of municipalities with extended competence commenced activity; they took over control of the flood from individual municipalities, thereby enabling the acceleration and improvement of communication and organization of security works during the passage of the flood. Further development of the flood situation required the subsequent activation of 4 flood commissions of regions and the declaration of a state of danger for the territory of the South Bohemian and Central Bohemian Regions. Working actively on all flood commissions were workers of Povodí Vltavy, who provided up-to-date information on the development of the hydrological situation, which helped the flood control authorities foresee the situation in affected areas.

Up-to-date values of the discharges in individual profiles on water courses and data on the levels in reservoirs managed by Povodí Vltavy were published on the website of Povodí Vltavy. At the same time, Povodí Vltavy was publishing on its website current data on the water level in main water reservoirs in its administration in 1-hour intervals. Compared to previous floods, only rare failures occurred in the March of 2006 in the continuous observation of water stages, namely thanks to construction modifications made to water stage gauging stations after the flood in 2002 and a change in the data transfer technology (GSM, GPRS) in comparison with transfer via fixed lines in the past.

The provision of information to flood control authorities, especially via representatives of Povodí Vltavy on these commissions, was an integral part of the information service provided by water-management control centres. A great number of phone queries about the flood situation were answered during non-stop 24-hour service, both to individual users on water courses and to the public.

Besides the activity of water-management control centres, the flood situation was also constantly monitored continuously and evaluated by the operating staff of Povodí Vltavy, státní podnik, who when needed were promptly solving all situations that arose directly in the affected locations; they provided field information to control centres and they became actively involved in the activity of the relevant flood control authorities. In case of need, workers of Povodí Vltavy immediately started security works as required by the flood situation.

The most important and complicated decisions during this flood included making decisions about handling operations on the reservoirs of the Vltava Cascade leading to a discharge of 1,500 m^3/s not being exceeded in the profile of the city of Prague. This discharge is relatively harmless discharge for Prague. Reaching this discharge, according to relevant flood plans, starts the implementation of significant flood control measures in the territory of the capital – the construction of an intricate and large complex of mobile flood barriers, the partial interruption of traffic including the operation of the metro in the central part of the city and the like. These measures can protect the city till the discharge almost 5 000 m^3/s , but they restrict and complicate the operation not only in the centre of town, but in all Prague. The refinement of a hydrological forecast and the feasible possibility of transforming the flood in the remaining free retention spaces of the reservoirs served as a basis for this decision. Since flood control authorities on the lower course of the Elbe were also interested in this discharge in the Vltava not being exceeded, closely interlinked co-operation of the relevant flood control authorities and other units of the integrated rescue system took place in the decision-making process. The discharge is estimated more than 2 000 m^3/s during this flood in case of absence Vltava Cascade with earlier culmination in Prague.

4.4 Impacts on the Population and Flood Damage

The most tragic impact of the 2006 spring flood was the loss of nine human lives, even though it is necessary to state that most of these victims were lost due to human lack of caution and daring. In comparison with the loss of human lives as a result of the floods in 2002, which claimed 19 victims, and in 1997, when the number of victims reached 60 human lives, these data are substantially lower. This is given partly by the smaller area and culmination extent of the flood but also indisputably by the better organization of activities of all units active in the sphere of an integrated rescue system and by instructions given to the inhabitants. The evacuation of around 200 municipalities was under consideration, the actual evacuation of inhabitants took place in 85 municipalities, mostly only in parts of these and it concerned 13,000 persons.

The 2006 spring flood caused damage, the overall amount of which reached, according to preliminary estimates, 200 million euro, mostly in the competence of agriculture, under which water-management infrastructure also falls. The flood was extensive as to area, it hit 799 municipalities and in seven regions it was necessary to declare a state of danger under Act No. 240/2000 Coll., on crisis management. Under Act No. 12/2002 Coll., on state aid in the reconstruction of an area affected by a natural or other disaster, financial resources were secured by this measure for the provision of state aid in the reconstruction of the area affected by the flood. The structure of the damage was diverse. Compared to the previous disastrous floods in the years 1997 and 2002, housing stock was hit to a relatively small extent (8.2%). Overall, the biggest damage was recorded in transport infrastructure (37.1%) and in water management (24.6%). The quality of water in courses or in reservoirs was not affected.

5 EVALUATION OF THE FLOOD, PROPOSED MEASURES

The final evaluation of the course of the flood situation in March 2006 and the efficiency of the activities of individual flood protection entities is dealt with by a summary report on the flood in March 2006. The summary report on the flood was executed within the deadlines and to the extent provided by law, and its structure is described in general in Chapter 4) hereof. In addition, a summary publication, Jarní povodeň 2006 v České republice (“The 2006 Spring Flood in the Czech Republic”) – author: Water Research Institute of Prague, and a number of partial reports and materials were processed.

Detailed documentation of the flood damage was carried out, and in view of the extent of this flood a state grant title was approved for removal of the consequences of the 2006 spring flood in water-management property. Works on the elimination of the flood damage to water courses and hydraulic structures may continue until 2008.

The highest levels reached were carefully documented directly in the terrain; they were geodetically surveyed and marked at visible places with permanent boards for the awareness of water management experts as well as the residents.

Listed at the conclusion of the summary report on the flood in March 2006 are proposed measures for further activity in the sphere of prevention against floods. In general, it is possible to say that a big step forward has been taken in the area of flood prevention, protection and integrated rescue system since the disastrous floods of 1997 and 2002, and today a number of measures proposed then remains in force. From these, we extract:

- to continue in the long-term programme of prevention in protection against floods and to complete the main part of the structural measures by 2012
- to continue with interventions leading to an increase in the retention of a territory, to strive for a change in the structure of utilization of plots of land in locations with the highest runoff
- to change the utilization of alluvial plains, to stop construction in these areas
- to be substantially further increasing the role of land-use planning and building regulations in flood lands
- to continue executing and updating flood plans of municipalities and higher units, to focus on critical places both on a water course and in villages/towns
- to update the handling regulations of hydraulic structures, to seek possibilities of increasing the existing retention spaces of reservoirs, to assess the possibilities of handling operations for the benefit of the transformation of a flood wave even on ponds and water-supply reservoirs on condition of preserving the quality and degree of meeting the demands for water
- power must be clarified absolutely clearly among flood protection entities
- to continue to increase the degree of security of the interconnection and functionality of information systems between all the units operating in the flood protection system
- to hold regular flood exercises and training of participants in flood protection, to utilize the conclusions thereof for further improvement of activities in this area, to limit the accumulation of functions of flood protection participants that leads to limitation of the expeditiousness of the activities
- to transfer the system of security survey and supervision at significant dams also on the level of smaller hydraulic structures, to address the verification of the capacity of their outlet structures after a flood and to carry out renovations (if needed) leading to the capacity and safety of hydraulic structures after a flood being increased
- to work on improving the long-range meteorological and hydrological forecast, to seek methods for improving forecasts of discharges with the aim of timely preparation of the flood control authorities

- to continue building further gauging stations with automatic measuring and transmission according to the needs of flood service participants, to make use of the internet, mobile services and other modern information means

A number of institutions and special-purpose bodies became involved in the flood control system in the course of the flood – flood control authorities of municipalities, of municipalities with extended competence, of regions; workers of ministries, basin administrators, administrators of water courses, owners of hydraulic structures, the Czech Hydrometeorological Institute, the Fire and Rescue Brigade, the Police of the Czech Republic, the Army of the Czech Republic. Based on this broad, well-thought-out co-operation, the goal-directed and universal transfer of current information was secured, and security activities being carried out were directed to particular places. This led to the negative consequences of the flood being markedly restricted and to the flood damage in the territory of our state and the neighbouring state being reduced. The transformation of the flood in individual reservoirs and the systematic control of flow from them was, in the case of a flood of such an extent, a significant element in the flood protection system.

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APPENDIX 2

CASE STUDY

THE KITAKAMI RIVER IN JAPAN

APPENDIX 2

CASE STUDY

THE KITAKAMI RIVER IN JAPAN

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

PAGE

No. **Title**

LIST OF FIGURES

PAGE

No. **Title**

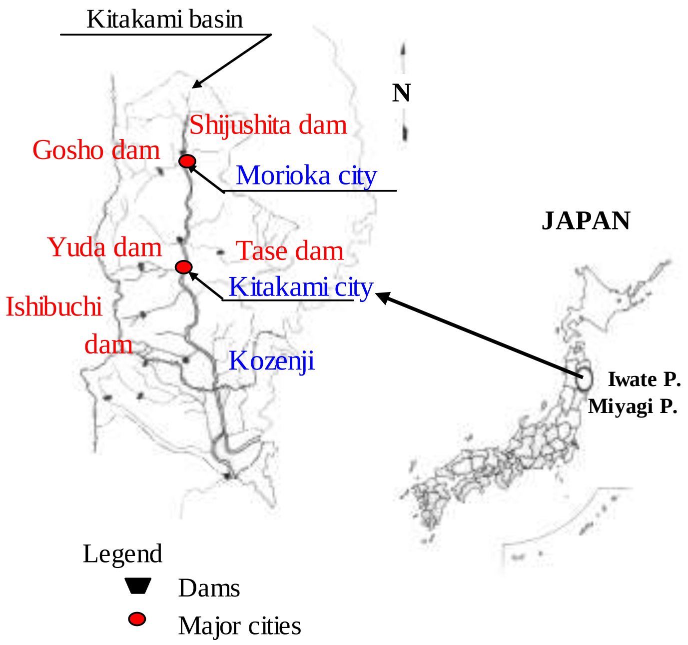
1 INTRODUCTION, CHARACTERISTICS OF KITAKAMI RIVER BASIN

1.1 Topographic features

The Kitakami River has its source in the Kitakami mountain of Iwate Prefecture in the northern part of Japan. The river runs from north to south through central Iwate Prefecture and flows from Kozenji through a narrow gorge into a plain in Miyagi Prefecture as shown in Figure 1. The Kitakami River is the largest river in the Tohoku Region, measuring 249 km in length and 10,150 km^2 in its river basin area.

The river basin extends from north to south in an almost rectangular shape. The tributaries of various sizes form an extended alluvial fan where they emerge from steep highland areas onto the plain. The river basin is rich in green plants. Mountain forests and uncultivated land occupy 56.5% of the basin and when this is combined with cultivated fields and pastures, 77.5% of the basin is covered with rich vegetation.

Figure 2~~21~~ **Kitakami River Basin**

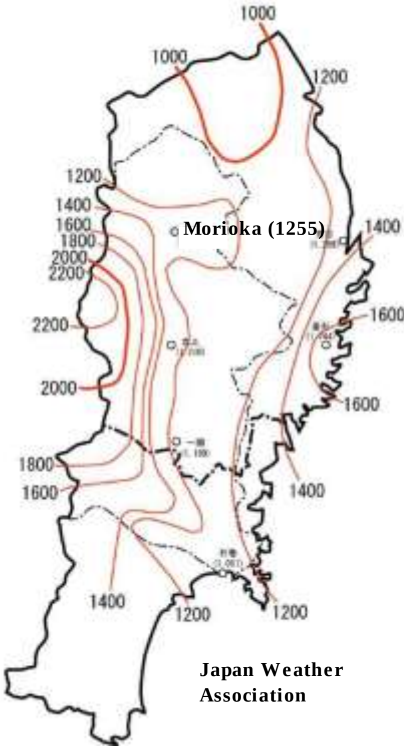


1.2 Climate

The Kitakami River Basin has an inland or basin climate in which the diurnal range as well as the annual temperature range are quite wide. On the other hand, at the foot of the western mountain range, there is a snowy climate typical of areas near the Sea of Japan. The lower river basin in Miyagi Prefecture has an oceanic climate, cooler in summer and warmer in winter than the upstream basin.

The precipitation feature in the basin is shown as the mean annual precipitation in Figure 2, indicating that the mountain area is subject to much precipitation.

Figure 3~~32~~ **Contour of mean annual precipitation in Kitakami Basin**



Japan Weather Association

(Data of1976-2002, mm/year)

1.3 Economic Features

The economic activities in Iwate prefecture and Miyagi prefecture concentrate much in the Kitakami river basin. Such figure is intensively predominant in Iwate prefecture.

The basin in Iwate Prefecture occupies 52% of the total prefectural land area, where seven cities including Morioka City, 18 towns and seven villages are located. In this key center of commerce, 71% of the total prefectural population, 82% of the total prefectural shipment of products, and 84% of the annual prefectural sales are concentrated. The basin in Miyagi Prefecture occupies 35% of the total prefectural land area, where two cities including Ishinomaki City, 27 towns and one village are located. 24% of the total prefectural population, 28% of the total prefectural shipment of products, and 5% of the annual prefectural sales are concentrated in this area.

2 FLOOD PROBLEMS

Table 1 indicates that many floods have occurred along the Kitakami River and have caused enormous damage. Among all, as Table 2 shows, the Catherine Typhoon in September 1947 and the Ayion Typhoon in September 1948 had a devastating impact on the people and economy of the Tohoku Region (Northern part of Japan). At that time, flood control projects including the five major dams were launched to reduce the danger from flooding in the region.

Table 3~~31~~ **Historical major Floods in Kitakami River**

Year of incident	Cause	2 Days precipitation in mm		Observed discharge in m^3/s		Maximum Water depth in m				Note
		Upstream area of Meiji bridge*)	Upstream area of Kozenji	Meiji bridge	Kozenji	Meiji bridge	Asahi bridge	Sakuragi bridge	Kozenji	
1910	Typhoon	259	171	* 4,250	* 5,800	4.89		6.28	13.7	Maximimum record at upstrema area
1913	Typhoon	145	163	* 2,650	* 4,800	4.01		6.43	14.67	
1947	Typhoon	170	186	* 3,030	* 7,900	4.52	6.87	6.25	16.89	Catherine Typhoon
1948	Typhoon	107	159	* 1,940	* 5,700	3.54	5.52	6.36	14.89	Aion typhoon
1981	Typhoon	145	152	1,530	4,750	2.23	4.72	5.1	12.51	
1987	Frontogenesis	145	162	530	2,940	1.72	4.4	5.17	12.11	
2002	Typhoon	147	158	1,780	4,500	2.26	5.42	5.5	13.51	

*) Measured points are indicated in Figure 3

Table 4~~42~~ **Flood damages in Kitakami basin**

Strike of Typhoon	Number of the dead, the missing and the injured	Estimated Damages (M US$)
1947/9 (Catherin typhoon)	3659	683
1948/9 (Aion typhoon)	1203	933

3 ADOPTED FLOOD MANAGEMENT SOLUTION

The Kitakami River flood control project is planned to reduce the estimated flood peak flow volume at Kozenji, located in the middle part of the river, of 13,000 m^3/s to the design flood discharge of 8,500 m^3/s by regulating 2,600 m^3/s at the group of upstream dams and 1,900 m^3/s at the Ichinoseki Retarding Basin. The five major dams take a big part in this program. This idea is illustrated in Figure 3. The features of the fives dams for the flood mitigation in the Kitakami River are tabulated in Table 3.

Figure 4~~43~~ **River control program in Kitakami River (unit: m^3/sec)**

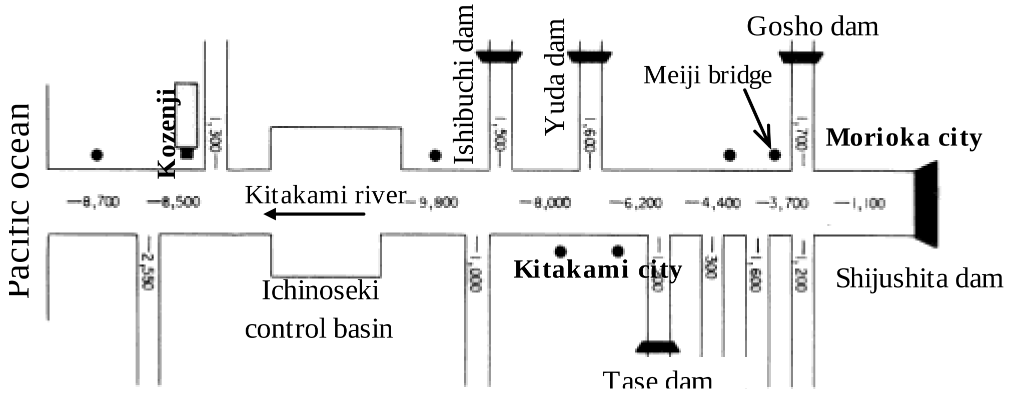


Table 5~~53~~ **Features of five major dams in Kitakami basin**

Name of dams		Ishibuchi	Tase	Yuda	Shijushita	Gosho
Basin		Kitakami	Kitakami	Kitakami	Kitakami	Kitakami
Name of rivers		Izawa	Sarugaishi	Toga	Kitagami	Shizukuishi
Dam type		CFRD	PG	VA	PG/TE	PG/ER
Drainage area	(km^2)	154	740	583	1196	635
Height of dams	(m)	53	81.5	89.5	50	52.5
Crest length	(m)	345	320	264.9	480	327
Dam volume	(m^3)	411300	420000	379900	PG: 29000 TE: 92150	PG: 220000 ER: 980000
Reservoir area	(km^2)	1.1	6	6.3	3.9	6.4
Total storage volume	MCM	16.15	146.5	114.16	47.1	65
Capacity of flood control	MCM	5.6	84.5	77.81	33.9	40
Design discharge	m^3/s	1200	2700	2200	1350	2450
Regulation discharge	m^3/s	300	2200	1800	650	1250
Power generation	MW	14.6	27	(1) 37.6 (2) 15.5	15.1	13
Year of Completion		1953	1954	1964	1968	1981

4 OBSERVATION OF THE ACTUAL OPERATION OF THE SOLUTION

4.1 Benefits on the September 1947 flood – Virtual case

The benefits of the five dams were evaluated on the assumption that the Catherine Typhoon of September 1947, which caused the worst flooding, occurred under current conditions of asset distribution and levee placement.

By comparing scenarios in Iwate Prefecture with and without the five dams, the damage reduction was estimated at approximately 2,900 ha of the area inundated, 4,800 houses flooded and total damage amount to 500 billion yen (4.1 billion US$) (Figure 4 and Figure 5).

In the case of Morioka City (Figure 5), the capital city of Iwate Prefecture, the damage reduction was estimated at roughly 150 ha of the area inundated, 1,700 houses flooded and total damage amount to 110 billion yen (0.9 billion US$), where it is estimated that two flood control dams (Shijushida Dam and Gosho Dam) could lower the peak water level by about 100 cm at the point of Meiji Bridge in Morioka City in the main Kitakami River (Figure 4).

Figure 5~~54~~ **Area Inundated in Morioka City with and without 5 dams on the September 1947 typhoon**

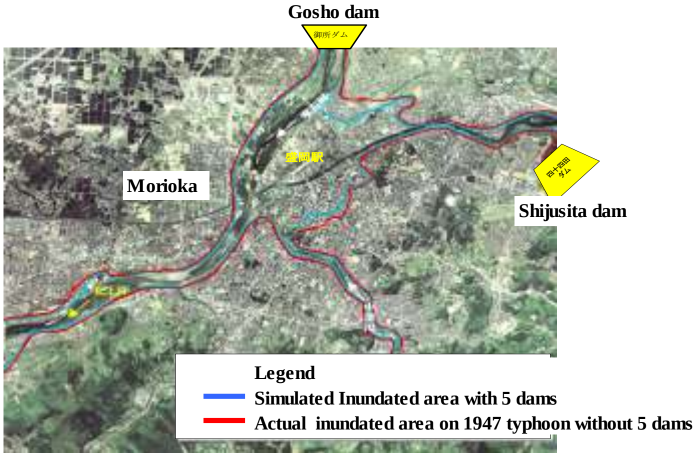
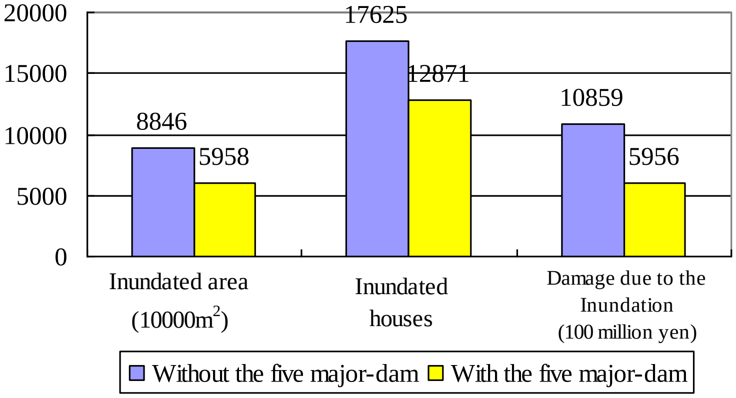
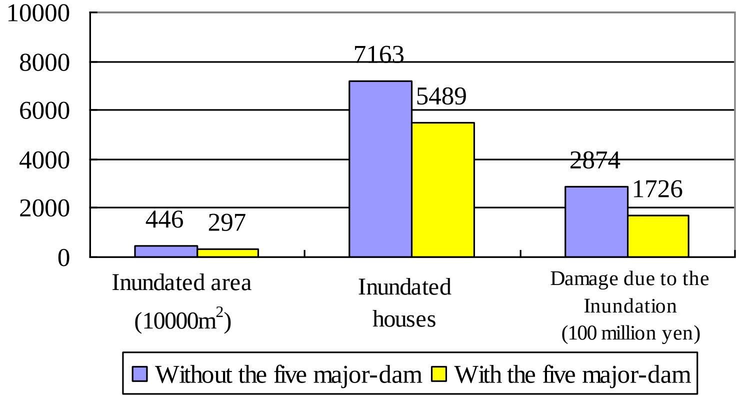


Figure 6~~65~~ **Damage due to the typhoon on Sep. 1947**



a) **Iwate prefecture**



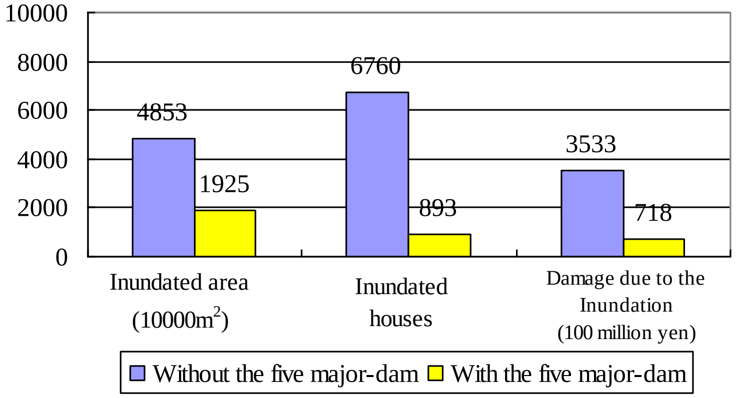
b) **Morioka city**

4.2 Benefits on the July 2002 flood – Actual case

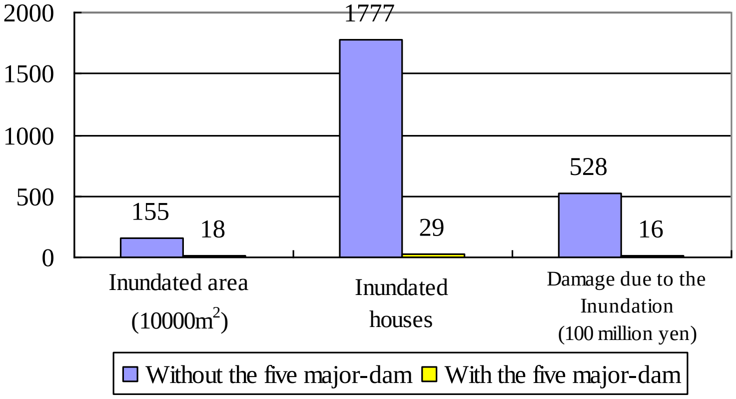
As a result of torrential rain brought about in July 2002 by Typhoon No. 6, major gauging stations located in the upstream area of the Kitakami River recorded that the water level had risen above the warning stage. When a comparison was made of flooding in Iwate Prefecture with and without the five dams, the damage reduction was estimated at roughly 2,900 ha of the area inundated, 5,900 houses flooded and total damage amount to 280 billion yen (2.3 billion US$) (Figure 6 and Figure 7). For Morioka City, the damage reduction was estimated at roughly 140 ha inundated, 1,700 houses flooded and total damage amount to 50 billion yen (0.4billion US$) (Figure 6), where it is estimated that flood control at two dams (Shijushida Dam and Gosho Dam) had lowered the peak water level by about 140cm at the point of Meiji Bridge in the main Kitakami River (Figure 7 and Figure 8).

In this situation, it is estimated that flood control at four dams (Shijushida, Gosho, Tase and Yuda Dams) had lowered the peak water level by about 50 cm at the point of Sakuragi Bridge (Mizusawa City) in the main Kitakami River. Without dam-aided flood mitigation, as Figure 9 indicates, the Mizusawa industrial complex located downstream from Sakuragi Bridge would be expected to suffer from more extensive inundation.

Figure 7~~76~~ **Damage due to the Typhoon on July 2002**



a) **Iwate prefecture**



b) **Morioka city**

Figure 8~~87~~ **Inundation at Moriaka City in July 2002 Flood**

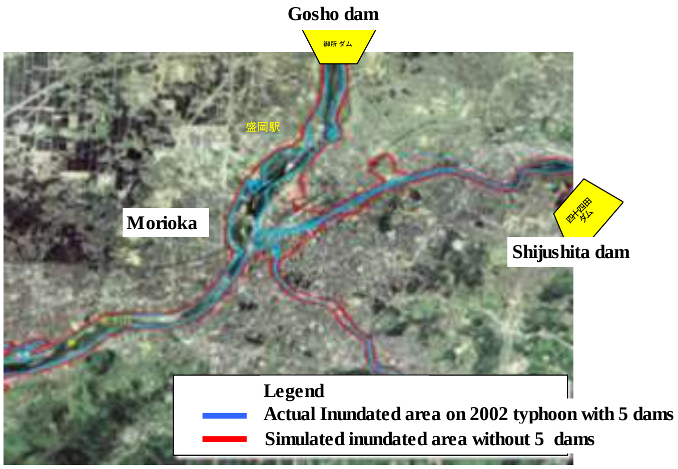
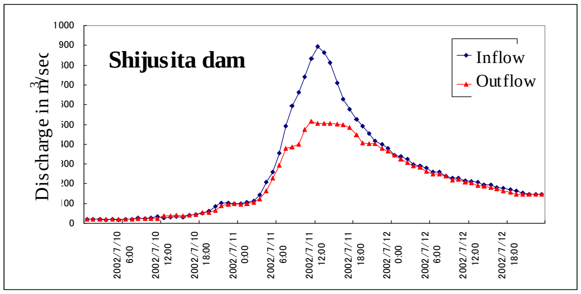
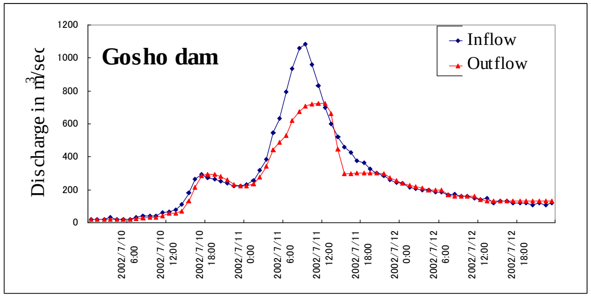


Figure 9~~98~~ **Flood control records in July 2002 Flood**

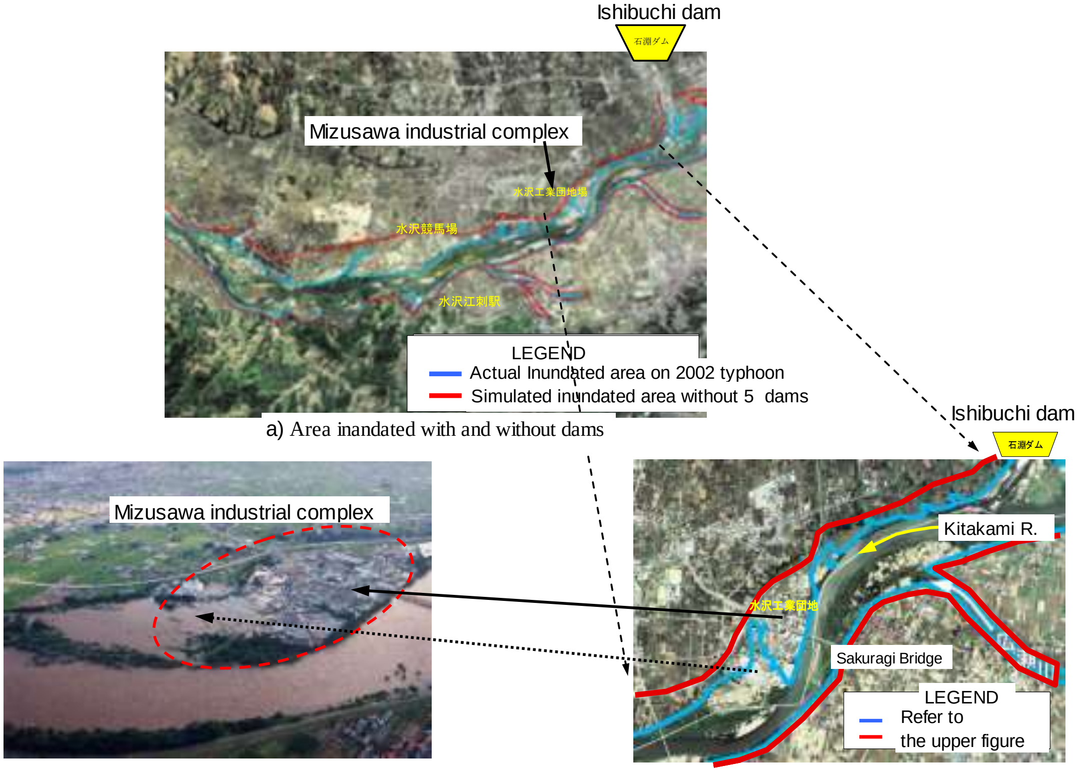


a) Shijushita dam



b) Gosho dam

Figure 10~~109~~ **Inundated situation of Mizusawa industrial complex**



a) Area inandated with and without dams

b) Picture of damages due to the flood

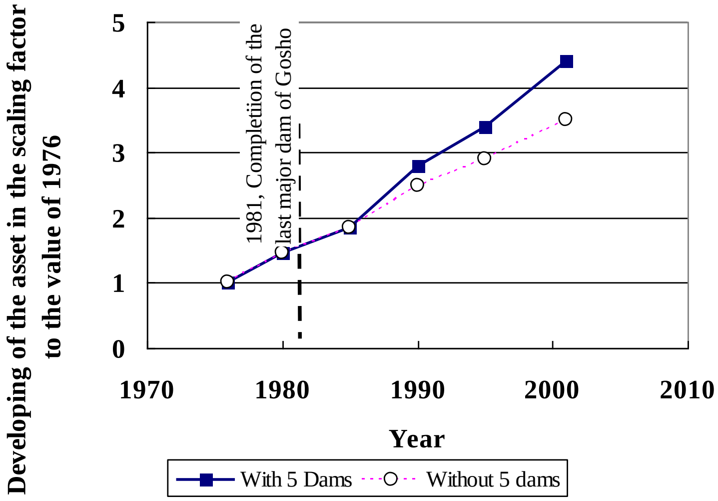
c) Detaild situation

4.3 Trend of asset distribution in the basin

Flood control by the five major dams prevents and mitigates flood damage, which contributes to population growth by enhancing regional safety and by promoting effective land use.

In this section, a comparison is made between an inundation area which does not yet have the benefit of flood control facilities including the five major dams against design flood and a non-inundation area which was created after all by the five flood control dams. The focus here is placed on how asset distribution has changed in the non-inundation area thanks to the development created by the five major dams. The area supported by the five major dams has steadily increased the value of its assets, as shown in Figure 10. The value in 2001 increased nearly 4.3 times from 1976. The growth rate of assets is particularly remarkable after the completion of the Gosho Dam in 1981.

Figure 11~~1110~~ **Developing in Property in Kitakami basin**



4.4 Advanced Land Utilization Associated with the Improvement in Flood Control

To clarify how land use has changed after the completion of the five major dams in the Kitakami River, areas inundated by the Catherine Typhoon in September 1947, Typhoon No. 15 in August 1981 and Typhoon No. 6 in July 2002 were compared with lands near Morioka as of 1970 and 2000. In areas where flooding is considered to have been reduced as a result of dam-aided flood control and river channel, urban development projects have been launched and have promoted advanced land use.

5 CONCLUSIONS

As stated earlier, in order for Japan to maintain its economic development in a monsoon alluvial zone, there is no choice other than to make an intensive use of flood plains. As its foundation, the assured safety of flood control through the construction of dams and river channel improvement is inevitable. The fact that many cities have grown up along the Kitakami River where viable economic activities are being carried out gives a good example of the quantifiable benefits of dams on flood control.

APPENDIX 3

CASE STUDY

THE AL WAHDA DAM IN MOROCCO

APPENDIX 3

CASE STUDY

THE AL WAHDA DAM IN MOROCCO

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

PAGE

No. **Title**

LIST OF FIGURES

PAGE

No. **Title**

1 INTRODUCTION

The catchment of the River Sebou in Morocco drains the south slope of the Rif Mountains and the North West slopes of the Middle Atlas. These mountains surround the Rharb-Plain, in the shape of an amphitheater, opening towards the Atlantic Ocean. The height differences in the two mountains ranges have a remarkable influence on the discharges pattern of the rivers.

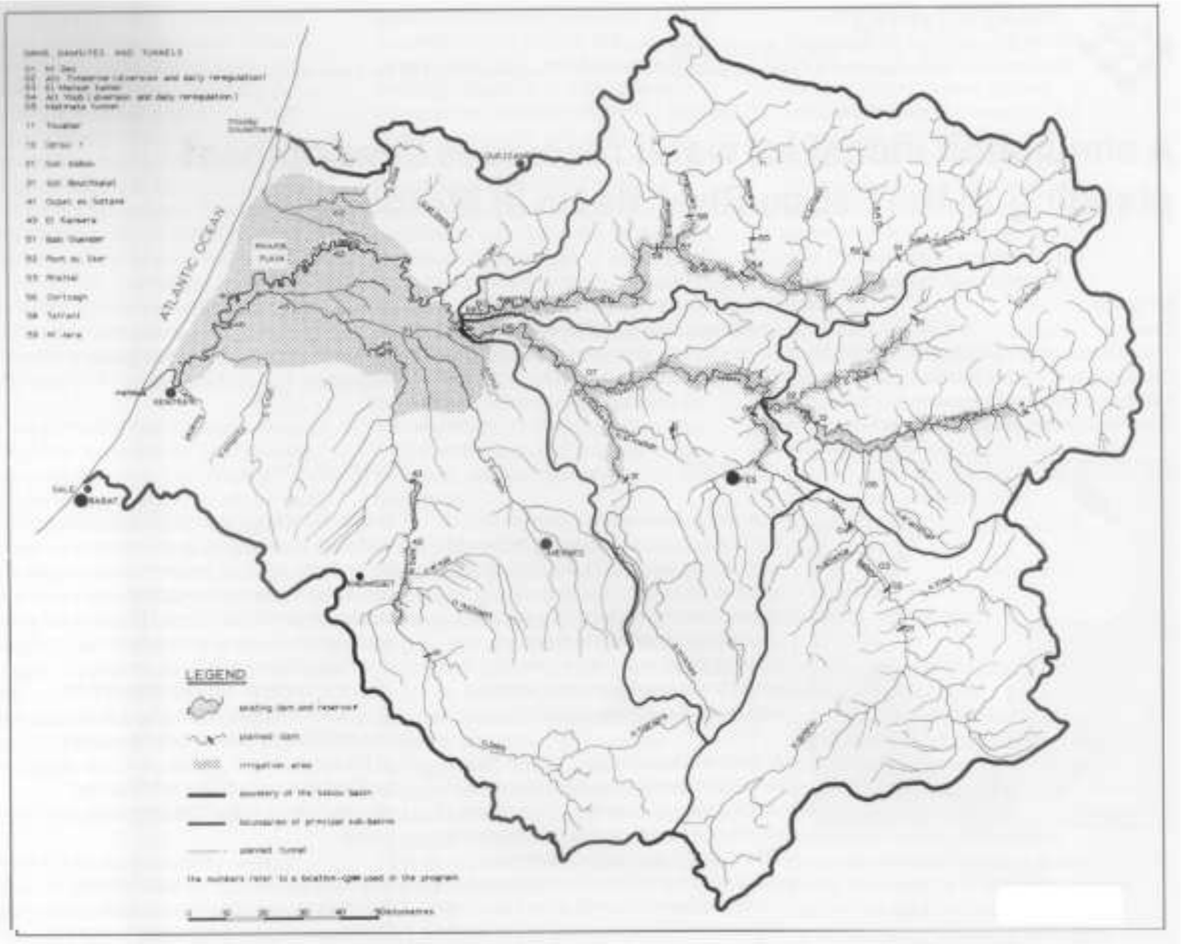


Figure 12 - Sebou river basin in Morocco

It is in fact the slopes and large precipitation figures which have made a torrential region of the Rif Mountains. Consequently, the floods originating from this region regularly in the past were causing inundations in the Rharb Plain as the Lower Sebou River was spilling over its banks during the flood period thus causing damages to agriculture, infrastructure etc.

This river, which meanders through the Plain, serves as a means of transport for the greater part of the runoff from the catchment. These water masses enter the Rharb Plain on the East side, at the confluence of the main tributaries Ouerrha and Middle Sebou, which from then form the Lower Sebou. The water volumes arriving here, flow to the sea through this Lower Sebou.

2 THE FLOOD PROBLEM

2.1 Flood Magnitudes

The flood volumes passing the confluence used to vary between half and six billion cubic metres (0.5 to 6 km^3), and the area inundated by bank overspills from these floods could be as large as 200,000 ha. During the period 1933 – 1983 (i.e. during 51 years) not less than 43 floods occurred which, altogether caused bank overspills in the order of 13.5 billion m^3.

The water left the river at the lowest spots in the banks; these spots having been created in the course of time. Then, the overspilled water flowed across the Plain and re-entered into the Lower Sebou North of the town of Kénitra. The narrow outlet of the Plain towards the sea precluded however the easy discharge of the overspilled water masses and as a result the region immediately north of Kénitra would stay underwater during a long time.

The flood of January 1970 which in magnitude exceeded all those known until that date and which caused considerable damage both to the agriculture and to the socio-economic infra- structure of the Plain, led the Government of Morocco to initiate a study for flood control measures in the Rharb plain.

2.2 Observed damages

Though, as stated above, 43 floods causing inundations have been observed during a period of some 50 years[10], observations of damages were only available to the study team for the more recent floods, i.e those of 1963, 1969, 1970 and 1971.

In order to make a systematic approximation of the damages possible, a distinction was made between five essentially different categories of damages:

a) agricultural damages: these are the damages caused to the agriculture and stock-farming and the damages as a result of shifting bank lines;
b) social damages:. the damages caused to housing, furniture and household utensils, family stocks of cereals and the various social facilities;
c) damages to the infrastructure: the damages to the rail way system, to the Port of Kénitra and to the road system;
d) damages to the irrigation equipment: damages to the irrigation and drainage system, to the levelling of the land, to agricultural service equipment, to the electricity and telecommunications system, etc.;
e) miscellaneous damages: this is the non-agricultural value added which is lost as a result of the floods and which cannot either be compensated or recovered later.

The analysis of the damages in the different categories was carried out using a certain number of data, the most important of which were the charts of the floods in the four years mentioned above. These charts showed the duration of the floodings. This was particularly important for the agricultural damages which, to a large extent were determined by the duration of the flooding. Through the introduction of a model of the plain in which the inundation was simulated, it was ultimately possible to establish relationships

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[10] In some of these years more than one flood occurred causing inundations

between, on the one hand, the volume of bank overspill in the plain for a historical flood and, on the other, the damages for each of the five categories.

2.3 Relation to land use (past, present and future)

The Moroccan Government is developing the fertile Rharb plain in phases by irrigating ultimately 212,000 ha of the land. The first phase of irrigation development, covering 43,000 ha, was part of an area irrigated by the waters of the river Sebou, which are controlled by the Idriss I dam constructed on one of its tributaries, the river Inaouoène. The first irrigated sector came into operation in 1972.

This project was studied between 1963 and 1968 by an F.A.0. - Moroccan Government Mission called the “Sebou Project”. For the first phase of development, the costs of flood control were not considered to be economically justified. Such flood control would, anyhow, be provided in part by the third main dam and reservoir in the catchment, the M’Jara dam, (now called Al Wahda dam) which ultimately would be constructed on the River Ouerrha during following phases of the irrigation development.

During the study for flood control measures, initiated after the flood of 1970, it was established that the future land use (i.e irrigated crops made possible by irrigation infrastructure) would result in a considerable increase in damages during floods. Therefore, the damage curves, established on the basis of historical floods and bearing on the situation ‘without irrigation project’ were further developed in order to reflect the damage in certain future reference years when the irrigation would have been implemented to a lesser or greater degree. This would, f.i., mean that, if a flood of the known type 1970 would occur the damage in the reference year 1976 would be known (Figure 2).

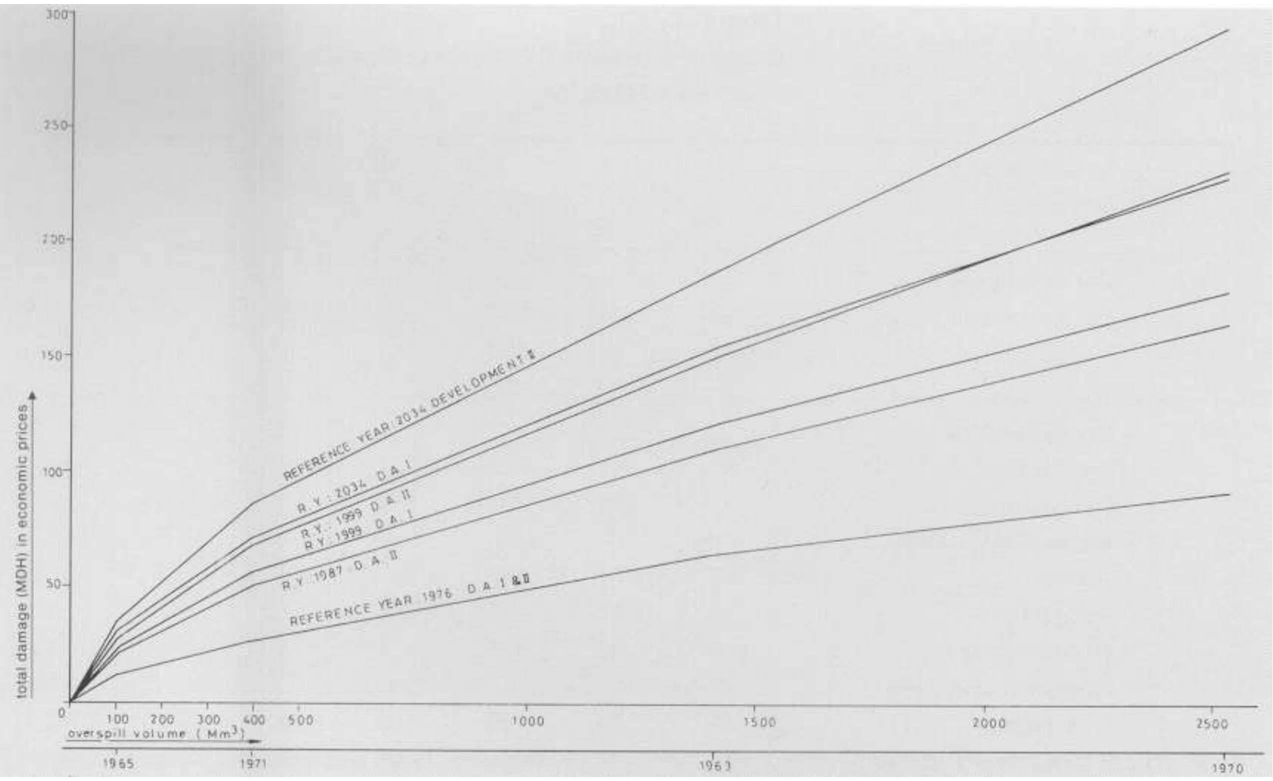

Figure 13 - Damage curves for selected reference years as a function of bank overspill

2.4 Environmental impacts

As will be seen in Chapter 3, during the early seventies comprehensive studies were made about the flooding problem and how it could be solved. At that time, however, a study on environmental impacts was not yet standard. In fact only some 15 years later, when the irrigation works in the Rharb Plain were already quite advanced a study was made about the environmental impact of the multipupose M'Jara dam which would largely solve the flooding problem in the Rharb Plain (NEDECO et al, 1991). This comprehensive report 'Etude d'impact du barrage M'Jara sur l'environnement, juin 1991' does, however, not discuss the environmental impacts of the earlier floodings in the Rharb Plain.

3 THE ADOPTED FLOOD MANAGEMENT SOLUTION

3.1 Short discussion of possible solutions

The flood control study, initiated by the Government of Morocco in 1971, was carried out in two phases during a period of 3 years[11].

During the first phase (Mission 1) of the Study it was investigated which measures could be taken against inundations, what would be their cost and their effectiveness (the avoided damages). In order to quantify the two parameters costs and benefits, studies were made of the various aspects of the inundation phenomenon, always taking into account as well the situation without protection as that with protection against flooding.

During the second phase (Mission 2) of the Study three possible flood protection schemes, formulated during Mission 1, were studied on feasibility level. Each of these three flood protection schemes consists of a number of protection elements which in turn are composed of civil engineering works (channels, embankments, spillways, weirs, dams, etc.). The schemes and their main elements are as follows:

<u>Scheme-I</u>

- Immediate flood protection of the first irrigation sectors by means of flood embankments;
- M'Jara (now Al Wahda) dam, to be studied for various reservoir volumes and completion dates;
- Embankment of the Lower Sebou.

<u>Scheme-II</u>

- Immediate flood protection as defined above;
- Diversion channel (by-pass), having a limited discharge capacity, on the left bank of the Lower Sebou;
- M'Jara dam (volume 1500 hm^3) for irrigation purposes only.

<u>Scheme-III</u>

- Immediate flood protection as defined above;
- Diversion channel (by-pass), with a large discharge capacity and cutting through the strip of dunes to the Atlantic Ocean;

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[11] See NEDECO (1973) and NEDECO (1975)

It is noted that the M'Jara dam and reservoir sized for satisfying the irrigation needs of the agricultural development works for the Rharb plain (M'Jara dam and reservoir having a volume of 1500 hm^3) in fact could be considered as a given situation for schemes I and II.

Apart from the Immediate flood protection, which was in fact an intermediate measure protecting only the first phase of the planned irrigation development (43,000 HA), all schemes had two flood control principles in common:

- **storage** by means of enlarging the planned reservoir behind the M'Jara dam; <u>and</u>
- **increased discharge capacity** of the downstream river system by, either, creating diversion (bypass) channels or by constructing flood embankments along the Lower Sebou.

In this particular case only the combination of storage and increased discharge capacity would result in an optimum protection against floods: 90 to 95 % of the original bank overspills would be annihilated while simulations learnt that from the 43 floods causing flooding during the period 1933 – 1983 only the three largest ones would still cause (considerably reduced) inundations.

3.2 The adopted solution and the philosophy behind it

In the years following the aforementioned flood control studies it was ultimately decided to skip most of the Immediate Protection as well as the flood embankments along the Lower Sebou but create instead a much larger reservoir behind M'Jara dam than originally planned[12].
Al Wahda dam is a multipurpose dam which, apart from water for irrigation (its original single purpose) now also can supply drinking and industrial water, electricity and control most of the floods originating from the river Ouerrha. As such the dam has provided no doubt the most beneficial solution in terms of flood control economics for the Rharb plain but it cannot control all floods. This is partly due to the shape and the enormous size of the floods[13] which require storage as well as discharge capacity for exercising (nearly complete) control. Moreover, floods originate also for a part from the river Haut Sebou and from some less important tributaries downstream of Al Wahda dam.
In terms of storage capacity: Even with a flood storage in the order of 2,750 hm^3 a certain discharge during floods is still required because the highest flood on record (1970) had a volume 4,039 hm^3 at M'Jara site.

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[12] In the first designs (EdF (1966)) the reservoir had a volume of 1500 hm^3 and its purpose was solely irrigation. But it was already contemplated at that time: (a) to share part (400 hm^3) of the irrigation storage (1,100 hm^3) with that for flood control, (b) to add another 510 hm^3 below full supply level for flood control and, finally, (c) to take into account a flood surcharge of 570 hm^3. Thus an overall flood storage of 1,680 hm^3 was created. After the flood of 1970 studies were made (Sofrelec et al (1970) and NEDECO (1975) which increased the flood storage to 2,080 hm^3 and the overall storage of the reservoir to 3,050 hm^3. Finally, it is worthwhile to know that Al Wahda dam, as completed in 1996, can store 3,730 hm^3.
Power generation was foreseen in all alternatives to a lesser or greater extent.

[13] See figure 3-1 in Chapter 3 of main text.

3.3 Description of the solution

3.3.1 Physical structures

The 88 m-high AI Wahda embankment dam on the Ouerrha River, a tributary of the Sebou River, was commissioned in 1996[14].

AI Wahda, 60 km from the town of Fes, comprises a zoned earthfill dam and a 30 m-high saddle dyke, separated by a block comprising reinforced concrete ancillary works. The dam is 2600 m long (including the saddle dyke), has a volume of 26.4 x 10^6 m^3, and impounds a reservoir with a storage capacity of 3.73 km^3. Jointly owned by the Water Board of the Ministry of Public Works and the National Electricity Bureau of the Ministry for Power Generation, it is Morocco's largest dam, and the second largest in Africa after High Aswan dam in Egypt.

The ancillary works comprise:

- a spillway equipped with six radial gates, designed to reduce the design flood of 20, 000 m^3/s down to 13 300 m^3/s at high water level;
- intake works and a tunnel;
- a bottom outlet; and,
- a powerplant housing three 82.5 MW Francis units, with a rated discharge of 150 m^3/s, which will operate under a head of 62 m, at 143 rpm.

The main objectives of the multi- purpose AI Wahda scheme are:

- protection of the Rharb plain from severe flooding;
- provision of about 1100 h m^3 of water per year for the irrigation of about 100,000 ha in the Rharb plain and lower Ouerrha valley;
- the production of 400 GWh/year of electricity; and,
- the transfer of more than 600 hm^3 of water to southern Morocco, where severe water shortages are predicted for the future, particularly in the greater urban district of Casablanca.

3.3.2 Operating mode

Because of its multipurpose function the mode of operation has to follow certain rules in order to satisfy the different objectives (Section 3.3.1) as much as possible. Moreover, Al Wahda dam must be operated jointly with various other dams and tunnels in the Sebou basin. The operation is carried out using a simulation model comprising all these structures[15].

The operation mode of Al Wahda dam is governed, on the one hand, by discharges and spillings taking into account (a) water requirements of various users, (b) release from other dams and (c) discharge capacity of the Lower Sebou and, on the other, by storage following from pool and rule curves as shown in Figure 3. It is in particular the seasonal variation during the year of the

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[14] See HP&D (1997)

[15] See Sbihi et al (1978).

volume of the pools reserved for flood storage and irrigation which enables an efficient operation to the benefit of all parties[16].

The power pool below the power curve is reserved for peak power generation during the winter months (in dry years used in November and the first half of December). When the volume in storage fails below the hedging curve, irrigation supply is decreased by a predetermined amount (fixed run input). This assumes that distribution losses can be reduced when storages are below normal. Except during high floods the water volume is not allowed to rise above the flood control curve. The seasonally variable flood pool is reserved for flood control.

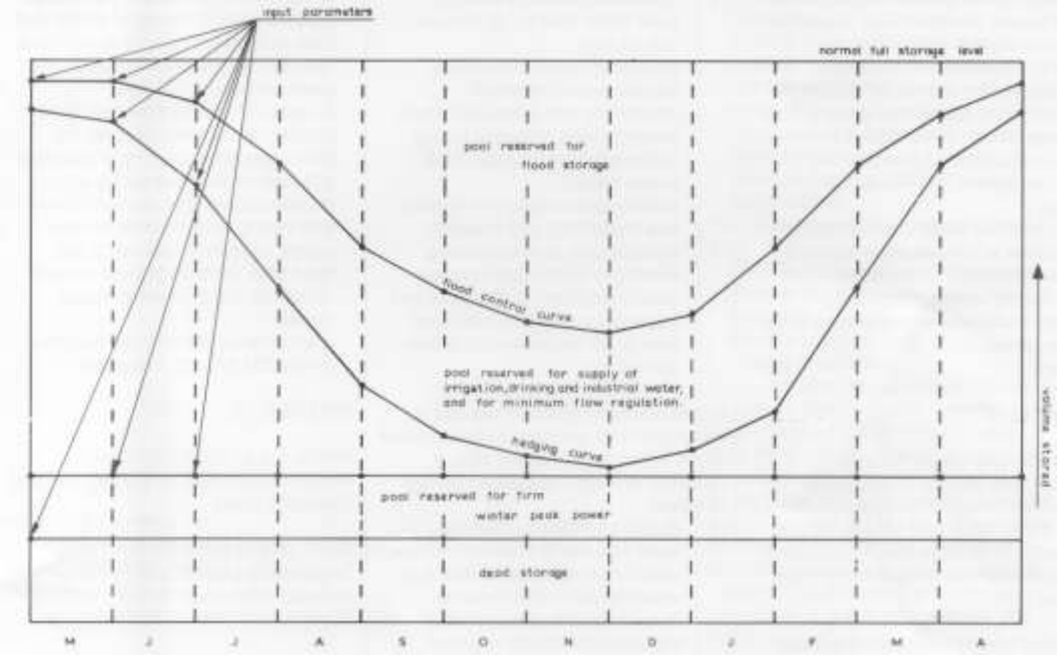

Figure 14 - Pools and rules curves

4 OBSERVATION OF ACTUAL OPERATION OF THE SOLUTION

Already within one year after its commissioning Al Wahda dam was able to prevent inundation of the Rharb plain. This is illustrated in Figure 4 and in Table 1.

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[16] See Sbihi et al (1976)

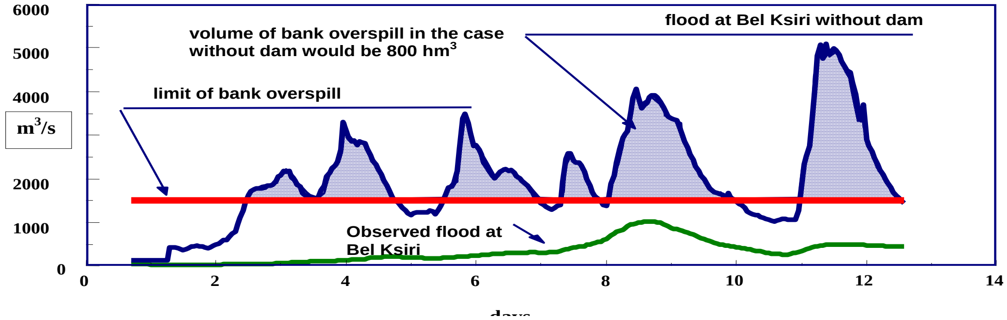

Figure 15 - Storage of the flood of December 1996 in the Al Wahda reservoir, Morocco (source: Benabdelfadel, 2003)

In Table 1 a comparison is made between the flood of 1995-1996 (without storage of flood waters in the Al Wahda reservoir) and the flood of 1996-1997 (with storage of flood waters in the reservoir).

Year	Peak discharge [m^3/s]	Flood volume [million m^3]	Volume of bank overspill [million m^3]	Area flooded [ha]
1995/1996	3700	3900	1450	150 000
1996/1997	5300	3500	17	6 000

Table 6 Flood regulation by Al Wahda dam[17]

5 CONCLUSION

According to a recent paper (Akalay et al, 2007), the flood control function of Al Wahda results in an average annual decrease in damages of 200 million Dirham (US$ 27 million). On average, bank overspills are reduced by more than 90 %.

From Figure 4 it follows that, apart from flood storage, a certain discharge capacity of the Lower Sebou is vital to reach this goal. There are however two reasons why the actual discharge capacity is lower than originally foreseen. First of all the planned flood embankments along the Lower Sebou which would enable a minimum discharge capacity of 2,200 m^3/s were never constructed[18]. This decision was prompted by the storage capacity of Al Wahda dam which is now much larger than originally foreseen. Still, a discharge capacity of the Lower Sebou between 1,500 and 2,000 m^3/s is considered desirable.

Now, during the flood control studies in the seventies the capacity at bankful stage (without flood embankments) was found to be in the order of 1600 to 1800 m^3/s. But this situation does not any longer exist. The weirs built in the Lower Sebou in the eighties to extract water for irrigation (by means of pumping) together with the uncontrolled sediment-rich lateral inflow from various tributaries downstream

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[17] Information received from the president of the Moroccan Committee on Large dams (CMGB).

[18] See NEDECO (1978)

of the large dams have led to local silting up of the river bed. In fact it would appear that, locally, the discharge capacity is now less than 1000 m^3/s[19]!

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[19] See NEDECO (1997)

APPENDIX 4

CASE STUDY

COORDINATED RESERVOIR OPERATION (VALAIS, SWITZERLAND)

APPENDIX 4

CASE STUDY

COORDINATED RESERVOIR OPERATION (VALAIS, SWITZERLAND)

TABLE OF CONTENTS

1 INTRODUCTION

Artificial reservoirs are in general operated independently from one another, especially if they are not located on the same river. During heavy floods, every operator seeks before all to protect its own installations. It conducts the operation within the limits fixed by its concession or its internal rules, without great consideration to the possible damages its decisions may cause downstream. However, if several schemes are in the same watershed, the addition of the consequences of independent decisions may prove detrimental to the safety of the common river stretch situated downstream of all reservoirs.

The upper Rhone valley, situated upstream of the lake Geneva (Switzerland) is characterized by a strongly alpine pattern. The river crosses the canton Valais like a backbone, draining numerous tributaries on both sides. Almost all main torrents have been harnessed by high dams and artificial reservoirs, allowing summer waters to be stored for the winter energy production. Initially these reservoirs served exclusively the production of electrical energy in high head power plants. A study has been carried out at the onset of the years 2000’s, which concludes to the real interest of coordinating their operation in the occurrence of a severe hydrological event. The ultimate goal is the reduction of the peak discharge and of the damages at critical plain locations.

2 SITUATION IN VALAIS

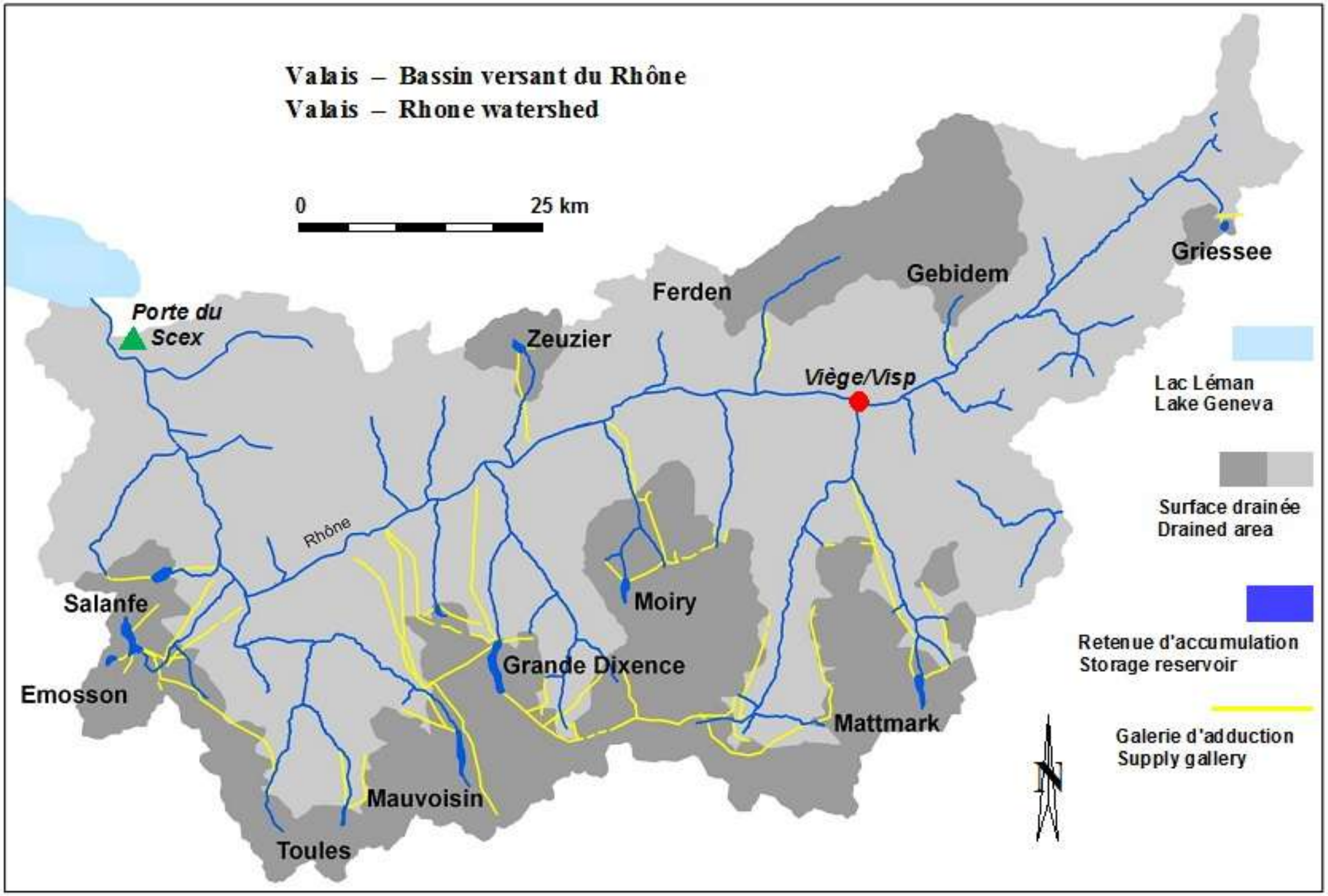
The Rhone watershed at its confluence in the Lake Geneva covers an area of over 5’000 km^2. The eleven most important artificial reservoirs of Valais form a total retention volume of 1’200 mio m^3, which controls 21% of the Rhone supply at the *Porte du Scex*, a reference section located nearby its confluence into Lake Geneva (see Figure 1). The reservoirs are on average filled up to ca. 94% at the beginning of the cold season. The prevailing meteorological conditions having evolved since their construction time, the large summer floods gave way to later events, which unfortunately occur just at the end of the filling period.

The mean discharge of the Rhone at *Porte du Scex* amounts to 180 m^3/s. The presence of artificial reservoirs has not changed this discharge but its variability, especially considering pronounced hydrological periods (floods, droughts). This figure may be compared with the total processing capacity of the eleven main schemes, which totals 350 m^3/s.

Three exceptional floods (in 1987, 1993 and 2000) caused important damages in the Rhone plain. Although the last two occurred as the reservoirs were full, theoretical reconstitutions showed that they could nevertheless damp the peak discharge of the Rhone by some 10 to 20%. The study also demonstrated that the additional flood limitation potential of these reservoirs is important.

A research program gathering the canton Valais, the Ecole Polytechnique Fédérale de Lausanne (EPFL) et the former Federal Office of Water and Geology (OFEG) was thus started, aiming at determining the influence of the coordinated operation of these reservoirs on the course of the floods downstream, as well as the conditions to fulfil for a successful implementation of these principles. The first results of this project (MINERVE) are very promising and show that it is possible to notably reduce the aggressiveness of a Rhone flood through a coordinated inflection of the operation of the main schemes without impairing the rights or the interests of their operators.

Figure 1 – The Rhone Watershed



3 THE MINERVE PROJECT

The MINERVE project (modelling of extreme events, of the Valais reservoirs and their effects) rests on the principle that it is economically preferable to adapt the operation of the existing reservoirs to reduce the magnitude of a flood downstream, rather than to invest to realize new flood protection reservoirs. For the operators, it is also less costly to follow this line than to leave a large free board in the reservoir for the flood management. The principle relies on an expert system working in real time and based on the most recent available hydrological data, integrating the weather forecasts and recalibrating the model on the reality at each calculation step.

The watershed is split into 239 partial catchments, with an average area of 23 km^2, and into 130 river sections. These elements cover an elevation range comprised between 372 and 4’634 m. Every partial catchment is divided into slices of 500 m of elevation, allowing on one hand the weather variables related to elevation (temperature, humidity) to be taken into account and on the other hand to model the ground conditions (glaciers, snow, ground cover, etc.). The hydrological reaction of each partial catchment is simulated (snow melt, percolation of precipitation, runoff, etc.), as well as the routing of the water coming from catchments located at higher elevation. Considering the spatial splitting (catchments and elevation slices), over 5’500 state variables and as many differential equations are to be solved simultaneously.

The reservoirs play a particular role, since they are the key components of the entire prevention system. Their filling grade must constantly be known, along with their operation conditions (pumping, turbining, water spilling, etc.). The decision variables serving to the optimisation of the reservoir management are the turbinated flows and the spilled discharges. It must be stressed that the priorities in the operation decisions, all aiming at keeping a temporary storage reserve allowing to master the floods, are the following:

- stop of water pumping into the reservoirs;
- closing of the water intakes;
- start of turbining;
- begin of spilling.

The hydraulic part of the management model relies on six basic hydraulic functions: the generation of discharges (hydrological models) – the separation of discharges (water intakes and reservoirs) – the transfer of discharges (routing) – the addition of discharges (confluence) – the storage of discharges (flood control) – the regulation of discharges (turbining, spilling, emptying).

The MINERVE project is oriented along five main lines:

- the administration of the project, which managed by the canton;
- the development of a communication system for the transfer of hydrological and meteorological data;
- the computer development of the numerical network simulation model;
- the weather forecast, which covers a duration of 72 hours; it is updated every 12 hours;

- the scientific development, which will mainly have to consider the refining of the model scale.

4 THE PREVENTIVE LOWERING OF THE WATER LEVEL IN THE RESERVOIRS

The preventive lowering of the water level through early turbining allows an additional reservoir volume to be created, which will be used when the flood occurs. The optimisation calculations, which lead to defining the best prevention strategies, must navigate between two major risks of errors, which are:

- the insufficient of late lowering of the water level in case of strong flood, leading to a too weak attenuation of the flood and to subsequent damages;
- the too strong lowering of the water level in the reservoirs in case of a weak flood, leading to a loss for the operators.

The schemes are treated individually by the management model, which allows for each scheme the optimal timing for beginning and end of the turbining period and the preventive emptying to be determined. To ensure the quality of the results and minimize the risks of errors, the quality of the weather forecasts is indeed crucial. The reliability of the spatial splitting and of the internal working rules of the expert system is no less.

For the management model, the problem consists thus in maximizing the water retention efficiency during the flood, and thus to preventively free the required storage room for this inflow. But the addition of a natural flow that has not reached its peak and of the turbining and preventive spilling discharges of the large schemes may simply lead to move the time of the peak flow in the Rhone without reducing it. An econometric objective function is thus considered, which expresses the total costs of the potential damages on the control stretches.

5 INFLUENCE OF THE COORDINATED RESERVOIR MANAGEMENT ON THE FLOODS

The mere presence of reservoirs and water diversions on streams plays a strongly moderating role on the flood violence. For instance, the amplitude of the floods at the confluence of the Vispa into the Rhone in Visp may be reduced by up to 52% thanks to the energy production schemes. In any case, even if the reservoirs are full and the power plants do not work, a significant reduction of the peak flow is observed.

Numerous simulations, taking into account a great quantity of different situations (temperature, precipitation, snow, filling grade of reservoirs, initial discharges in the rivers, among others), and aiming at optimising the preventive lowering of the main Valais reservoirs, have been carried out. The key results are the following :

- the most efficient protection obtained thanks to the preventive lowering of the reservoir level is reached for the middle size floods (return period of 50 to 100 years);
- a preventive emptying of the reservoirs through a turbining start 18 hours before the peak flow of the flood leads to a reduction by 15% of the peak flow of the Rhone at the reference station;

- combined with a preventive opening of the flood evacuation system, a preventive turbining leads even to a decrease by 21% of the maximal flood discharge in the Rhone;
- to guarantee a positive effect, the minimum time lapse to observe for the preventive lowering of the reservoirs before the occurrence of the peak flow amounts to twenty to thirty hours, depending if the flood evacuation system is activated or not;
- a simulation of the 1993 flood shows that if a preventive turbining had started 50 hours before the occurring of the flood, its peak (960 m^3/s) could have been reduced by 200 m^3/s, and even by 330 m^3/s if the bottom outlets had been opened. The relative reduction would have amounted to 27%, respectively to 34 %.

6 IMPLEMENTATION OF THE CONCEPT

Most of the reservoirs belong to different owners, who had to be convinced to accept the idea of abandoning part of their management prerogatives in case of a critical event. According to the Valais constitution, le canton must guarantee the safety of its citizens. A police order (turbining, emptying, operation stop) can thus become restricting. The operators of hydroelectric schemes have agreed to temporarily comply with an external authority (without compensation), in order to ensure the common good downstream of their installations.

A convention has been signed between the canton and the companies operating the schemes. According to this agreement, the canton carries the responsibility in case of wrong manoeuvre resulting from an erroneous cantonal order. All the operators contributed to the development of the model, by providing data. During the 2006 alert, some even performed preventive operations (stabilisation of water level) without formal police order.

The first experiences made since the implementation of MINERVE show that the model performs well and that the indicators have been correctly selected. The weather errors prove prominent; most critical point, the notion of reliability of the weather forecast must be integrated into the decision. Apart from this, the contribution of the model is paramount: it requires the comparison between forecast and observations to be performed continuously during a crisis situation. The rapid and reliable explanation of the origin of possible discrepancies become then the most important element in case of observed differences.

7 CONCLUSION

Not only the coordinated preventive lowering of artificial reservoirs in case of large floods is theoretically thinkable, it is even possible to practically implement it, as a study on the management of the alpine Rhone in Switzerland showed. An expert model allows individual strategies of reservoir management to be proposed during critical meteorological situation. These strategies lead to significant reductions of the peak flow and of the damages on the common river downstream of the reservoirs during large floods, while minimizing the risks of errors in case of small or middle size events.

Technically, the efficiency of the management model rests in particular on a detailed splitting of the watersheds, an excellent communication system of meteorological and hydrological data and the real time integration of weather forecasts covering the following 72 hours. On a broader scale, an important component of the success of such an endeavour resides in the proper integration of its political, legal and institutional aspects. The system implementation has received the agreement of all operators, whose federation for this project did not pose major problems. The first experiences gathered in real time are conclusive.

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APPENDIX 5

CASE STUDY

EXPERIENCE OF THE EXTREME FLOOD IN AUGUST 2002 IN SAXONY – EXPECTATIONS AND REALITY ABOUT THE ROLE OF DAMS FOR FLOOD CONTROL

APPENDIX 5

CASE STUDY

EXPERIENCE OF THE EXTREME FLOOD IN AUGUST 2002 IN SAXONY – EXPECTATIONS AND REALITY ABOUT THE ROLE OF DAMS FOR FLOOD CONTROL

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

PAGE

No. **Title**

LIST OF FIGURES

PAGE

No. **Title**

9 INTRODUCTION

The most dams fulfil different requirements of the society. Often several objectives have to be considered and ranked in their priorities. As the operation of dams belongs to the questions of public interest any modification of these priorities can result in conflicts between different user groups. One main problem of operation consists in the need to cope with uncertainties. The most important uncertainty results from the stochastic character of the hydrological conditions but also from socio-economic developments which affect the water demand as well as the boundary conditions of water supply are uncertain aspects of reservoir management planning. In Germany the conditions for reservoir management were changed in the last decades caused e.g. by (Schultz & Schumann, 2001):

- a general reduction of water demand due to decreasing population, water recycling, more efficient supply systems, reduced losses, water saving industries etc.,
- a trend towards more efficient larger water supply systems,
- changing perception of acceptable risk,
- new water demands, e.g. for recreation, improvement and rehabilitation of ecosystems
- raised water quality requirements, e.g. by the EU Water Framework Directive .

If the demand for water is changing, the weights of the different multiple objectives of reservoir operation could be shifted. However this is in many cases a complicated process affecting the economic bases of reservoir management. The shift from use to non-use values demand complex discussions between the water users and the administration responsible for the planning of reservoir operation. At a specific dam the demand for changes in operation will often be articulated if public perception becomes aware of a problem caused by a surplus of water (flood) or a water deficit (drought). As both phenomena have stochastic character it is difficult to explain that the control of the water balance and runoff cannot be ensured in such extreme situations completely. If the function of a reservoir seems to be unsatisfying for stakeholders reservoir operations become a subject of political influence. Hydrological extremes lead to public discussions and a general demand for changed operation or even new dams will be articulated.

In the following the behaviour of several reservoirs during an extreme flood in the year 2002 in Germany is discussed to demonstrate the differences between technical options of flood control and the public expectations about the flood control function of reservoirs. As a result of strong criticisms significant modifications of reservoir management were initiated. Under consideration of multiple functions of reservoirs any modifications of the operation could result in other water problems which will be discussed also.

10 THE FLOOD IN AUGUST 2002

The decade from 1993 to 2002 was characterized by a significant accumulation of flood events and damages in Germany. The total amount of damages summed up to 15 billion € (discounted for 2005). In August 2002 a extreme flood in East Germany caused a damage of 9.2 billion € damage. Damages of more than 6 Billion € were located in the federal state of Saxony. This federal state is represented by more than 30 dams and flood control reservoirs with a total capacity of 397 Mio m³ within the ICOLD-Register of Dams. The storage capacity dedicated to flood control is 57 hm³. Most of this capacity is located at headwaters of the Ore Mountains. In the narrow valleys of this region the flood in August 2002 was extremely harmful. In the following a short description of the problems of flood control during this event will be given.

The flood in 2002 was the largest event since the beginning of regular hydrological observations in this region. In the first 13 days of August a specific meteorological situation caused extreme rainfalls in large parts of Austria, the Czech Republic, Slovakia and East Germany. In Saxony advective precipitation was connected with extreme intensive raincells. The main period of precipitation, which caused the flood event, was from 10th to 13th of August 2002. Due to the previous rainfall a high soil moisture content has been accumulated which resulted in high runoff coefficients during the following extreme precipitation. Compared with flood statistical assessments from 1999 the flood peak was in a range of a return period above 1.000 years, at some gauges also close to 10.000 years. During this extraordinary flood event at some dams gauging stations and spillways were damaged, but the dam safety was not affected. The tables 1 and 2 summarize some aspects of the behaviour of 12 selected reservoirs in the Ore Mountains in order to show the hydrological loads and the performance of reservoirs. Table 1 presents the effects on the flood volume, Table 2 on the flood peak of these reservoirs. As it can be seen from Table 1 the share of the flood volume which was stored by dams varied between 13 and 67 percent. The reduction of the flood peaks was between near zero (Klingenberg Dam) and 81 percent (Mordgrundbach Dam). To explain these differences some specific cases will be discussed.

Table 7 - Hydrological characteristics of the extreme flood in 2002 at dam sites in the Ore Mountains in relationship to the flood storage capacity of these reservoirs

Reservoir	Watershed Area (km^2)	Flood storage capacity as runoff height (mm)	Total rainfall in 72 hours (mm)	Total inflow (mm)	Runoff coefficient (corresponding to 72 h rainfall)	Maximum stored inflow volume (mm)	Ration flood storage capacity to inflow	Ratio actual flood storage to inflow
Eibenstock	199.8	28.9	214	84.1	0.393	46.3	0.35	0.55
Saidenbach	60.8	0.0	245	96.2	0.393	64.9	0	0.67
Lichtenberg	38.8	20,6	302	201.1	0.665	51.8	0.10	0.26
Lehnmuehle	60.4	34.1	349	234.0	0.671	92.3	0.15	0.39
Klingenberg	89.4	21.9	338	193.5	0.572	40.4	0.11	0.21
Malter	104.6	21.8	331	235.9	0.713	30.2	0.09	0.13
Gottleuba	35.3	56.7	282	160.6	0.569	79.5	0.35	0.49
Reinhardtsgrimma	8.4	45.7	340	178.9	0.526	46.3	0.26	0.26
Buschbach	27.4	87.6	237	179.1	0.754	95.3	0.49	0.53
Liebstadt	11.5	94.3	319	198.6	0.623	92.2	0.47	0.46
Friedrichswalde	26.9	56.4	275	129.9	0.473	58.3	0.43	0.45
Mordgrundbach	12.9	89.1	268	143.8	0.536	83.1	0.62	0.58

Table 8 - Retention of flood waves during the extreme flood in 2002 at dam sites in the Ore Mountains

Name of Reservoir	Watershed area (km^2)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Reduction (%of inflow)	Time shift - inflow and outflow peaks (hours)
Eibenstock	199.8	180.8	55.4	69.4	11
Saidenbach	60.8	71.9	36.5	49.2	5
Lichtenberg	38.8	53.2	45.0	15.4	2
Lehnmuehle	60.4	155.3	114.4	26.3	3
Klingenberg	89.4	170.0	167.7	1.4	1
Malter	104.6	228.1	222.0	2.7	0
Gottleuba	35.3	67.9	35.0	48.5	3
Reinhardtsgrimma	8.4	23.0	17.5	23.9	0
Buschbach	27.4	47.2	27.0	42.8	23
Liebstadt	11.5	36	20.3	43.6	11
Friedrichswalde	26.9	70.3	26.5	62.3	10
Mordgrundbach	12.9	25.1	4.7	81.2	(12)

The Eibenstock reservoir which is located in the western part of the Ore Mountains has been used very efficiently for flood control. The inflow and outflow relationships are shown in Fig.1. The normal flood storage capacity of this reservoir which is mainly used for freshwater supply was extended by an additional free storage which is normally preserved for water supply. The runoff over the spillway started nearly simultaneously with the peak of the inflow (see Fig. 1). The surcharge flood storage caused a flood peak reduction of 69 percent. In a total of 55 percent the flood volume could be stored to protect two cities located downstream of the reservoir. The positive effects on the flood were caused by favourable relationships between the volume of the flood and the retention capacity of the reservoir.

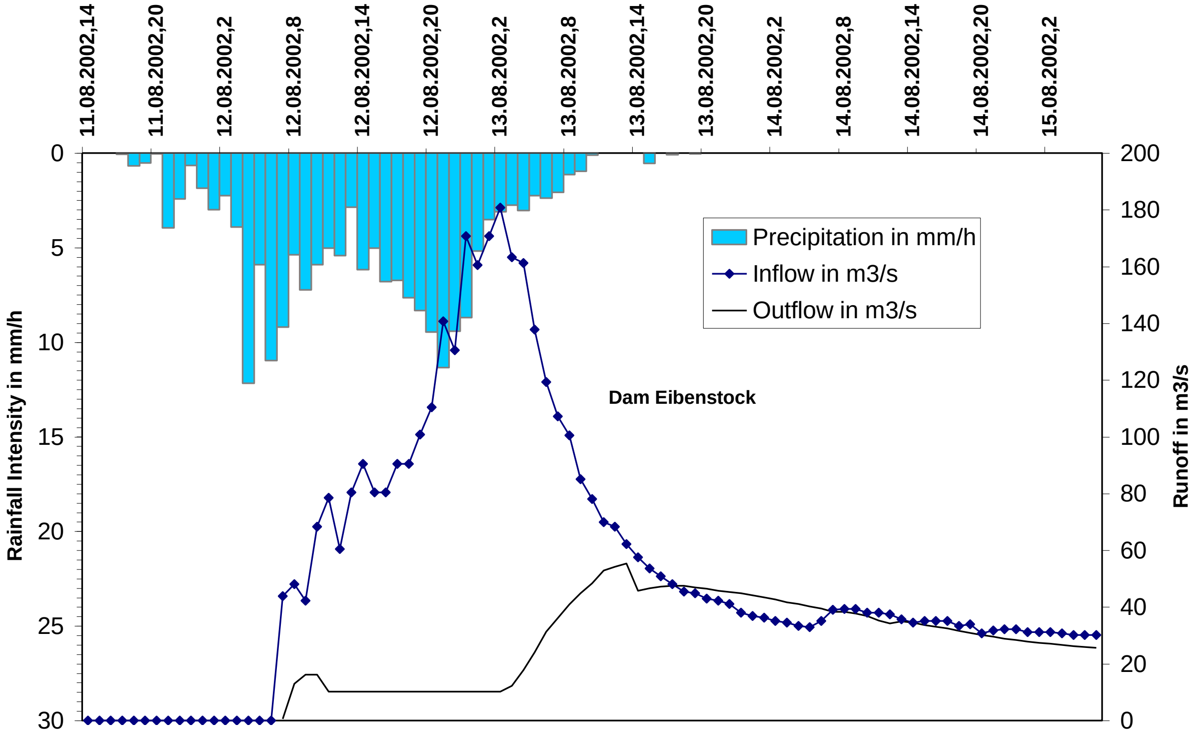

Figure 16 - Inflow and outflow of the Dam Eibenstock during the flood event in 2002

The relationships between flood volume and storage capacity especially of old reservoirs in the eastern part of the Ore Mountains caused more problems. As shown in Tab.1 and 2, Klingenberg and Malter reservoirs were not able to reduce the flood significantly. This can be explained by relatively small flood storage capacities which were below 10 percent of the inflow volume. As it can be seen from the example of the Malter Dam in Fig. 2 the flood storage was filled very early during the rising limb of the inflow wave. The two reservoirs had no significant effect on the flood peak. Downstream of the Klingenberg Dam and Malter Dam high damages were caused by this flood event. As a result the public discussion of the operation of both reservoirs started immediately. The criticisms were related to two points: The flood storage capacity of both reservoirs seemed to be too small and it was doubted that the operation of the reservoirs was appropriated to the situation. With regard to the first point it should be considered that the Klingenberg reservoir supplies the city of Dresden with freshwater. As the alternative bank infiltration system was flooded by the Elbe River the reservoir was used after the flood intensively for water supply. The normal storage content of the reservoir at the beginning of the flood event ensured that the section of water with a good quality was not completely mixed with the inflow. Thus the freshwater supply with a sufficient quality could be ensured. The Malter Dam was completed in 1913. This reservoir is used nowadays for recreation and water energy production. Both uses demand a relative high water level within the reservoir. Resulting from this utilizations the flood storage was with 2.28 Mio m^3 (exclusive flood control storage) and 0,42 Mio m^3 (additional flood storage) smaller than the normal operated storage content of the reservoir (5.9 Mio m^3).

In order to demonstrate that the impact of a reservoir on a flood depends not only from the total storage capacity Fig. 3 shows the inflow and outflow of the Gottleuba Dam. The first peak of the incoming flood wave could be stored completely. A second peak resulted in an increase of the water level which exceeded the maximum controllable water surface elevation. The uncontrollable discharge over the spillway reduced the flood retention efficiency.

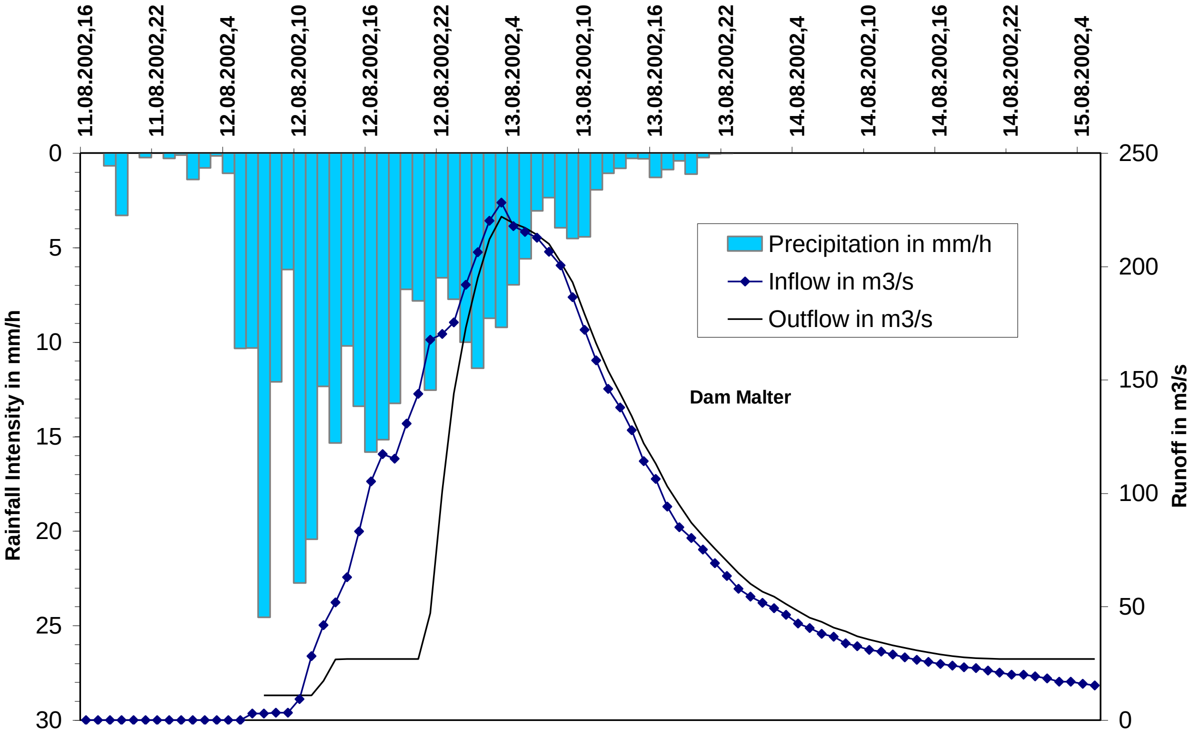

Figure 17 - Inflow and outflow of the Dam Malter during the flood event in 2002

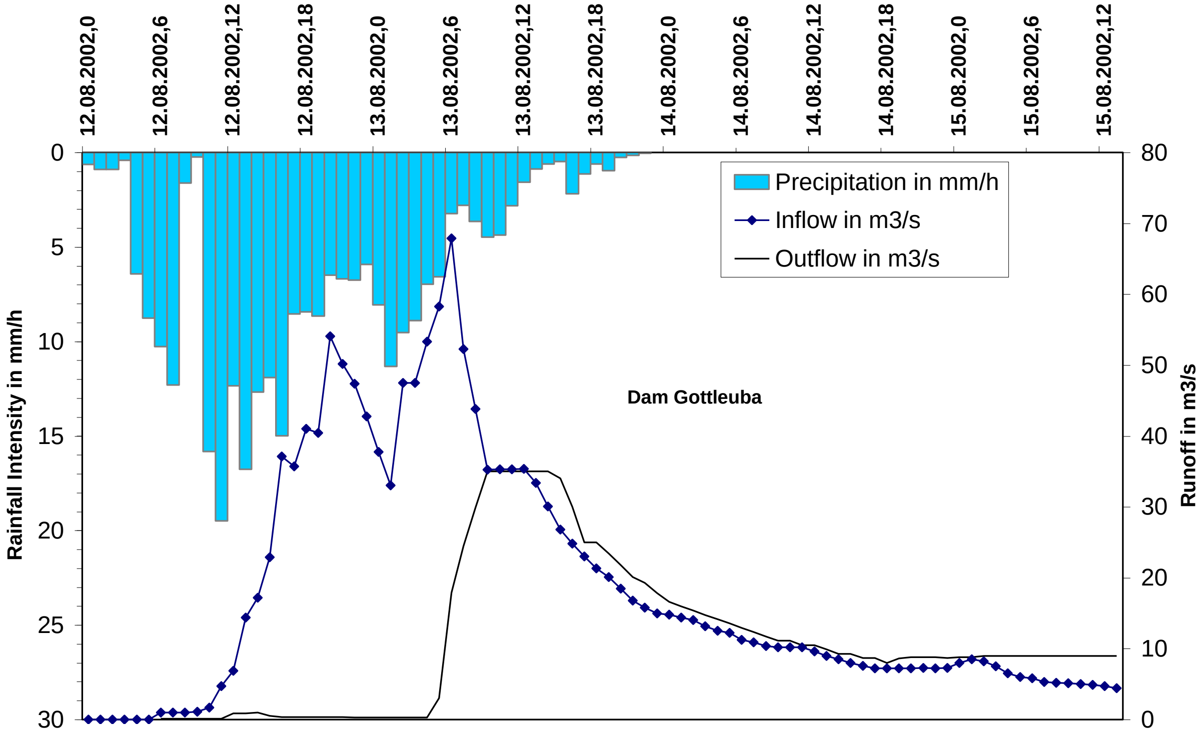

Figure 18 - Inflow and outflow of the Dam Gottleuba during the flood event in 2002

It was demonstrated that the flood retention efficiencies of the dams in the Ore Mountains differed significantly. As a result of these differences the operation of some reservoirs were criticized. Here the options of reservoirs to control extreme floods were overestimated as the physical limitations of them were not considered. Theoretical discussions about not used options to influence the flood by reservoirs resulted in a general demand for improvements of flood control by reservoirs.

11 INCREASE OF FLOOD CONTROL STORAGE AFTER 2002

Under the impression of the flood event in 2002 the flood storage capacities of several Saxon dams was increased. As it was mentioned before most of the reservoirs in this region are used for freshwater supply. Nearly 80 percent of the total population in the Ore Mountain region receive water from reservoirs. Until the political changes at the end of the 20th century an absolute priority in reservoir management had to be given to the freshwater supply. From 237 Mio m^3 storage capacity of Saxon drinking water dams only 5.8 percent (13.7 Mio m^3) were dedicated to flood control. In the nineties the water demand decreased substantially. Reduced industrial demand, a declining number of inhabitants and more efficient water supply systems reduced the freshwater demand in total by 47 percent since 1989. The resulting availability of storage capacities which were no longer needed for freshwater supply were used by the State Reservoir Administration to increase the inactive storage capacity to ensure improved fish and wildlife purposes and to reduce the limnological constrains of water supply from reservoirs with an intensive agricultural use of the catchments. The inactive flood storage was increased as well as the ecological release from reservoirs. An increase of flood control capacities was planned also. Here a stepwise procedure of adaptation was foreseen to ensure the economic efficiency of reservoir operation.

In 2001 an increase of the flood control capacities was planned with the beginning of 2003. The flood 2002 accelerated these activities and enhanced the increase of flood control capacities. In Tab. 3 the changes of the flood storage capacities are listed. The last column of Tab. 3 shows the relationship between the volume of the flood 2002 at dam sites and the increased capacities for flood control after 2003. These relationships were significantly improved at some reservoirs. However the effect of these reservoirs on extreme floods will be limited also in future. The example of the Malter reservoir can be used to demonstrate the remaining technical constrains.

Table 9 - Increase of the flood storage capacities of reservoirs in Saxony after 2002

Reservoir	Area watershed in km^2	Exclusive flood storage in 2002 in Mio m^3	Exclusive flood storage in 2003 in Mio m^3	Relationship between exclusive flood storages 2002 to 2003	Exclusive flood storage 2002 in mm	Exclusive flood storage 2003 in mm	Flood event 2003 Sum inflow in mm	Relation sum inflow to exclusive flood storage 2002	Relation sum inflow to exclusive flood storage 2003
Eibenstock	199.8	5.78	10.01*	1.73	28.9	50.1	84.1	2.91	1.68
Saidenbach	60.8	0.00	1.08**		0.0	17.8	96.2		5.41
Lichtenberg	38.8	0.80	3.00	3.75	20.6	77.3	201.1	9.76	2.60
Lehnmühle	60.4	2.06	7.00	3.40	34.1	115.9	234.0	6.86	2.02
Klingenberg	89.4	1.96	2.00	1.02	21.9	22.4	193.5	8.84	8.64
Malter	104.6	2.28	4.34	1.90	21.8	41.5	235.9	10.82	5.69
Gottleuba	35.3	2.00	3.00	1.50	56.7	85.0	160.6	2.83	1.89

*additional 5 Mio m^3 are planned for 2006.

** additional 2.92 Mio m^3 are planned for 2006

As shown above the relationship between the total inflow during the flood event and the flood control capacity was unfavourable at the most dam sites for instance at the Malter Dam. The question raised how the flood could had been influenced if the flood control capacity would had been increased before the event raised in 2002. To answer this question with an example, different values of the exclusive flood control capacity at the Malter Dam were compared with the flood volume in August 2002 at this site. To estimate the demand for flood storage the integral of the hydrograph above the threshold of controlled outflow was used (Fig.4). Of course such an idealized operation is not realistic. With regard to the mountainous character of the watershed and very short time of runoff formation nearly no flood forecast options exist. However with the assumption of an ideal flood management (the volume of the inflow above a threshold is stored completely) the relationship between the flood storage capacity and the controlled outflow can be shown (Tab. 4). In the middle of Tab.4 the return period of the controlled outflow is listed. In one column the outflow is related to the statistics which was valid before the flood in

2002 and in other one it is related to the new statistical flood assessment including the data of the flood of the year 2002.

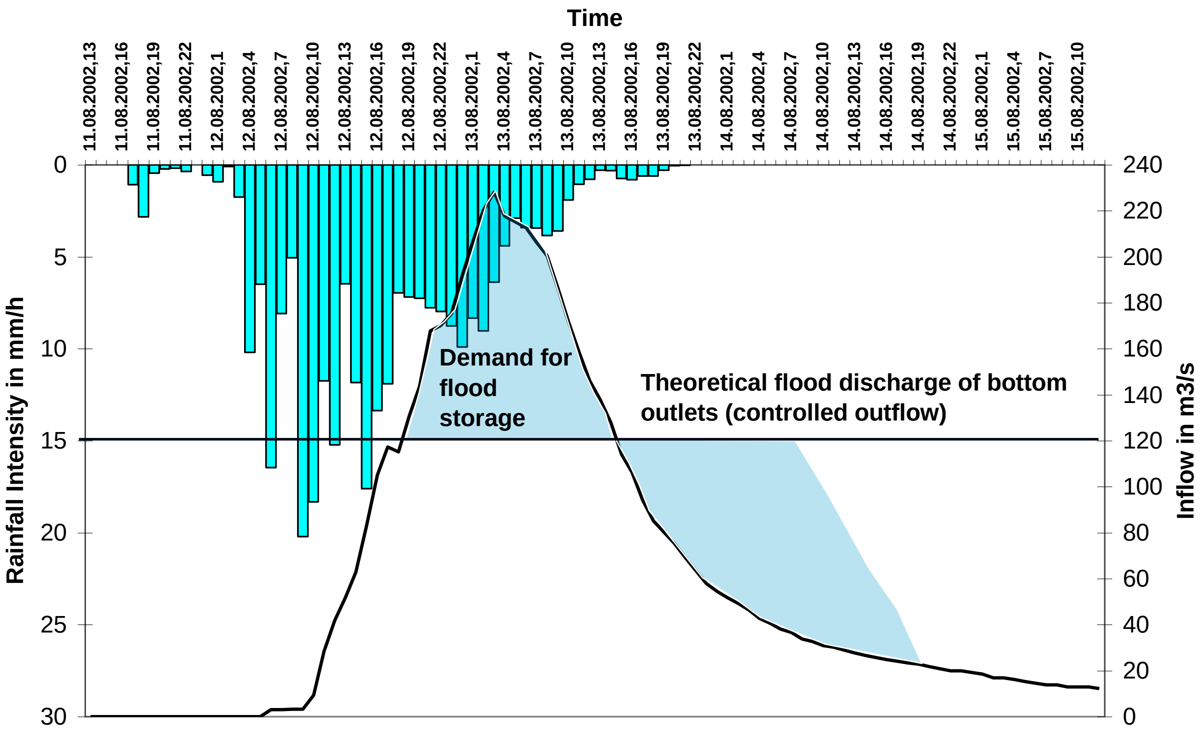

Figure 19 - Demand for flood storage at the Malter Dam site during the flood event in 2002

It can be shown that with the flood control capacity of 2002 the flood peak would have been reduced by 32 percent if the theoretical assumptions of an ideal flood control could have been realistic. The reasons, why this was not the case, are:

- The capacity of the outlet is actually less than 20 percent of the here assumed controlled outflow. The maximum controllable water surface elevation would in all cases be reached in the rising limb of the incoming flood wave, starting the runoff over the spillway and increase the outflow.
- The planning of a controlled outflow with a size corresponding to a statistical flood return period of more than 10.000 years would have been not accepted until 2002 as such an outflow would cause high flood damages downstream of the reservoir
- The shape and the peak of the flood wave were not known in advance as no forecast was possible.

Maximum controlled outflow (m³/s)	Maximum controlled outflow in percent of the inflow peak in 2002	Return Period of the controlled outflow (based on statistics until 2002)	Return Period of the controlled outflow (based on statistics including year 2002)	Demand for Flood storage capacity (Mio m$^{3)}$	Remarks
62	28 %	200	34	10,4	Flood storage capacity higher than reservoir capacity (9.62 Mio m^3)
83	37 %	1000	--	8.78	Flood storage capacity equivalent to the reservoir capacity minus dead capacity
120	54 %	10000	128	4.34	Exclusive flood control capacity after 2002
152	68 %	--	200	2.28	Exclusive flood control capacity before 2002

This example of the Malter reservoir demonstrates the basic problem of flood management by reservoirs: the relative effect of a reservoir depends strongly from the size of the flood event. Small floods are reduced more than large ones. Extreme floods of a certain level cannot be affected significantly. With regard to the flood control planning the relationships between the flood retention by a reservoir and runoff from the watershed downstream of the dam should be considered also. Dams located at the headwaters will be more and more limited in their effects on flood damages at locations further downstream if the catchment area increases.

12 RESTRICTIONS FOR FLOOD CONTROL AND CONCLUSIONS

The multiple use of reservoirs limits the options to shift the different storage categories without disadvantages for some uses. For dams which are used for freshwater supply this is not only a question of water quantity. (The dams in the Ore Mountains have to provide water during hydrological drought conditions with a safety of 99 percent.) A minimum storage content is also needed to ensure water quality. Thus the volume of a water body is a criteria in all models of eutrophication (e.g. Vollenweider & Kerekes, 1982). If nutrients are not limiting factors, the change of the energy balance by lower water levels (the relative part of the water body with sufficient energy from sun radiation for algae blooms is increased and also the relative volume of water with an higher temperature) could result in accelerated growing processes of biomasses, oxygen deficits and water quality problems.

Under consideration of these and other problems a change of the priorities between multiple purposes of reservoir management should be based on optimization where the boundary conditions have to be considered. Among them the technical facilities (esp. capacities of outlets, spillways), the hydrological conditions and the specific requests of other users (e.g. water quality) seem to be most important. The integrative character of this optimisation can be shown by the following example: A release of water from a reservoir through bottom outlets it would increase the flood storage capacity but could result in water quality problems if the stratification of the water body in summer would be disturbed. These and other problems show that the planning of flood storage capacities of reservoirs with multiple uses demand detailed analyses of options and constrains. In order to avoid the conflicts with respect to multipurpose dams it should be preferred to build dams for flood control purposes only, may be as “green” flood reservoirs whenever possible.

The planning of flood control by reservoirs has to be seen as an economical and political determined process in which technical options, hydrological boundary conditions and public risk awareness have to be considered. Planning of flood control measures have to be founded on assessments of benefit-costs-ratios.

In order to estimate the options for flood control by dams following information is needed:

- the flood risk in general and the hydrological conditions in particular,
- the technical options to affect floods,
- the costs of measures to improve flood control if possible,
- the effects of flood control on damages downstream,
- the options to forecast flood events and to adapt the operational reservoir management to the specific hydrological conditions of an on-going flood.

Among the constraints of flood management the multiple use of reservoirs has to be related with the stochastic character of floods. It is very difficult to ensure a flood control for rare and extreme events only. In the absence of flood forecasts all floods have to be controlled. Small floods will be affected more than large floods. From this circumstances the paradox of flood safety results:

Flood control reduces the harmful effects of relatively small floods. The public awareness of flood risks is reduced as such floods cause no damages. If an extreme flood happens, which cannot be controlled, the flood damages and losses can be higher than without flood protection, as people are now not familiar with floods and the concentration of values in flood endangered areas was increased. If the limits of flood control are not considered sufficiently the public awareness of flood risks will be affected negatively as flood control options are overestimated. But there is also a danger for an underestimation of these options which could result in sub-optimal utilizations of existing control capacities.

Flood protection measures by means of dams should be a substantial part of a complex of measures to reduce flood risks. Under consideration of this complexity it is not understandable, that the new “Proposal for a Directive of the European Parliament on the assessment and management of floods” specifies the demand for flood risk management by a complex planning approach but does not mention flood control by dams explicitly. The general aim of such a directive, to assess flood risk and to plan measures to reduce it, cannot be fulfilled without integration of dams as the most important technical facilities to control floods into the planning.

13 REFERENCES

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