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FLOODS AND DROUGHTS: COPING WITH VARIABILITY AND CLIMATE CHANGE

Thematic Background Paper

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EXECUTIVE SUMMARY

Water-related extreme events, floods and droughts, are natural phenomena, which will continue to happen. The risk is likely to grow in the 21st century, heralded as the age of water scarcity, while flood losses also show a rising tendency.

Increasing vulnerability to water-related disasters is due to growing exposure, which in many cases cannot be matched by an appropriate adaptive capacity. Recent climate variability and change seems to have adversely affected flood and drought hazard in several areas and this tendency is likely to continue.

Preparedness systems should be built based on the following attitude: protect as far as technically possible and affordable, and accommodate, i. e. prepare to "living with water-related extremes". If a necessary level of protection cannot be provided and accommodation is not possible, a retreat could be a solution. Water-related extremes badly hit vulnerable informal settlements, scattered around big towns in less developing countries, adequate water supply, and flood protection cannot be provided.

A general change of paradigms is needed in order to reduce the human vulnerability against water-related extreme events. Anticipation and prevention are more effective and less expensive than reaction in emergency. There is no such thing as perfect security, as all defences may fail in case of an extreme event. What is needed is to design preparedness systems, which may fail in a safe way.

Due to the complexity of interacting pressures that cause water-related extremes, a holistic perspective should be taken and integrated solutions sought for the preparedness systems. There is no single universal remedy against water-related extremes and it is necessary to use a site-specific mix of measures, including structural and non-structural ones.

A holistic perspective calls for a joint consideration of data collection, availability and use, a forecasting, warning – response system, and for striving to improve the weakest elements of this chain.

An immediate challenge is to improve flood and drought forecasting at a whole range of time horizons of concern. This is where technology has a role to play. Substantial developments in short-term weather forecasting and quantitative precipitation forecasts are needed for flood preparedness. Improving long-term predictability, based on climatic variability and sea surface temperature, emerges as an important tool of drought preparedness.

Among further important activities strengthening preparedness systems are: risk assessment, watershed management (source control), and increasing water storage, serving both drought and flood protection.

Water-related emergencies illustrate the need of concerted action, effectively co-ordinated across sectors. A number of institutional and organizational issues have been identified to strengthen the preparedness systems, such as enhancing coordination, division of competence, tasks and responsibilities among different agencies acting in watershed, rather than administrative boundaries, and assuring participation of stakeholders.

Less developed countries do not have adequate financial and qualified human resources and cannot cope with hydrological extremes without foreign and international assistance. Increase of effective assistance to the less developed countries is badly needed.

1. INTRODUCTION

Water-related extreme events, floods and droughts, have been a major concern since the dawn of human civilization. They continue to hit every generation of human beings, bringing suffering, death and immense, and still growing, material losses. The 21st century is heralded as the age of water scarcity. Yet, flood losses worldwide continue to rise, soaring to tens of billions of US dollars material damage and thousands flood fatalities a year.

Hydrological variables, such as precipitation, river flow, soil moisture or groundwater level, display strong spatial and temporal variability. >From time to time they take on extremely low or extremely high values.

Even if colloquial understanding of the notions of droughts and floods is straightforward, no uniform, rigorous, and broadly agreed upon, definitions of these terms exist. The notions refer to situations when an arbitrarily-defined threshold is exceeded. A drought can result from low precipitation over some time period, possibly accompanied by high temperature, driving evapotranspiration. The notion of drought should not be confused with aridity, where water is always in short supply, i.e., where a near permanent dryness is a normal condition. Droughts may strike large areas (up to sub-continental scale) and, by their nature, they extend in time for months through years to decades.

Droughts have been considered and treated from different angles. Longer time intervals without rain (or with rain totals considerably below average) are typically referred to as meteorological drought. A hydrological drought implies low flows and low levels of surface waters (rivers, lakes) and of groundwater. An agricultural drought refers to low soil moisture and its effect on cultivated vegetation.

A combination of droughts and human activities (such as overcultivation, overgrazing, deforestation) may lead to desertification of vulnerable areas whereby soil and bio-productive resources become permanently or near-permanently degraded. While droughts and desertification have always been present in Africa, a long lasting recent Sahelian drought (cf. Annex A), combined with demographic pressure, has dramatically accelerated the desertification process.

Floods are often understood as tantamount to outbank flow, when a channel cannot convey the total flood flow and water must spill beyond the channel, causing damage. There are several kinds of floods, each having different properties and each with a long history of human protective activities: examples include rainfall-induced and/or snowmelt-induced river floods, including flash floods due to intense and short-lasting rainfall. According to IPCC (2001), the sea level, which increased in the XXth century by 10-20 cm, will continue to rise. This will have substantial adverse effects on low-lying lands and river deltas, among others in the area of risk of flooding. Increasing probability of storm surges and tidal flooding is forecast. It is important to stress that some major floods, including the most disastrous one in Bangladesh in 1991 have been caused by storm surges. Yet, coastal flooding is beyond the thematic scope of this paper..

2. CURRENT SITUATION

2.1. Pressure

Freshwater, a necessary condition of life and a raw material used in very high volumes in virtually every human activity, is becoming increasingly scarce in many places and times. Water use has risen considerably in the past hundred years, at a pace twice as fast as the population growth, and water demands for food production, hygiene and human well-being, industry, etc. continue to grow fast. Societies are becoming increasingly vulnerable to droughts and water deficits.

There is a significant increase in losses caused by extreme hydrological events due to the soaring anthropopressure. Massive deforestation, urbanization and river regulation reduce the available water storage capacity and amplify flood waves. Water runs off faster to the sea, yet may be acutely missed in a period of low flows and droughts. The rapid growth of industry and service in Asia during the 1990s resulted in a considerable change of land use pattern. In Thailand for example, it caused a reduction of natural retention and over-bank storage in the lower Chao Ph raya river basin, contributing to the downstream flooding by about 3,000 m^3/s.

Economic development of flood-prone areas is a driver increasing flood hazard. Human pressure and shortage of land cause encroachment into floodplains, especially by mushrooming informal settlements in endangered zones around mega-cities in developing countries. Hopes to overcome poverty drives poor people to migrate, frequently into places vulnerable to flooding and where effective flood protection is not assured. In fact, in many countries such places are left uninhabited on purpose, exactly because they are flood-prone.

There is an over-reliance on the safety provided by flood control works, such as levees, reservoirs etc. In reality, no flood defence offers perfect security. Dykes protect against small and medium size floods, so the number of floods within this range is decreasing. When a deluge is of disastrous size and dykes break, losses in a levee-protected landscape can be very high; higher than they would have been in a levee-free case. This is so because of a false feeling of security of the riparians and growing wealth accumulated in endangered areas.

Mechanisms of climate change and variability are intimately interwoven with the more direct anthropogenic pressures. Scenarios for future climates indicate the possibility of amplifying the water-related extremes. Observations confirm that atmospheric moisture is increasing in many places of the warming planet. The reason is that the atmosphere's capacity to absorb moisture, and thus its absolute water content, increases with temperature. Thus, the potential for intensive precipitation, and likewise floods, is also increasing.

Instrumental records of land surface precipitation continue to show an increase of 0.5 to 1 % per decade over much of mid- and high latitudes of the Northern Hemisphere (IPCC, 2001). Furthermore, in regions where the total precipitation has increased, there have been even more pronounced increases in heavy and extreme precipitation events. Moreover, increases in intense precipitation have been documented even in those regions where the total precipitation has decreased or remained constant

There are a number of studies, especially in Europe, reporting that high floods have become more frequent. A 100-year-flood determined for older data may correspond to much lower return periods for more recent data. A similar tendency is foreseen for the future. Yet, one has to be careful with generalizations - it would be a gross oversimplification to state that floods have exhibited growing trends everywhere. The time series of flood data show a complex response (due to other, non-climatic factors), the behavior of which is not necessarily in tune with gross climate-related prognostications.

Adverse effects have already been observed in water-related extremes linked to climatic variability. The frequency and intensity of El Niño–Southern Oscillation (ENSO) have been unusual since the mid 1970s, when compared with those of the previous 100 years. Warm phase of ENSO has become more frequent, persistent and intense. During this El Niño phase, extreme water-related events occur more frequently - intensive precipitation and floods in some locations and precipitation deficits and droughts in other regions.

Characteristics of extreme climatic phenomena related to floods, can change in the future, in the light of scenario analyses (cf. IPCC, 2001 and 2001a). Among expected climate-related impacts relevant to floods are: increased magnitude of precipitation events of high intensity in many locations, more frequent wet spells in mid / high latitude winters, more intense mid-latitude storms, and more El Niño-like mean state of El Niño-Southern Oscillation (ENSO).

The frequency of extreme precipitation events is projected to increase over many areas. In the continental interiors, there is a growing risk of summer droughts: less precipitation and higher temperature may coincide, causing higher evapotranspiration and reducing available water resources.

This increased climatic pressure will exacerbate the increasing vulnerability of societies, to other global change processes such as population growth, increasing density of population and economic values in areas at risk, in particular within developing countries with their limited adaptive capacity.

2.2. State

According to the Red Cross, floods in 1971-1995 affected more than 1.5 billion people worldwide. In this number are included: 318000 killed and over 81 million homeless (IFRCRCS, 1997). Additional suffering occurs through increased spreading of diseases such as diarrhea or Leptospirosis in flooded areas.

Berz (2001) examined inter-decadal variability of great flood disasters, understood as those where the ability of the region to help itself is distinctly overtaxed, making international or interregional assistance necessary. Based on the data for the period 1950-1998, presented by Berz (2001), one could state that the number of great flood disasters has grown considerably worldwide in the past decades (six cases in the 1950s, seven in the 1960s, eight in the 1970s, 18 in the 1980s, and 26 in the 1990s). The number of great flood disasters in the last decade was higher than in the three decades 1950-1979.

In 1990s, there have been over two dozen flood disasters worldwide in each of which either the material losses exceeded one billion US dollars or the number of fatalities was greater than one thousand, or both. In the most disastrous storm surge flood in Bangladesh, during two days in April 1991, 140, 000 people were killed. The highest material losses, of the order of 30 and 26.5 billion US dollars, were recorded in China in the 1996 and 1998 floods, respectively.

As far as the geographic distribution of most disastrous floods is concerned, the majority of recent large floods has occurred in countries of Asia. Yet, few countries worldwide are, indeed, free of flood danger. Even countries located in dry areas, such as Yemen, Egypt and Tunisia have not been flood-safe. It is counter-intuitive that in dry areas, more people may die of floods than from lack of water, as the dryness is a normal state to which humans have adapted, while floods strike suddenly unprepared populations.

Droughts have also recently struck several regions. Even in developed countries, an extreme drought may cause considerable disturbances: environmental, economic and social losses. It is assessed that the 1988 drought in the USA may have caused direct agricultural loss of 13 billion US$. The more recent 1998-9 drought affected the eastern region of the country and the vegetative period in 1999 was the driest on record for four states.

An extreme example of a man-made, and pronounced, hydrological drought comes from the Aral Sea basin, where, due to excessive water withdrawals from the tributaries Syr Darya and Amu Darya, the Aral Sea has shrunk dramatically.

The finding in IPCC (2001a) is that the costs of extreme weather events have exhibited a rapid upward trend in recent decades and yearly economic losses from large events have increased ten-fold between 1950s and 1990s (in inflation-adjusted dollars). A part of the observed upward trend in weather disaster losses is linked to socio-economic factors, such as increases in population and wealth as well as developing settlements in vulnerable areas. However, these factors alone cannot explain the observed growth. A part of losses is linked to climatic factors, such as the observed changes in precipitation.

Pielke & Downton (2000) studied the rates of change in flood characteristics and socio-economic indicators in the USA for the time period from 1932 to 1997. They found that the total annual flood damage, adjusted for inflation, has grown at an average rate of 2.92% per year, that is more strongly than population (+1.26%) and tangible wealth per capita (in inflation-adjusted dollars +1.85%).

The increase of flood damages is evident in many regions. For example, the statistics of flood damage maintained by the Department of Public Welfare and the Department of Local Administration for the years 1978 to 1997 in the provincial areas of Thailand show a clearly increasing trend.

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986
Damage Value	21	3	1,549	314	224	1,104	321	350	628
Year	1987	1988	1989	1990	1991	1992	1993	1994	1995
Damage Value	832	7,54	11,739	6,652	2,620	5,240	2,181	45	11,558

Unit : million Baht (1US$ = 26 Baht)

2.3. Response

Owing to the complexity of interacting pressures that cause water-related extremes, protection will increasingly call for integrated solutions, which will consist of a mix of components. There is no single universal remedy against water-related extremes and a site-specific mix of measures is necessary, depending on geographic factors and human dimension (socio-economic development and awareness). A roster of means available for reducing flood losses may modify susceptibility to flood damage, characteristics of flood waters, or the impact of flooding (during and after the flood).

Flood protection measures can be structural or non-structural. Dams and flood control reservoirs, dykes, etc. belong to the former category of structural measures. Constructing reservoirs where the excess water can be stored allows a regulated temporal distribution of streamflow and helps alleviate the flood problem by flattening flood peaks. A sample of possible non-structural flood protection means include:

- zoning, i.e. regulation for flood hazard areas development leaving floodplains with low-value infrastructure;
- flood mitigation systems of forecasting, warning (issuing and dissemination), evacuation, relief and post-flood recovery;
- flood insurance, i.e. division of risks and losses among a higher number of people over a long time;
- capacity building (improving flood awareness, understanding and preparedness), and enhancing participatory approach.

Among drought protection measures, augmenting the supply of water can be achieved locally by exploiting surface water and groundwater, if available in the area. It can also be realized by transfers from surface water sources (lakes and rivers) and from groundwater, if socio-economically and environmentally acceptable. Increasing storage of water, i. e. the classical drought management policy option, is becoming increasingly difficult to implement because of decreasing availability of resources and adverse consequences on the environment. In Thailand, a large upland reservoir storage was created, allowing regulation of dry season flow in the upper and middle basin to satisfy domestic and irrigation water demand. Yet, upstream activity resulted in a serious decline in water quality, particularly in the lower part of the basin area. Also intensive groundwater withdrawal for drought management is not a sustainable remedy – it has caused severe land subsistence in many countries, including Mexico, the United States, Japan, China and Thailand.

Recently, the emphasis in action plans to combat drought is being increasingly shifted from supply management by provision of water resources in required quantities to effective demand management for the finite, and scarce, freshwater resource, i. e. seeking "negalitres of conserved water" rather than "megalitres of supplied water". The needs for improvements in efficiency of use of existing supplies as well as in water productivity are essential. Among the measures in question are: improved land use practices; watershed management; rainwater/runoff harvesting; re-cycling water (e.g., use of treated municipal waste water for irrigation); development of water allocation strategies among competing demands. Groundwater reservoirs (aquifers) storing water when available can be more advantageous, despite the pumping costs, than surface water storage, which may be subject to very high evaporation losses. Drought contingency planning, including restrictions of water use, rationing schemes, special water tariffs and reduction of low-value uses (agriculture), require thorough consideration. Reduction of wastage and improvement of water conservation via reduction of the non-accounted for water and re-thinking of the system of water pricing and subsidies deserve attention.

Enhancing water storage is a remedy for both classes of hydrological extremes: floods and droughts. Catching water when abundant and storing it for times of need can be realized in reservoirs of all scales and also in underground retention (e. g. by enhancing infiltration). An optimal combination of storages of different size is necessary to maximize water availability at a minimum cost, with appropriate consideration of externalities..

2.3.1. Risk assessment and risk maps

The assessment of risk due to extreme hydrological events, indispensable in risk management (Plate, 2001) provides the basis for long-term management decisions on flood or drought preparedness systems. Risk assessment requires two steps: an evaluation of the hazards and a quantification of the vulnerability:

- The hazard is evaluated by calculating the likelihood of an extreme hydrological event of a certain intensity (e. g. inundation level and duration).
- The vulnerability is assessed by quantifying the potential damage of persons or objects ("elements at risk") in the endangered region associated with the intensity of the extreme event.

Risk assessment includes the generation of risk maps using Geographic Information Systems (GIS), based on surveys of vulnerability and hazard maps. Risk maps can serve to identify vulnerable spots and weak points of the defence system, or indicate a need for action, which may lead to an improvement of the system.

2.3.2. Forecast – warning - response

One of the sound policies to mitigate flood and drought risks is to change from reactive to an anticipatory stance. This calls for establishing an effective monitoring and early warning system, embedded in a well-functioning response strategy.

Operational management of extreme hydrological events can be considered as a sequence of several steps (Todini, 2000):

- Detection of the likelihood of the formation of a flood or a drought, where this is a matter of forecasting the meteorological conditions and the hydrological processes which may lead to an extreme event;
- Forecasting of future river flow conditions and water storage in reservoirs (relevant for floods and droughts), and of other water resources, e.g. groundwater (relevant for droughts);

- Warning issued to the appropriate authorities and to the public on the magnitude, areal extension, duration and timing of the event;
- Response by the population at risk and the authorities responsible for the defence; and
- Post-disaster assistance, e.g. provision of food, shelter and medical care; reconstruction of infrastructure, industry and agriculture; regeneration of the environment and of the defence system.

Forecasting of the place, time and extent of extreme events is based on mathematical modelling, including meteorological, hydrological and hydraulic models (Bronstert, 2001).

Today, weather forecasting models can supply information on temperature, wind and precipitation up to approximately one week in advance. However, such models cannot yet assess in detail the location and the magnitude of precipitation, especially of local convective heavy rainfall (thunderstorms), which may cause flash floods.

Hydrological models, which simulate the transformation of precipitation into runoff, are not always a routinely applied part of a real-time flood prediction system. Under conditions of extreme rainfall, the physically based hydrological models may not work well.

Hydraulic models provide details (flow rate and stage for different places and times) of propagation of the flood wave in the river channel. These models are highly developed for many large river systems, and they have served to produce flood level projections for many years. Since such models mimic propagation of a flood wave, which already exists in a channel, they only work for relatively short lead times. While for the river Rhine in Cologne this lead time is only slightly longer than two days, for smaller rivers the lead times are short and hydraulic models are of little use for real-time flood forecasting.

The challenge for the future lies in the improvement and coupling of the above modelling systems to allow for improved early warning times in accordance with increased reliability of weather forecasts. Another challenging area is modelling extreme events under future climatic conditions.

Recent advances in predictability augur well for improvements in preparedness systems for water-related disasters. In particular, improved understanding of the role of the land surface in coupled land-atmosphere-ocean models and of hydrological response of very large river basins offers new challenges and opportunities.

In ensemble climate forecasting (Wood et al., 2001), a global land-atmosphere-ocean model (initialized with atmospheric, land surface and ocean conditions at forecast time), is run into the future for forecast horizons of months to years, using prescribed sea surface temperatures (SSTs). Although the atmosphere is essentially chaotic, the prescribed SSTs effectively constrain the evolution of model forecasts. By perturbing the initial conditions and repeating the simulation a number of times, an ensemble of forecasts is constructed which represents the range of global atmospheric conditions, which may occur over the forecast period.

Wood et al. (2001) applied this approach during the summer 2000 drought in the eastern and central U.S. Ensemble climate forecasts (precipitation and average temperature for six-month lead times, updated monthly) were downscaled and spatial model output and streamflow were generated for each month of the six-month forecast horizon. The results of the study show that the retrospectively gridded precipitation and temperature and hindcast simulations of soil moisture and runoff can be used as surrogate observations.

More recently, this streamflow forecasting strategy has been implemented over the Columbia River basin to produce six-month lead time forecasts beginning with April, 2001 (see www.hydro.washington.edu for details). The gridded observed spin-up forcings for the VIC model (Liang et al., 1994, Lohmann et al., 1998, 1998a) are updated to the time of forecast, and the hydrologic ensemble forecasts are then generated. This application to very long lead forecasts allows the probability of reservoir refill to be assessed.

2.3.3. Watershed management

Since millennia, people have been settled in floodplains in order to till fertile soils, to profit from flat terrain appropriate for settlements, to have easy and safe access to water and to use the river for transport. Floods as natural phenomena have always been there and people tried to benefit from them to the extent possible. However, human pressures like an increasing population density in flood-prone areas, urbanization and agricultural expansion have steadily increased the vulnerability to floods. As a consequence, floods have become more and more disastrous. Structural measures, such as the building of dykes or the straightening of river courses, i. e. the most common flood defences often led to a false sense of security. Nowadays, the negative side effects, such as shifting flood problems downstream, high maintenance costs or adverse ecological impacts have been widely recognized. Flood risk mitigation is now considered to consist of a mixture of appropriate options, i. e. an optimal and site-adapted combination of structural and non-structural measures.

Non-structural options for flood risk mitigation often follow the concept of ”keeping water where it falls” (Bronstert et al., 1999), thus including the whole catchment into the flood management plan. According to Demuth (1999), modern watershed management is aimed to:

- support a site-adapted, ecologically sound agriculture with soil conservation measures, cultivation of sub-crops and intercropping to avoid surface runoff and erosion;
- improve the rainwater drainage in urban areas;
- re-establish natural floodplains and riparian forests;
- designate flood zones (zoning); and
- indicate the existing hazard.

These actions are often combined in integrated programmes with overall land management plans. They are completed by ”soft” technical measures with a high benefit:cost ratio, such as the realization of small flood retention basins or improving conveyance by removal of hydraulic bottlenecks in the streams.

However, the implementation of watershed management plans needs considerable financial resources. In developing countries, related funds (if available) are often needed to recover from past disasters (Plate, 1999) with no money left for preparedness for future extreme events. In less developed countries, long term flood protection plans are not easy to implement, as people’s household security concerns are often restricted to food and water supply for the next days or weeks (Schulze, 2000).

3. SUCCESS STORIES AND LESSONS LEARNED

Humankind has interacted with water-related extreme events with various degrees of success since the history began. Sometimes they failed and floods or droughts (*cum* desertification) have wiped out entire civilizations. A number of case studies of recent experiences have been assembled in Appendices A-F.

A class of success stories relate to cases when a disaster repeatedly occurs in the same area at short time intervals. Then it is still fresh in memory, and the damages are usually smaller thanks to better preparedness. An example of a success story is the flood mitigation along the rivers Rhine and Moselle and their tributaries, where people have learned to live with recurring floods. Large floods, each considered a nearly 100-year flood magnitude, occurred repeatedly on the Rhine within 13 months. In December 1993 the level of the Rhine in Cologne reached 1063 cm, while in the beginning of 1995 it went up to 1069 cm. Yet, the damage during the second deluge was much lower than during the first. The establishment and continuous extension of precautionary measures over the past decades and informing the local population helped to withstand major floods. The adverse effects of river straightening and the building of dykes along the Rhine are presently compensated by Integrated River Programmes (e.g., Demuth, 1999) and the restoration of floodplains through polder systems.

The Great Flood of 1993 in the Mississippi-Missouri system has been labelled as the most devastating deluge in the modern history of the USA. Historical flood records on the main stem of the Missouri were broken at several observation stations by up to 1.2 m. In St. Louis on the Missouri, the previous record stage was exceeded for more than three entire weeks (cf. Natural Disaster Survey Report, 1994). The Great Mississippi Flood had significant impact on flood policy. Recommendation of the US Interagency Floodplain Management Review Committee after the 1993 flood was that federal, state and local governments and those who live or have interest in the floodplain should have responsibility for development and fiscal support of floodplain management activities (cf. Galloway, 1999). The Committee recommended that the administration should fund acquisition of needed lands from willing sellers and buyout of structures at risk in the floodplain. The number of families relocated from the vulnerable floodplain locations in the Mississippi Basin andin other regions in the USA is of the order of 20000 (after Galloway, 1999).

Japanese strategy of flood preparedness deserves attention (see Annex F). The number of flood fatalities in that country with high flood hazard has decreased dramatically. Yet the Japanese system cannot be mimicked in less developed countries, because it would be unaffordable there.

Although water-related extremes strike developed and less developed countries alike, their consequences are largely different. In developed countries, the material flood losses continue to grow, while the number of fatalities decreases. Advanced flood preparedness systems can save lives - the fatality toll in developed countries is far less than in the less developed ones. Figure 1 illustrates the ratio of material losses to a number of deaths (in simple words - material losses per one death) as function of GNP per capita in US$, established for large floods of 1990-1996 (Kundzewicz & Takeuchi, 1999). As expected, there is a general pattern in this relationship. For catastrophic floods in developing countries, material losses per one fatality can be as low as 21000 US$, while in developed countries they can go up to 400 million US$.

In developed countries, droughts seldom kill directly. In drought emergencies, concerted actions are necessary, requiring co-operation between water users, water providers and authorities. There is a roster of short-term options which could be used. Glantz (1982) described the many activities triggered by a drought forecast in the catchment of the river Yakima (USA), such as drilling additional wells, trading water rights, system of subsidies (e. g. subsidizing farmers with annual crops to leave their land fallow) and tax breaks (for drought-forced cattle sales), launching a bank of virtual water, transplanting high value perennial plants, encouraging water conservation practices, enhanced studies of options of long-distance water transfer, using water from dead storage zone of reservoirs.

Another success story of drought preparedness comes from Thailand (Binnie et al., 1997), where strong local water user organizations have been managing their local water resources. In the result, a system of prices and incentives was introduced, which allow water use to be managed efficiently, especially in small irrigation projects.

Although there is a roster of drought mitigation measures that work in a developed country, they are not of much help in vast areas of the developing world. As stated by Glantz (1977): "[E]ven if a six month forecast of weather were available, few of the areas could have responded in any different way to that which actually happened". In developing countries, drought-induced hunger or infections and diseases developed in weakened undernourished organisms may kill (see Annex E). Sometimes, drought is an element of a “complex emergency”, including a civil war (cf. Annex A).

There are several general lessons, which can be drawn from recent experiences:

- Floods occur all over the world, even in arid regions.

- Recent climate variability and change seem to have adversely affected flood and drought hazard in several areas and this tendency is likely to continue.
- The poorer a society, the more tragic in disasters. Those who lose most have least to lose (in absolute terms). They may virtually lose all they have, including life.
- If a so-called 100-year flood (with a probability of exceedence of the order of 0.01) occurs, it does not imply that one will need to wait a long time for an event of a similar magnitude occurring in the same place (a common misconception amongst the general public). A large flood may recur again soon, as shown by several recent examples.
- Peoples' experiences of floods reduce damages in the next floods but the memory fades very quickly (short memory syndrome).
- Adequate water law could improve drought preparedness in many regions. Under current legislation and open access regime, the rights of individuals and public agencies are not clearly specified.

4. ISSUES AND POLICY IMPLICATIONS

A general change of paradigm is needed in order to reduce the human vulnerability to water-related extreme events. As a protection system guaranteeing complete safety is an illusion. The attitude: "living with water-related extremes" and accommodating them in planning, seems more sustainable than a hopeless striving to eradicate them. The policy of fail-safe systems is now giving place to safe-fail ones. It is impossible to design a system that never fails (fail-safe). What is needed is to design a system that fails in a safe way (safe-fail). On the other hand, integrated approaches can help reduce the frequency, severity, and impacts of water-related extreme events.

There are several aspects of water-related disasters linked to the sustainability – overarching principle of development, which states that the needs of the present generation should be fulfilled without compromising the ability of future generations to meet their needs. Devastating droughts and floods can be viewed as enemies of sustainable development, destroying human heritage and breaking continuity. Moreover, several strategies for flood and drought defence are being criticised in the context of sustainable development because they close options for future generations and introduce unacceptable disturbances in ecosystems. A brief discussion of relevant issues in this regard is given in the Annex G.

A basis for sustainable integrated development has been provided through a number of international conventions, strategies and declarations. An implementation and enforcement of the principles of the UN Framework Convention on Climate Change and the UN Convention to Combat Desertification, for example, could offer pathways towards a future with reduced climate extremes, more adapted land use and hence less vulnerable populations with respect to water-related extremes. For principles from Agenda 21 and the UN Millennium Declaration, Annex H should be consulted. With respect to water-related disasters, a Comprehensive Disaster Risk Management (CDRM) strategy is currently being developed. This includes such aspects as risk identification, risk reduction, risk transfer and financing.

A number of concrete actions in support of mitigation and adaptation strategies are outlined below:

Data and Information: Progress in the systems of protection against hydrological extremes depends highly on collecting and analyzing hydrological data, archives of information and mechanisms of data distribution and exchange. Hydrological information is pre-requisite to the design and operation phase of preparedness systems to water-related extremes. Furthermore, collecting and analyzing long time series of hydrological, climatological and related data are needed to detect changes in hydrological processes and in extreme events, e.g. those caused by climate variability and change or land-use change. Yet, owing to financial stringencies in many countries, hydrological services are shrinking and are not able to provide the required information. Networks of observing stations are in marked decline in much of Africa, and the data base to assess the drought and desertification risks, and to plan for their abatement is not adequate. It is of extreme importance to reverse this adverse tendency. International initiatives to this effect are the World Hydrological Cycle Observing System (WHYCOS) project of the World Meteorological Organization (WMO), aimed at strengthening hydrological networks (see www.wmo.ch/web/homs/whycos.html) and the International Global Observing Strategy (see www.igospartners.org).

Forecasting: An immediate challenge is to improve flood and drought forecasting over a whole range of time horizons of concern. Substantial developments in short-term weather forecasting and quantitative precipitation forecasts are needed for improvement of the reliability of real-time flood predictions, particularly in small and mid-sized river catchments. It has been found that extreme hydrological events in several regions of the world a re highly influenced by particular phases of oceanic temperature/pressure oscillations. There is, therefore, a potential for development of long-term forecasts, based on sea surface temperatures. Yet the problem has to be seen in a holistic perspective and good forecasting system should be embedded in an integrated system, so that a forecast is effectively used.

Integrated water resources management: It is increasingly recognized that integrated management of water resources is required (see for example Agenda 21, whose statements are applicable to the context of water-related extremes, Annex H).

Integrated Water Resources Management, based on the concept of water as an integral part of the ecosystem and as a natural resource as well as a social and economic good recognizes:

- the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems;
- all natural physical aspects of the surface water and groundwater resource systems, including variations in time and space, quantity and quality;
- all sectors of the economy that depend on water and hence the entirety of inputs and outputs related to water;
- the complexity of spatial resource distribution and competing demands, such as upstream-downstream interactions, inter-basin transfers, shared watercourses etc .

Scientific support of integrated management: Improved scientific understanding of human-environment interactions and assessments of current and future environmental status (such as the UN Millennium assessment, see www.ma-secretariat.org) can provide a basis for decision-making in integrated water resources management, including coping with water-related extremes. Prominent examples of recent integrated research efforts to this end are vulnerability assessments, which evaluate the combined effects of multiple environmental stresses under global change and potential adverse outcomes for water resources, with focus on the river basin scales. The vulnerability approach goes beyond the mere prediction of a stress occurrence and its impacts. It rather presents to local and regional stakeholders the full range of drivers of change and climate, hydrological and environmental effects and societal feedbacks, with emphasis on extreme events. It involves the evaluation of thresholds of environmental systems, beyond which adverse effects occur, and their inherent uncertainty. Vulnerability to water-related extreme events turns out to be a function of societies' adaptation capacity, its exposure to and the incidence of events. Research initiatives implementing this approach can be found, for example, in the International Geosphere-Biosphere Programme–BAHC (see www.pik-potsdam.de/~bahc/wadi/vulnerab. htm) - and, at a national scale, in the GLOWA research initiative (see www.glowa.org) in Germany. GLOWA research deals with a transect of study basins and provides an integrated study approach taking into account ecosystem perspective and socio-economic conditions for understanding changes of water resources, including extreme events and strategies for integrated management. Another example of a research initiative in support of Integrated Water Resources Management and Comprehensive Disaster Risk Management, WADI, is presented briefly in Annex I.

Perspectives of developed and less developed countries: Prospects for human mitigation of hydrological extremes differ substantially between developed and less developed countries (Kundzewicz & Kaczmarek, 2000). A number of recent investigations of the vulnerability of societies to extreme hydrological situations has resulted in policy recommendations (e. g. USA, Norway). Governments in developed countries understand their duty to undertake effective appropriate actions to build preparedness systems and to minimize negative consequences of hydrological extremes. However, less developed countries do not always have adequate financial and human resources and cannot always cope with hydrological extremes without foreign and international assistance. Increase of the size and efficiency of assistance to the less developed countries is badly needed.

Given current (i.e. 2001) situation, due to the economic crisis in Asia and Pacific regions as well as prevailing issues of poverty, unemployment and environmental stress, there is a danger that sustainable management of flood and drought disasters could take a back seat and its priority be reduced as each country seeks to regain economic momentum. Support in capacity building from international, regional and national external support agencies is thus urgently needed.

Kulshreshtha (1993) has shown that food insecurity is a major water-resource related issue in the arid and semi-arid lands of Africa. His study shows that over a dozen countries in Africa are already under water stress, or water scarcity, if they were to attain the goal of food self-sufficiency alone. In the face of increasing severity of water deficits, striving towards national food self-sufficiency in water-poor countries may not be a sustainable option, and a shift from the food self-sufficiency to the food self-reliance is needed. Importing virtual water (incorporated in food and other products) from water-endowed countries may be more viable. One of the problems with drought preparedness is that low-income irrigation-based countries have not the financial resources to shift development away from intensive irrigation into other sectors that would create employment and generate higher income.

Flood and drought management and planning of the preparedness system in most developing countries is largely carried out by civil administrative region rather than by catchment. Management and planning need to take place on a catchment level, a natural scale to deal with water systems. In addition, management and planning is undertaken largely by organizations from their central offices, thus emphasizing problems of the central province, sometimes at the expense of other water-related activities outside. In general, water resources management is institutionally fragmented. Water affairs are being dealt with by a number of agencies established under different laws and regulations for various purposes. Sometimes their functions and powers overlap. Problems emerge with information exchange, coordination, cooperation, distribution of competences, responsibility and accountability.

Capacity building, stakeholders and gender issues: Capacity building, an essential step in preparing flood and drought mitigation, is a burning need especially in less developed countries. It includes education, awareness raising and creation of a legal framework and well-formed institutions, with clearer mandate, which enable people to access information and participate in decision-making.

Possibility of reduction of the impact of water-related disasters depends on the state of the science and technology of each country. Many countries lack the capacity to take up the new technology applicable to disaster reduction and prevention. The international community needs to share their experience for narrowing the gap between current knowledge and policy making.

Appropriate procedures for evaluation of economic, social, and environmental damage due to flood and drought disasters, for risk assessment and planning of the preparedness systems should be established.

The Comprehensive Disaster Risk Management (CDRM) strategy for water-related extremes requires that the key agencies collaborate in a co-ordinated way in pursuing the recommended management actions. Early consideration should be given to institutional arrangements suitable for assuring that decisions on various actions are taken with appropriate consultation and that the responsibility for implementing each action is assigned to the most appropriate agencies.

In making decisions about flood and drought management, it is important to broadly involve various stakeholders, while devolving as much responsibility as feasible to lower levels (subsidiarity principle). The process of bringing together national and local governments, private sectors, NGOs and other representative groups of civil societies has been useful in consensus building about preparedness system to water-related extremes. Encouraging public participation in self-protection strategies has been successfully adopted in some areas.

Any decision making in flood and drought relief strategies should include public participation of all sectors in society. In many developing countries, women and female children are frequently the main providers of water for household uses. Drought alleviation could reduce the annual expenditure of many million women–years of effort to carry water from distance sources. Women play a central part also in management and safeguarding of water, which makes it critical to involve them at all levels of the decision making process. It is important to stress that in some cultures, response to flood warning is largely gender-dependent (e. g. inadequate reaction to flood warning of married women in absence of their husbands can be observed).

5. CONCLUDING REMARKS

Water-related extreme events, floods and droughts, are natural phenomena, which will continue to happen. The 21st century is heralded as the age of water scarcity, but flood losses worldwide also continue to rise, soaring to tens of billions of US dollars material damage and thousands flood fatalities a year.

Costs of extreme weather events have exhibited a rapid upward trend in recent decades, part of which is linked to socio-economic factors, but another part - to climatic factors, such as the observed changes in precipitation.

Preparedness systems should be built based on the following attitude: protect as far as technically possible and affordable, and accommodate, i. e. prepare to “living with water-related extremes”. If a necessary level of protection cannot be provided and accommodation is not possible, a retreat could be a solution, such as relocation of 20 thousand families from floodplains in the USA.

Due to the complexity of interacting pressures that cause water-related extremes, a holistic perspective should be taken and integrated solutions should be found for the preparedness systems. There is no single universal remedy against water-related extremes and it is necessary to use a site-specific mix of measures, including structural and non-structural ones.

Enhancing water storage is a remedy for both classes of hydrological extremes: floods and droughts. Catching water when abundant and storing it for the times of need can be realized in reservoirs of all scales and also in underground retention (e. g. by enhancing infiltration). However, there is a growing opposition against development of structural (especially large) defenses in several countries.

Hydrological information is a pre-requisite in the design and operation phase of preparedness systems to water-related extremes. Progress in the systems of protection against hydrological extremes highly depends on collecting and analyzing hydrological data, archives of information, and mechanisms of data distribution and exchange.

An immediate challenge is to improve flood and drought forecasting at a whole range of time horizons of concern. This is where technology has a role to play. Substantial developments in short-term weather forecasting and quantitative precipitation forecasts are needed for improvement of the reliability of real-time flood predictions, particularly in small and middle-size river catchments. Improving long-term predictability, based on climatic variability and sea surface temperature, emerges as an important tool.

Water-related emergencies illustrate the need of concerted action, effectively co-ordinated across sectors. A number of institutional and organizational issues have been identified to strengthen the preparedness systems, such as enhancing coordination, division of competence, tasks and responsibilities among different agencies acting in watershed, rather than administrative boundaries, and assuring participation of stakeholders.

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ANNEX

A) The Sahel drought

The Sahel is a zone with high variations in annual rainfall averages over decades. During the past century, several severe droughts have occurred, including a long-lasting extraordinary drought, without precedence in the observed climatological record. Significant drops in precipitation, and in consequence, a decreasing flow tendency has been observed in the past decades over large areas in Africa (Sehmi & Kundzewicz, 1997). For example, since 1970 the mean discharge of the river Niger at Koulikoro has nearly halved from its levels in the sixties. The river virtually dried up at Niamey in 1984 and 1985. The Senegal at Bakel nearly stopped flowing in 1974 and 1982, and again in 1984 and 1985. The mean annual discharge of the Nile has fallen from the long-term mean of 84 km^3 (1900-1954) to 72 km^3 in the decade 1977-1987, whereas the mean flow between 1984 and 1987 was as low as 52 km^3, with an absolute minimum of 42 km^3 observed in 1984 (Howell & Allan, 1994).

Usually, the causes of drought are complex and interacting and not attributable to one single factor. However, beside meteorological effects, there are a variety of clearly identifiable human-induced factors for the Sahel droughts. The traditional reaction of humans in the Sahel during periods of low rainfall was nomadism or semi-nomadism. The governmental aided establishment of permanent settlings with a maximisation of livestock and cultivation programmes led to an over-exploitation of water resources. An accompanying problem is the soil and vegetation deterioration by overgrazing, with rising potentials for increased wind and water erosion. The related increase in surface albedo might adversely affect regional rainfall mechanisms. Mainguet (1994) proposes a variety of small and specific actions for the gradual rehabilitation of the environment in the Sahel. Among these, the reduction of arable land to those areas with reliable irrigation possibilities is required. The widespread use of solar energy could be considered as an alternative to burn wood. Further drilling of wells for water supply should be restricted. However, the demographic growth in the Sahel region will render any measures to combat drought and desertification extremely difficult. The high vulnerability to climate change can aggravate social and environmental problems (Sokona and Denton, 2001). Awareness building is therefore urgently needed as an area of bilateral and international aid programmes.

In the Horn of Africa, a complex emergency can be observed, where drought interplays with political instability. Long-lasting civil wars in Eritrea, Ethiopia and Somalia hamper the establishment of reliable political systems and the development of stable economies. A prolonged drought threatens the countries' main grain harvest. A large proportion of the vital sorghum crop has already failed due to drought, and much of the remainder has been damaged by insects. Drought-displaced populations in urban centres of Somalia and Ethiopia live under poor sanitation and hygiene conditions, which have led to serious health problems and deaths among children. The repatriation of war-affected Eritrean refugees from Sudan causes enormous problems to handle the large number of returnees. The lack of water, massive land erosion and the presence of landmines with an alarming increase in mine incidents hinders the re-establishment of agricultural activities and a long-term food production. A large proportion of the population which produced a major part of the countries' food supply in former times now depends on emergency food delivered by international donor programmes.

B) Flooding in Bangladesh

Bangladesh is a low lying flat country with a dense network of rivers of which the Ganges and Brahmaputra are among the largest streams In the world. Total runoff drains mostly humid areas which are 12 times larger than Bangladesh's territory (Ahmed and Mirza, 2000). Therefore, flooding is a recurring and natural phenomenon occurring practically every year. Since about 60 percent of Bangladesh is flood-prone land (Siddique and Chowdhury, 2000) major parts of the country will be inundated regularly. Like other riverine communities Bangladeshis learned to live with yearly low to moderate floods and to profit from the overall ecological and agricultural benefits of seasonal flooding. The regular improvement of soil fertility by the sedimentation of alluvial sediments by the so-called *barsha* floods is the occasion for traditional festivals of rural communities (Smith and Ward, 1998). Even nowadays, the direct economic losses of moderate floods are often in contrast to indirect and intangible improvements in agricultural food production through improved moisture conditions for intensified cultivation.

However, severe floods emerging once in 6–7 years are causing serious damage to human life, property and crops. High population increases, an extremely high population density of more than 800 inhabitants per km² and urban growth rates in the range of 20–25% (D'Ercole and Pigeon, 1998) expose millions of people to extreme flood risk. Available space in the floodplains is used for food production which impedes the establishment of flood protection measures. Especially the poorest sections of the population are often pushed to areas with highest susceptibility for inundation (Ahmed and Mirza, 2000). D'Ercole and Pigeon (1998) report that between 1900 and 1971 approximately 460,000 people died and 43 million were affected by hydro-climatic disasters (mainly cyclones and floods) in the territory of today's Bangladesh. These numbers jumped to 200,000, respectively 290 million in the comparatively short period between 1972 and 1996. There were several recent devastating floods in Bangladesh. In 1988, about two-thirds of the country was submerged. In 1991, a storm surge killed 140,000. The destructive 1998 deluge lasted for 2–3 months and seriously affected the economy of the country, mainly by damaging infrastructure and agricultural sectors (Siddique and Chowdhury, 2000). Indeed, D'Ercole and Pigeon (1998) indicate that the number of flood disasters increased during the past century which might be ascribed to human impacts, such as deforestation in the headwaters or increasing direct runoff rates and drainage congestion from the growing urban centres. Climatic variability has been identified as another serious impact factor for flooding in Bangladesh, mainly due to variable snow and glacier melt in the Himalayas or to ENSO effects.

The given circumstances of high population growth rate, scarcity of land, financial difficulties, make the issue of flooding in Bangladesh very difficult. Possible sea level rise and increased river flow due to global climate change as well as further population growth narrows available action strategies to a minimum. A national Flood Action Plan is still under discussion, however its huge financial needs are not affordable and technically and economically problematic. Beside a consequential population policy the reflection on traditions of centuries-old proven abilities to cope with floods would be part of the possible options. In addition to this, Islam (2000) proposes the re-excavation of smaller rivers, dead riverbeds and other surface water bodies and the construction of canals to ease the drainage of flood waters. A side effect might be the establishment of fisheries in order to feed the country. Since most of the reasons for flooding lie outside the control of Bangladesh, the concerns of flooding should be international, thus involving the upstream countries into flood mitigation plans. Furthermore, the scientific community is invoked to give any possible research support.

C) Odra / Oder flood of 1997

One of the most devastating recent floods in Europe was the July 1997 flood on the Odra (Oder in German), the international river whose drainage basin is shared by the Czech Republic, the Republic of Poland and the Federal Republic of Germany. The flood, caused by a sequence of intensive and long-lasting precipitation, turned to be extreme in terms of both river stage/discharge and consequences.

From the hydrological point of view, the Odra flood was a very rare event with return period in some river cross-sections of the order of several hundred years or more. In large parts of the region in which the flood originated, the July values of precipitation were more than 300 % of the monthly mean, in the mountainous areas even more than 400 % (Malitz, 1999). In Racibórz-Miedonia, on the Polish stretch of the Upper Odra, water reached the culmination stage over two meters higher than the maximum observed to date and the corresponding flow was about twice higher than the historical record. When moving downstream, the flood became less intense. However, even in several downstream river reaches, the peak discharge exceeded return periods of 100 years. The summer of 1997 flood on the Oder lasted several weeks. Even the exceedance of historical absolute maximum water levels persisted up to 16 days.

The number of flood fatalities in Czech Republic and Poland reached 114 (Grünewald et al., 1998). In all three riparian countries, and the economic losses were immense, though, there is a very high uncertainty in quantifying the economic losses. The values range between 0.55 and 2.2 billion US$ in the Czech Republic, between 2.5 and 4.0 billion US$ in Poland and between 0.3 and 0.7 billion US$ in Germany.

Since for several years before 1997 only minor floods had occurred in Poland, the awareness and preparedness of the nation was largely inadequate (Kundzewicz et al., 1999). The structural flood defences, for several larger towns upon the Odra and its tributaries and for vast areas of agricultural land, proved to be dramatically inadequate for such a rare flood. Flood defences, designed for smaller, more common floods, fail when exposed to a much higher pressure.

Organisation was also a weak point, especially in the beginning of the flood. Legislation was inadequate; e. g. financial aspects and division of responsibilities and competence. As a result, regional and local authorities were uncertain as to their share in the decision making (with financial implications).

The upsides were accelerated awareness raising and generation of national solidarity. Combating the flood at the Polish reach of the Lower Odra was a real success story. The impression of disorder gradually decreased. Indeed, if a surprise of such an extraordinary scale occurs, time is needed to adapt.

An analysis of the course of the flood and related damages clearly shows up the necessity for a series of flood protection and management strategies in all three riparian countries (Bronstert et al; 2000). They include the creation of an increased water retention potential in the river network system, measures to reduce and delay flood runoff generation and operational needs such as an improved and transboundary flood forecasting system. Research needs comprise an inter-disciplinary perspective of flooding, including human factors. Finally, it should be emphasized that a change of people's view towards a culture of living with risks needs political initiatives and related, long-term conceptions.

D) Southern Afrika / Mozambique flood of 2000

In the beginning of February 2000, torrential rains of return periods in excess of 200 years in places poured over parts of Southeast Africa (Smithers et al., 2001). The combination of the two cyclonic systems and high levels of antecedent soil moisture from a wet early summer resulted in extraordinary flooding. Mozambique has been most severely affected, but other countries in the region such as South Africa, Zambia, Zimbabwe, Botswana, Swaziland and Madagascar also suffered. Mozambique experienced the biggest flood ever known in the history of that country. A year later, in February 2001, Mozambique once again faced a flood disaster, while still suffering from the effects of previous year's devastating floods.

The damage in 2000 was catastrophic: whole villages covered by water, entire crops destroyed, arable land rendered unusable for the next three years, people seeking refuge on roofs of houses and tree tops. Whole sections of main roads were also washed away isolating many towns and villages, including Maputo, the capital city. The disaster left 700 people dead and half a million homeless. According to the UN World Food Programme, Mozambique lost at least a third of the staple maize crop and 80 percent of its cattle. A quarter of the country's agriculture has been damaged.

The 2001 flood disaster carried away thousands of homes, inundated vast areas of farmland. At least 400,000 have been affected, with more than 40 people killed and 77000 rendered homeless.

During and after the catastrophic flood of 2000, it became clear that as well as food and medicine, availability of clean water is a critical issue. The threat of diseases, malnutrition and lack of clean water after the flood cause a higher death toll than that directly by the flood. That implies, that besides the direct assistance during the inundation it is most important to start with the post-flood aid as early as possible. Here, international aid started late (with the exception of that from the Republic of South Africa), as the international press coverage on the flood was initially scanty. The heavy rainfall began on February 3, inundations already started on February 9, but there were no major press reports in, e.g. the USA until March 1.

An expert workshop organised by the Mozambique government, the preparatory secretariat of the 3rd World Water Forum and the IAHR (3rd WWF, 2000) listed the required actions for a improved flood mitigation of the southern African catchments. This list includes the pledge for an improved hydrological observation network, well balanced non-structural and structural measures, and an integrated approach for flood management, including the involvement of the local people and the establishment of regional river boards for the international river basins in that region.

E) Droughts in Northeast Brazil

Northeast Brazil has a semi-arid climate, with strong spatial and temporal variations of rainfall. Water scarcity is a major constraint for agricultural production, quality of life and development of that region. The future situation might be aggravated by the impacts of climatic change.

The region has been struck by droughts in the past with 18 to 20 droughts per century since the 17th century. The population, especially the poor, have been directly affected by the lack of drinking water, food and work. According to some estimates, nearly half of the population (estimated total population: 1.7 million) died in the drought-related famine of 1877-1879 (Magalhaes et al., 1988). Today, during drought years, the effects on the population are not that severe, due to existence of governmental assistance and emergency programs. However, during the extreme dry year 1983, there were still a significant number of drought-related fatalities. The economy continues to suffer considerably during drought years, in particular the production of subsistence crops such as beans and manioc, which were almost totally destroyed during the extreme drought of 1983, while the total GNP of that region declined "only" by about 16%.

During the past decades, emergency programmes to combat drought have proven to be an efficient measure in preventing starvation as well as reducing migration to the coast or to Southern Brazil (Magalhaes et al., 1988). However, sustainable development must not be based on the concept of continuing emergency programs.

With an increasing population and a possibly even higher rainfall variability resulting from climatic change, scarcity of water resources is increasingly constraining development in the semi-arid northeast of Brazil. An efficient, rational, and sustainable use and management of water resources is an imperative. This implies both water storage in small dams to improve the water availability for the local, subsistence farmers and large dams combined with long-distance water diversions for water supply of urban centres (e.g. Recife or Fortaleza) and regions with a very pronounced water deficit. Assessment of water availability and use are key issues within this context.

Taking into account both the internal process dynamics of the causal chain (climate - water availability - agricultural production - quality of life) and the changes of the driving forces (e.g. climate variations; population increase) requires an integrated interdisciplinary approach. In a recent joint Brazilian-German research project (Krol et al., 2001) this approach has been followed by means of developing an integrated model to identify sustainable management strategies on a regional scale. With this model, strategies for a sustainable system control are assessed and - under consideration of the interactions - the potential effects of alternative development strategies of social and natural systems are evaluated. First results show that an integrated model can be a suitable tool for complex and interdisciplinary studies. However, it cannot produce accurate, or always reliable, results for each of the sector-specific details involved, especially regarding small scale processes.

F) Flood protection in Japan (based on Kundzewicz & Takeuchi, 1999)

A comprehensive flood control management in Japan was initiated in the late 1970s after several dyke collapses along major rivers. Realizing that the physical control works alone could not completely protect from floods, the basic strategy of this management was an integrated approach to flood damage mitigation, especially promoting the storage and retardation functions of river basins, including urban ones.

A discharge suppression strategy, sometimes called "law of discharge conservation", implies that new developments should not increase the flood discharge from the area when compared to the original state. Storage and retardation function of disappearing paddy fields and the infiltration capacity of forests, grass and farm lands converted to industrial or urban areas should be replaced by artificial storage and means enhancing infiltration (and storage underground).

Furthermore, land use zoning, flood-proofing, publicizing flood hazard maps, strengthening community systems for evacuation were also emphasized. Other very expensive means were underground storage facilities. Some tunnels cost more than US$ 120000 per meter, such as an underground water-storage tunnel in Tokyo (at depth of 40 m, of diameter 12.5 m, planned to be extended to the length of 30 km).

The current Japanese strategy for flood protection management embraces different components for distinct cases:

<u>Strategy for large rivers</u>: structural means such as dams, levees, flood diversions, channel improvements, upstream sediment control; and non-structural means such as flood forecasting, warning, evacuation and community self-protection teams.

<u>Strategy for major cities</u> along major rivers where absolutely no embankment collapse is allowed: protection by "super levees", high and wide (width 300-500 m).

Strategy for small urban basins: retardation facilities such as district ponds, building storages, emergency use of school playgrounds and parks, underground retardation and drainage pipes; infiltration facilities, conduits with infiltration holes, permeable pavements, improved drainage facilities including drainage pumps in lowlands, flood proofing by elevated house foundations and district walls, protection of subways from entering of a flood wave. The runoff forecast based on quantitative precipitation forecasts.

Strategy for environmental concerns: artificial restoration to a more original state of the hydrological system by enhancement of water storage and infiltration of rainfall in urban areas and in river basins is an efficient solution to both ecological and water resources requirements and implementation of nature-oriented river improvement works. This is of importance for both flood and drought protection.

G) Sustainable development context (after Kundzewicz, 1999)

While flood and drought protection is necessary to the present generation to attain a fair degree of freedom from extreme water-related events, it must be done in such a way that future generations are not adversely affected. According to the UK Environment Agency (1998, p. 9), sustainable defence schemes should "avoid as far as possible committing future generations to inappropriate options for defence".

In order to measure the progress towards sustainable development a set of suitable criteria and indicators are needed, assisting one to steer action, to make decisions and to increase focus on sustainable development. One can take recourse to a general proposal of four conceptual criteria for evaluation of sustainability, viz.: fairness, reversibility, risk and consensus, all relevant in the context of flood defences (cf. Takeuchi et al., 1998).

Fairness, or equity, means that flood protection should be extended to all members of the society. Yet, difference in vulnerability to floods even between neighbouring households can be enormous, especially in less developed countries. Wealthier households can receive flood warning on the radio or TV and can escape by their vehicle, whereas poorer families, deprived of such warning, may remain on site and suffer destruction of their houses and belongings and even death.

Reversibility is not a strong feature of large, structural flood defences. Yet, there have been several examples of decommissioning of dams and of intentional removal of dykes (renaturalisation of rivers). The cost of transformation of an engineered system to the original unengineered state can be predicted.

Risk is typically understood here as a product of low probability of failure and high consequences. The concept of risk can be illustrated in the context of structural flood defences such as dykes. Dykes may provide excellent protection against more frequent small to medium floods, yet their existence creates a false feeling of absolute safety and may trigger intensive development of low-lying areas. If a dyke breaks, this defence does not act as a protection, but rather as an amplifier of destruction; flood losses without a dyke would be lower.

Consensus implies that involved and affected parties should agree as to the programme of flood protection and management. Yet, striving for absolute consensus can suffocate decision-making, as is clearly seen in newly democratised countries.

Which flood protection measures are sustainable? There is little doubt, that source control (watershed management, e. g. by “keeping the water where it falls”) belongs to this category. Yet, this is not sufficient as a remedy against extreme floods and, in particular, urban flooding. Despite the criticism of structural flood protection measures, they are needed to safeguard existing developments, in particular in urban areas. An effective flood protection system is therefore a mix of structural and non-structural measures.

Floods constitute a “hazard” only when human encroachment into flood-prone areas has occurred. Consequences of the inherited non-sustainable development, such as elimination of wetlands and replacing flood storage in floodplains by settlements and infrastructure, can be overcome if humans move out of harm's way. When adequate flood protection cannot be provided, permanent evacuation of floodplains is a viable option that definitely belongs to sustainable development This issue deserves elaboration in the context of global strategies and research actions to engender understanding and execution of this option.

H) The UN context

There are a number of instances, where important UN documents are applicable to the issue of water-related disasters. A few examples pertaining directly to present considerations are given below.

The UN Millennium Declaration from September 2000

Values and Principles:

…

Solidarity: Global challenges must be managed in a way that distributes the costs and burdens fairly in accordance with basic principles of equity and social justice. Those who suffer or who benefit least deserve help from those who benefit most.

….

Shared responsibility: Responsibility for managing worldwide economic and social development, as well as threats to international peace and security, must be shared among the nations of the world and should be exercised multilaterally.

Protecting our common environment

…

We reaffirm our support for the principles of sustainable development, including those set out in Agenda 21.

…

We resolve therefore…

to stop the unsustainable exploitation of water resources by developing water management strategies at the regional, national and local levels, which promote both equitable access and adequate supplies…..

to intensify cooperation to reduce the number and effects of natural and man-made disasters.

Protecting the vulnerable

….

We will spare no effort to ensure that children and all civilian populations that suffer disproportionally the consequences of natural disasters….are given every assistance and protection so that they can resume normal life as soon as possible.

Agenda 21, chapter 18 makes ample reference to disasters and hydrological extreme events.

18.1. Freshwater resources are an essential component of the Earth's hydrosphere and an indispensable part of all terrestrial ecosystems. The freshwater environment is characterized by the hydrological cycle, including floods and droughts, which in some regions have become more extreme and dramatic in their consequences.

Basis for action [*extracts from various sections of chapter 18*]:

Safe water-supplies and environmental sanitation are vital for protecting the environment, improving health and alleviating poverty.

….

Water resources assessment, including the identification of potential sources of freshwater supply, comprises the continuing determination of sources, extent, dependability and quality of water resources and of the human activities that affect those resources.

…

Establishment of national databases is, however, vital to water resources assessment and to mitigation of the effects of floods, droughts, desertification and pollution [*basin-wide databases are of much importance – comment added]*.

Objectives [*extract from one of the sections of chapter 18*]:

The complex interconnectedness of freshwater systems demands that freshwater management be holistic (taking a catchment management approach) and based on a balanced consideration of the needs of people and the environment.

Activities [*extracts from various sections of chapter 18*]:

All States, …, could undertake / implement the following activities to improve integrated water resources management:

- Develop flood and drought management, including risk analysis and environmental and social impact assessment;
- Establish and strengthen the institutional capabilities of countries, including legislative and regulatory arrangements, that are required to ensure the adequate assessment of their water resources and the provision of flood and drought forecasting services;
- Review existing data-collection networks and assess their adequacy, including those that provide real-time data for flood and drought forecasting;
- Provide forecasts and warnings of flood and drought to the general public and civil defence;
- Develop long-term strategies and practical implementation programmes for agricultural water use under scarcity conditions with competing demands for water;
- Monitor the hydrologic regime, …, and related climate factors, especially in the regions and countries most likely to suffer from the adverse effects of climate change and where the localities vulnerable to these effects should therefore be defined;
- Formulate specialized programmes focused on drought preparedness, with emphasis on food scarcity and environmental safeguards;
- Develop and apply techniques and methodologies for assessing the potential adverse effects of climate change, through changes in temperature, precipitation and sea level rise, on freshwater resources and the flood risk;
- Initiate case-studies to establish whether there are linkages between climate changes and the current occurrences of droughts and floods in certain regions.

Means of implementation [*extracts from various sections of chapter 18*]:

Because well-trained people are particularly important to water resources assessment and hydrologic forecasting, personnel matters should receive special attention in this area.

…..

Strengthening of the adaptive research capacities of institutions in developing countries.

…..

States should undertake co-operative research projects to develop solutions to technical problems that are appropriate for the conditions in each watershed or country. States should consider strengthening and developing national research centres linked through networks and supported by regional water research institutes.

…

Monitoring of climate change and its impact on freshwater bodies must be closely integrated with national and international programmes for monitoring the environment.

….

Extensive research is necessary in this area and due account has to be taken of the work of the Intergovernmental Panel on Climate Change (IPCC), the World Climate Programme, the International Geosphere-Biosphere Programme (IGBP) and other relevant international programmes.

…..

There is also a need for co-ordinated research networks such as the International Geosphere-Biosphere Programme/Global Change System for Analysis, Research and Training (IGBP/START) network.

International Strategy for Disaster Reduction (ISDR) is a recent initiative, a UN-created successor body to the International Decade for Natural Disaster Reduction, which for the first time shifted focus from disaster response to disaster reduction, underscoring the crucial role of human action. The IDNDR ended in 1999.

ISDR is a global framework for action with a view to enabling all communities to become resilient to the effects of natural disasters and to proceed from the protection against hazards to the management of risk through the integration of risk prevention into sustainable development.

I) WADI: An example of integrated research in support of Integrated Water Resources Management (IWRM) and Comprehensive Disaster Risk Management (CDRM)

The WADI (WAter-related DIsasters), recent research initiative of the Potsdam Institute for Climate Impact Research (PIK) responds directly to the increasing vulnerability of humankind to water-related disasters, i.e. floods and droughts in a changing world, subject to increasing climate variability and change, environmental degradation, increasing population densities in disaster-prone areas, loss of traditional adaptation strategies etc.

The interdisciplinary WADI research initiative is designed to provide a better understanding of driving forces, impacts and feedbacks of water-related extreme events in the Earth system. WADI uses a common modeling framework that integrates the various subsystem analyses. This integrated modeling framework was developed over the past five years and will be applied to selected regional water systems.

WADI is taking a global approach by identifying critical thresholds and ”hot-spots” in the Earth system, that are particularly vulnerable to water-related extreme events. Regional water systems, selected according to this global assessment of vulnerability, will be analyzed for their exposure and sensitivity to water-related extremes and their adaptive capacity.

WADI provides a scientific basis for adaptation and mitigation options for a sustainability transition, that are developed jointly with stakeholders from the selected regions, e.g. NGOs and governmental organizations, the private sector and regional scientists.