

## Coping with variability and change: Floods and droughts

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### Abstract

*Floods and droughts are natural phenomena for which the risks of occurrence are likely to continue to grow. Increasing levels of exposure and insufficient adaptive capacity are among the factors responsible for the rising vulnerability. The former is conditioned by anthropopressure (e.g., economic development of flood-prone areas) and adverse effects of climate change; scenarios for future climates indicate the possibility of amplified water-related extremes. This article presents the current situation of coping with extreme hydrological events within the pressure-state-response framework. Among promising response strategies, the role of forecast and warning, and of watershed management are reviewed. Sample success stories and lessons learnt related to hydrological extremes are given and policy implications discussed.*

*Keywords:* Extreme hydrological events; Floods; Droughts; Global change; Climate variability; Climate change; Sustainable development; Vulnerability; Risk.

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### 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 being, bringing suffering and death, as well as immense, and still growing, material losses. The 21<sup>st</sup> century is predicted to be an age of water scarcity. Yet, flood losses worldwide continue to rise, soaring to tens of billions of US dollars in material damage and thousands of fatalities per year.

Hydrological variables, such as precipitation, river flow, soil moisture and groundwater levels, display strong spatial and temporal variability. From time to time they take on extremely low or extremely high values, exerting considerable, and adverse, impacts on society, and ecosystems.

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Even if common understanding of the notions of droughts and floods is straightforward, no uniform, rigorous and broadly agreed upon definitions exist of these terms. The notions refer to situations that arise when an arbitrarily defined threshold is exceeded. A drought can result from low precipitation over a certain time period, possibly accompanied by high temperatures, driving increased evapotranspiration. The notion of drought should not be confused with aridity, which means that water is always in short supply, i.e., a near permanent dryness is a normal condition. Droughts may strike large areas (up to sub-continental scale) and, by their nature, they may extend in time for months, years or even 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 droughts. 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, while an environmental drought would refer to impacts on ecosystems (e.g., freshwater ecosystems, riparian zones and forests).

However, droughts should not be viewed as exclusively physical or natural phenomena. Their socio-economic impacts may actually arise from the interaction between the natural conditions and human water consumption, both of which are subject to variability and change. Human consumption effectively exacerbates the impact of drought. A socio-economic drought occurs when the demand for water and water-related economic goods and services (e.g., fish,

hydropower, irrigated agriculture and horticulture) exceed supply. It is important to note that certain aspects of water scarcity may be related to socio-economic activities and policy. Thus, in urban areas, water scarcity can be related to inadequate service delivery as well as physical scarcity of the resource.

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

The term flood is often understood to indicate out-of-bank flow, when the normal channel cannot convey the total water flow, which spills beyond the channel, causing damage. There are several kinds of floods, each with different properties and a long history of human protective activities, such as river floods induced by rainfall and/or snowmelt, including flash floods from intense rainfall during a short period. According to the Intergovernmental Panel on Climate Change (2001a), sea levels rose by 10–20 cm in the 20<sup>th</sup> century and will continue to rise. This will have substantial adverse effects on low-lying lands and river deltas in flood prone areas: increased probability of storm surges and tidal flooding is forecast. It is stressed here that major floods have been caused by storm surges, such as the disastrous flood in Bangladesh in 1991. Coastal flooding is beyond the thematic scope of this article, however.

## 2. Current situation

### 2.1. Pressure

Freshwater, a necessary condition of life and a raw material used in very large volumes in virtually every human activity, is becoming increasingly scarce in many places and time zones. Water use has increased considerably over the last hundred years, twice as fast as the population growth, and water demand for food production, hygiene and human well-being, industrial uses, etc. continues to grow rapidly. Societies are becoming increasingly vulnerable to droughts and water shortages.

For thousands of years, people have settled in floodplains, attracted by the fertile soils, the flat terrain appropriate for settlements, the easy and safe access to water, and the possibilities of riverine transport. Floods are natural phenomena that have always existed, and people have tried to use them to advantage to the extent possible. However, increased population density, urbanization and agricultural expansion in flood-prone areas have steadily increased society's vulnerability to the negative effects of floods. As a consequence, floods have become more and more disastrous to human settlements.

Economic development of flood-prone areas is a factor that increases flood risk. Population pressure and shortage of land cause encroachment into floodplains. Mushrooming informal settlements often form endangered zones around mega-cities in developing countries. Poor migrants often flock to places vulnerable to flooding and where effective flood protection measures are not in place. In fact, many such areas had purposely been left uninhabited exactly because they are flood-prone.

Structural measures, such as the building of dykes or the straightening of river courses — the most common flood defences — have often led to a false sense of security. Nowadays, the negative side effects of such structures are widely recognized: for instance shifting flood problems downstream, high maintenance costs or adverse ecological impacts. Flood risk mitigation policy is considered to consist of a mixture of appropriate options, i.e., an optimal and site-adapted combination of structural and non-structural measures.

In most countries, there is an over-reliance on flood-control works, such as levees, reservoirs etc. In reality, no flood-defence structures offer perfect security. Dykes protect against floods corresponding to a certain magnitude depending on the required level of protection (e.g., a 10 year flood, i.e., a flow magnitude with a 10% probability of being exceeded in any given year). However, in the event of a deluge of disastrous magnitude, causing dyke break, losses can be very high in a levee-protected landscape — higher than they would have been without the levees. This is partially due to a false feeling of security among riparians and a growing accumulation of wealth in endangered areas.

There is a significant increase in losses caused by extreme hydrological events resulting from soaring anthropopressure. Massive deforestation and urbanization reduce the available water storage capacity and increase flood waves. Water runs off faster to the sea, yet may be acutely missed in periods of low flow and drought. The rapid growth of industry and services in Asia during the 1990s resulted in a considerable change in land-use patterns. In Thailand, for example, deforestation caused a reduction in the natural retention and over-bank storage capacity in the lower Chao Phraya basin. It is estimated that the contribution to incremental downstream flooding has been in the order of 3,000 m<sup>3</sup>/s.

Mechanisms of climate change and variability are intimately interwoven with more direct anthropogenic pressures. Scenarios for future climate conditions indicate that water-related extremes may become amplified. 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 0.5–1% per decade over much of the mid- and high latitudes of the northern hemisphere (IPCC, 2001a). Furthermore, in regions where the total precipitation

has increased, there have been even more pronounced increases in heavy and extreme precipitation events. Actually, increases in intense precipitation have been documented even in some regions where the total precipitation has decreased or remained constant.

A number of studies report that high floods have become more frequent (e.g., Milly et al., 2002). A 100-year-flood magnitude determined from older data may correspond to much shorter return periods for more recent data and a tendency of increasing flood frequency 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 rising trends everywhere. The time series of flood data show a complex response (due to other, non-climatic factors), the behaviour 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 in comparison with those of the previous 100 years. The warm phase of ENSO has become more frequent, persistent and intense. During this phase (El Niño), extreme water-related events occur more frequently, with intense precipitation and floods in some locations and precipitation failure and droughts in other regions.

Scenario analyses indicate that characteristics of extreme climatic phenomena related to floods and droughts may change in the future (cf. IPCC, 2001a, 2001b). 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 winter in mid- to high latitudes, more intense storms at mid-latitude, and a more El Niño-like mean state ENSO. The frequency of extreme precipitation events is projected to increase over many geographical areas. In the continental interiors, there is a growing risk of summer droughts, as reduced precipitation and higher temperatures may coincide, causing higher evapotranspiration and taxing available water resources.

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

Usually, droughts arise from complex and interdependent causes, and are not attributable to any single factor. Regarding the Sahel droughts, there are a variety of clearly identifiable human-induced factors aside from the meteorological effects. The traditional reaction of inhabitants of the Sahel during periods of low rainfall was nomadism or semi-nomadism. The government-assisted establishment of permanent settlements, with livestock and cultivation programmes, has led to an overexploitation of water resources. An accompanying problem is the deterioration of soil caused by overgrazing, leading to increasing exposure to wind and water erosion.

## 2.2. State

According to the Red Cross, floods affected more than 1.5 billion people worldwide in the period from 1971 to 1995. This number included: 318,000 dead (i.e., over 12,700 fatalities per year, on average) and over 81 million homeless (IFRCRCS, 1997). Additional suffering occurred through the spread of diseases in flooded areas, e.g., diarrhea or leptospirosis.

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 Berz's data for the period 1950–98, one could state that the number of great flood disasters worldwide has risen considerably over 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 large flood disasters during the 1990s was greater than the combined total of the three decades from 1950 to 1979.

In the 1990s, large flood disasters in which either the number of fatalities was greater than a thousand or the material damages exceeded one billion US\$, or both, numbered over two dozen worldwide. During two days in April 1991, 140,000 people were killed in Bangladesh in the most disastrous storm surge flood. The highest material losses, of the order of US\$ 26.5 and 30 billion, were recorded in China in the 1996 and 1998 floods, respectively. During the recent floods in Europe, the peak discharge observed at Raciborz-Miedonia on the Odra (Poland) in the 1997 flood was twice as high as the next highest flow rate in the instrumental record (Kundzewicz et al., 1999), while the level of the river Elbe at Dresden (Germany) observed in August 2002 was 939 cm, as compared to the previous record of 877 cm in 1845.

Bangladesh is a low-lying, flat country with a dense network of rivers, the largest of which are the Ganges and the Brahmaputra, draining mostly humid areas 12 times larger than the territory of Bangladesh itself. Flooding occurs practically every year in Bangladesh, where 60% of the territory is flood-prone. As in other riverine communities, Bangladeshis have learned to live with yearly low to moderate floods (*barsha*) and to take advantage of the overall ecological and agricultural benefits of benign floods.

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

Droughts have recently occurred in several regions. Even in developed countries, an extreme drought may cause considerable disturbances in terms of environmental, economic

and social losses. It is assessed that the 1988 drought in the USA may have caused a direct agricultural loss of US\$13 billion. The more recent 1998–99 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.

Northeast Brazil has been struck by 18 to 20 droughts per century over the past 400 years. During drought, the population was directly affected by lack of drinking water, food and work — especially the poor. According to some estimates, nearly half of Brazil's total population died in the drought-related famine of 1877–79. Recently, drought losses have been less severe, due to government assistance and emergency programmes. However, during the extremely dry year 1983, there were still a significant number of drought-related fatalities and the economy suffered badly, mainly due to the almost total destruction of subsistence crops, such as beans and manioc.

The Intergovernmental Panel on Climate Change finds (2001b) that the costs of extreme weather events have exhibited a rapid upward trend in recent decades. From the 1950s to the 1990s, yearly economic losses from weather extremes increased tenfold (in inflation-adjusted dollars). A part of the observed upward trend in weather disaster losses is linked to socio-economic factors, such as population increase and accumulation of wealth in vulnerable areas. However, these factors can only partially explain the observed growth. A portion of the losses is linked to climatic factors, such as the observed changes in precipitation.

Pielke and Downton (2000) studied the rates of change in flood characteristics and socio-economic indicators in the United States for the period from 1932 to 1997. They found that the total annual flood damage, adjusted for inflation, had grown at an average rate of 2.9% per year, which was higher than the population growth rate of 1.3% and that of tangible wealth per capita of 1.9% (in inflation-adjusted dollars).

The increase in flood damage is evident in many regions. For example, the statistics of flood damage maintained by the Thai Department of Public Welfare and the Department of Local Administration for the years 1978 to 1995 in the provincial areas of Thailand show a clearly increasing trend (Table 1).

### 2.3. Response

#### 2.3.1. Response to floods

Owing to the complexity of the mechanisms of water-related extremes and their impacts, protection will increasingly call for integrated solutions, combining 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, *inter alia*, geographic factors and

**Table 1. Statistics of flood damage 1978–95 in provincial areas of Thailand.**

Year	Flood damage in US\$ millions	Year	Flood damage in US\$ millions
1978	1.03	1987	32.36
1979	0.15	1988	298.38
1980	75.75	1989	457.13
1981	14.40	1990	260.15
1982	9.75	1991	102.78
1983	48.06	1992	206.38
1984	13.60	1993	86.24
1985	12.90	1994	1.79
1986	24.85	1995	464.3

*Source:* From statistics in Baht from departments of Public Welfare and Local Administration, Government of Thailand.

*Note:* Damages within the city of Bangkok not included in the above.

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, the former including dams and flood-control reservoirs, dykes, etc. Constructing reservoirs to store excess water allows a regulated temporal distribution of streamflow and helps alleviate flooding problems by flattening flood peaks. Possible non-structural flood-protection measures include:

- Zoning, i.e., regulation of development in flood hazard areas, 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; and
- Capacity building (improving flood awareness, understanding and preparedness), and enhancing the participatory approach.

#### 2.3.2. Drought response

Among drought-protection measures, augmenting the supply of water can be achieved locally by conjunctive use of surface- and groundwater in the area, if available, or by transfers from external surface water sources (lakes and rivers) and from groundwater. Increasing the storage of water (i.e., the classical drought management policy option), is becoming increasingly difficult to implement because of decreasing availability of the resource and adverse environmental and social impacts of reservoirs, especially large ones. Also intensive groundwater withdrawal for drought management is not a sustainable solution. In many countries, including Mexico, the US, Japan, China and Thailand, this has caused severe land subsidence.

Recently, action plans to combat drought have increasingly shifted from provision of additional water (supply management), to effective demand management of the finite and scarce freshwater resource. This means seeking “negalitres”, i.e., negative litres of conserved water rather than megalitres of supplied water (von Weizsäcker et al., 1997). The need for improved efficiency in water use as well as water productivity is essential. Measures include:

- improved land-use practices;
- watershed management;
- rainwater/runoff harvesting;
- recycling of water (e.g., use of treated municipal wastewater for irrigation); and
- development of water allocation strategies among competing demands.

Despite the pumping costs, using groundwater reservoirs (aquifers) to store water when available can be more advantageous than surface water storage, which may suffer very high evaporation losses. Drought contingency planning, including restrictions on water use, rationing schemes, special water tariffs and reduction of low-value uses (agriculture), needs to be seriously considered. Reduction of wastage and improvement of water conservation via reduction of the unaccounted for water losses and re-thinking of the system of water pricing and subsidies deserve attention.

Enhancing water storage serves to mitigate both types 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 storage at different scales is necessary to maximize water availability at a minimum cost, with appropriate consideration of externalities.

### 2.3.3. Risk assessment and risk maps

The assessment of risk of possible extreme hydrological events, indispensable in risk management (Plate, 2002), provides the basis for long-term management decisions regarding 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 to persons and objects (“elements at risk”) in the endangered region.

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.

### 2.3.4. Forecast and warning response

One of the sound policies to mitigate flood and drought risks is to change from a 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 possible formation of a flood or a drought, through 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 both 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
- Assistance during and after the disaster hit: 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, 2002).

Today, weather forecasting models can supply information on temperature, wind and precipitation up to approximately one week in advance. However, such meteorological 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 run-off, 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 locations and times) of propagation of the flood wave in the river channel. These models are highly developed for many large river systems, and have served to produce flood level projections for many years. Since such models mimic propagation of a flood wave already existing in a channel, they can only provide relatively short lead times depending on the size of the basin. While for Cologne on the river Rhine this lead-time is slightly more than two days, for smaller rivers the lead times are considerably shorter and hydraulic models 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 increased early warning lead-times in accordance with

increased reliability of weather forecasts. Another challenge 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 the hydrological response of very large river basins promises new challenges and opportunities.

In ensemble climate forecasting (Wood et al., 2002), 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. (2002) applied this approach during the drought in the summer of 2000 in the eastern and central United States. 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 run-off can be used as surrogate observations.

More recently, this streamflow forecasting strategy has been implemented over the Columbia River basin to produce forecasts with six months lead time starting with April 2001 (see [www.hydro.washington.edu](http://www.hydro.washington.edu) for details). The gridded observed spin-up forcings for the VIC model (Liang et al., 1994; Lohmann et al., 1998a, 1998b) 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.

### 2.3.5. Watershed management

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 aims to:

- Support site-adapted, ecologically sound agriculture with soil conservation measures, cultivation of sub-crops and intercropping to avoid surface run-off and erosion;
- Improve rainwater drainage in urban areas;
- Re-establish natural floodplains and riparian forests;
- Designate flood zones (zoning); and
- Inform local populations of the existing flood risk.

These measures are often combined into integrated programmes including overall land-management plans. They

are complemented by “soft” technical measures with a high benefit/cost ratio, such as the installation of small flood retention-basins or improving conveyance by removal of hydraulic bottlenecks in the streams in the basin.

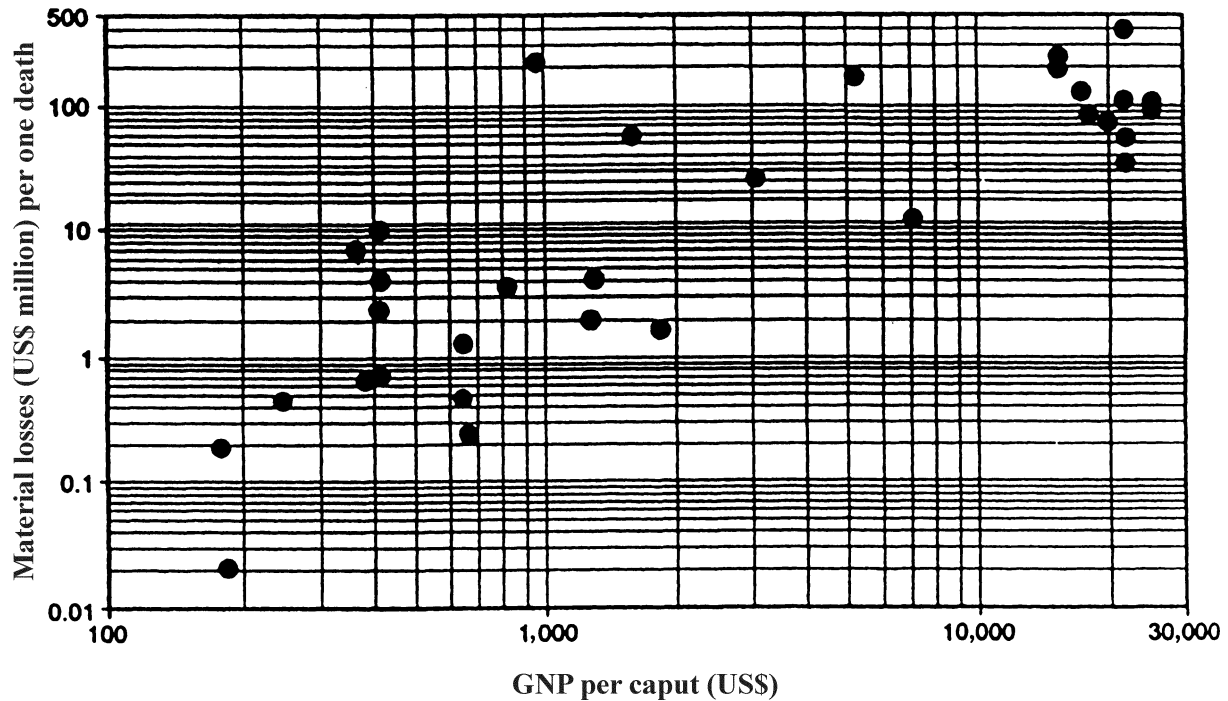
However, the implementation of watershed management plans requires considerable financial resources. In developing countries, available funds (if any) are often needed for the recovery from past flooding disasters (Plate, 1999) and often no money remains to prepare for future extreme events. Thus, in 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 few days or weeks (Schulze, 2000).

## 3. Success stories and lessons learned

Humankind has interacted with water-related extreme events throughout history, with various degrees of success. Sometimes efforts have failed and floods or droughts (*cum* desertification) have wiped out entire civilizations.

A special class of success stories relate to cases where a disaster repeatedly occurs in the same area at relatively short intervals. With the event still fresh in people’s memory, mitigation works are undertaken more vigorously, and damages of subsequent events are usually less thanks to the better state of preparedness. An example of this type of successful mitigation relates to floods along the rivers Rhine and Moselle and their tributaries, where people have learned to live with recurring floods. Large floods, each of a nearly centennial magnitude, occurred in the Rhine basin twice within 13 months, 21–31 December 1993 and again 24 January–4 February 1995. In December 1993, the level of the Rhine at Cologne reached 1063 cm, while in the 1995 flood, it reached 1069 cm. Although the second flooding was more severe, damages were considerably less. The reason was the greater state of preparedness and readiness on the part of the public due to continuous extension of precautionary measures and information to local populations, which helped the region to accommodate the floods better. The adverse effects of river straightening and the building of dykes along the Rhine are currently being compensated for to some extent 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 modern United States history. 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 level was exceeded for more than three weeks (*cf.* Natural Disaster Survey Report, 1994). The Great Mississippi Flood had a significant impact on flood management policy. The recommendation of the US Interagency Floodplain Management Review Committee after the 1993 flood was that federal, state and local governments and those



**Figure 1.** Relationship between the ratio of material losses in million US\$ to number of deaths and GNP per capita for disastrous floods in the 1990s. *Source:* Kundzewicz and Takeuchi (1999).

who live on or have an interest in the floodplain should take responsibility for development and fiscal support of floodplain management activities (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 and in other regions in the United States is of the order of 20,000 (after Galloway, 1999).

The Japanese strategy for flood preparedness deserves attention (*cf.* Kundzewicz and Takeuchi, 1999). The number of flood fatalities in that country with a high flood risk has decreased dramatically. However, the Japanese system, containing very expensive infrastructure (such as super-levees), may not be replicable in less developed countries, due to the high cost.

Although water-related extremes strike developed and developing 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 considerably lower than in developing countries. Figure 1 illustrates the ratio of material losses per one death as a function of GNP per capita in US\$, established for large floods during 1990–96 (Kundzewicz and Takeuchi, 1999). As expected, there is a general pattern to this relationship. For catastrophic floods in developing countries, material losses per fatality can be as low as US\$ 21,000, while in developed countries they can go up to US\$ 400 million.

In developed countries, concerted measures during drought emergencies are in place, requiring cooperation between water users, water providers and authorities. There is a roster of short-term options which could be used. Glantz (1982) describes the many interrelated activities triggered by a drought forecast in the catchment of the Yakima River (USA), such as drilling additional wells, trading water rights, 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 the 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 the resource. A system of prices and incentives was introduced, which allows water use to be managed more efficiently, especially in small irrigation projects.

Although there is a roster of drought mitigation measures that work in developed countries, they are not of much help in vast areas of the developing world. Commenting on the value of long-range weather forecasting in the West African Sahel, Glantz (1977) notes that even if a six-month weather forecast has been available, few of the areas could have responded differently. In developing countries, droughts can indirectly decimate populations, as drought-induced hunger weakens populations, and undernourished people are more prone to infections and diseases that may kill many. There

are cases where drought is an element in a complex emergency, comprising many stresses including civil war.

Several general lessons can be drawn from recent experiences (after Kundzewicz and Takeuchi, 1999):

- Floods occur all over the world, even in arid regions.
- Recent climate variability and change seems to have aggravated flood and drought hazards in many regions; this tendency is likely to continue.
- The poorer a society, the more tragic are its disasters. Victims who lose the most have the least to lose (in absolute terms); some may lose all they have, including their lives.
- 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 to occur in the same place (a common misconception amongst the general public). A large flood may recur again soon, as shown by several recent examples.
- People's experience of a flood tends to reduce damages caused by the following flooding event, especially if it occurs within a relatively short time. However, memory fades very quickly (short-memory syndrome).
- Adequate water management laws could improve drought preparedness in many regions. Under current legislation and in open access regimes, the rights of individuals and public agencies are not clearly specified.

#### 4. Issues and policy implications

To reduce human vulnerability to water-related extreme events, a general change of paradigm is needed. The attitude: "living with water-related extremes" and accommodating them in regional/local planning, seems more sustainable than hoping for a protection system that guarantees complete safety. It is impossible to design a system that never fails (fail-safe). What is needed is a system that fails in a safe way (safe-fail). The policy of fail-safe systems is therefore ceding to safe-fail preparedness (*cf.* Hashimoto et al., 1982). Also, integrated approaches can help reduce the frequency, severity, and impacts of water-related extreme events.

Several aspects of water-related disasters are linked to the overarching principle of sustainable development (Kundzewicz, 1999): 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 criticized in the context of sustainable development because they reduce options for future generations and introduce unacceptable disturbances in ecosystems.

A blueprint for integrated sustainable development has been provided through a number of international conventions,

strategies and declarations. 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 into the future that do not increase climate extremes, but improve land-use patterns and hence reduce the vulnerability of populations to water-related extremes. Moreover, with regards 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.

##### 4.1. Data and information

Progress in establishing systems of protection against hydrological extremes depends on collecting and analyzing hydrological data, maintaining archives of information, and on the existence of mechanisms for the distribution and exchange of data. Hydrological information is a prerequisite to the design and operation of preparedness systems to cope with water-related extremes, such as reservoir design and operational flow forecasting. Furthermore, collecting and analyzing extended time-series of hydrological, climatological and related data is needed to detect changes in hydrological processes and in extreme events, such as those caused by climate variability and change or land-use change. Yet, in many countries, owing to financial constraints, hydrological services are shrinking and are unable to provide the required information. Networks of observation stations are in marked decline in much of Africa, and the available database to assess drought and desertification risks and plan for their abatement is inadequate. It is very important to reverse this declining tendency. International initiatives in this area include the World Hydrological Cycle Observing System (WHYCOS) project of the World Meteorological Organization (WMO), which aims at strengthening hydrological networks (see [www.wmo.ch/web/homs/whycos.html](http://www.wmo.ch/web/homs/whycos.html)) and the International Global Observing Strategy (see [www.igospartners.org](http://www.igospartners.org)).

##### 4.2. 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 in order to improve the reliability of real-time flood predictions, particularly in small and medium-sized river catchments. It has been found that, in several regions of the world, extreme hydrological events are highly influenced by particular phases of oceanic temperature/pressure oscillations. There is, therefore, a potential for development of long-term forecasts, based, for example on sea surface temperatures. Yet the problem has to be seen in a holistic perspective and a



good forecasting system should be embedded in an integrated disaster preparedness and mitigation policy, so that a forecast is effectively used.

#### 4.3. *Integrated water resources management (IWRM)*

It is increasingly recognized that integrated management of water resources is required. The statements contained, for example, in Agenda 21 (Chapter 18) (UNCED, 1993), are applicable to the context of water-related extremes.

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, takes into account and recognizes the importance of:

- The coordinated development and management of water, land and related resources, in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems;
- All natural physical aspects of surface water and groundwater systems, including their 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; and
- The complexity of the spatial distribution of water and competing demands, such as upstream/downstream interactions, inter-basin transfers, shared watercourses etc.

##### 4.3.1. *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) 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 unit. The vulnerability approach goes beyond the mere prediction of an occurrence of stress and its impacts: it presents to local and regional stakeholders the full range of drivers of change and climate, hydrological and environmental effects and public feedback, 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 the adaptive capacity of a society, the incidence of extreme events, and a population's exposure to them.

#### 4.4. *Perspectives of developed and developing countries*

Prospects for human mitigation of hydrological extremes differ substantially according to level of development (Kundzewicz and Kaczmarek, 2000). A number of recent

investigations of the vulnerability of societies to extreme hydrological situations have resulted in policy recommendations, for example in the US and Norway. Governments in most developed countries have undertaken effective and appropriate action to build preparedness systems that minimize negative consequences of hydrological extremes. However, in most developing countries, scarcity of financial and human resources have hampered such efforts. Developing countries are not always able to cope with hydrological extremes without foreign and international assistance.

Given the current economic situation in the Asian and Pacific and other regions, as well as prevailing problems of poverty, unemployment and environmental stress, there is a danger that the priority given to sustainable management of flood and drought events could be lowered, as each country seeks to regain economic momentum. Support for capacity building from international, regional and national external support agencies is thus urgently needed.

Kulshreshtha (1993) indicates that, in the arid and semi-arid regions of Africa, food insecurity is a major issue related to water resources. His study shows that over a dozen countries in Africa were already under water stress, or experiencing water scarcity, in terms of reaching the goal of food self-sufficiency alone. In the face of increasingly severe water shortages, achieving national food self-sufficiency may not be a sustainable option for water-scarce countries, and a policy shift is needed from self-sufficiency to self-reliance in food. 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 many low-income countries that rely heavily on intensive irrigation-based agriculture do not have the financial resources to shift development to other sectors that could create employment and generate a higher income.

Flood and drought management and preparedness planning in most developing countries is largely carried out according to civil administrative units and divisions, rather than by water drainage basins (catchments). Management and planning need to be undertaken at the catchment level, a natural scale at which to deal with water systems. In addition, management and planning is mostly conducted from central government offices — thus emphasizing needs of the central province, sometimes at the expense of other water-related activities in outlying provinces. In general, water resources management is institutionally fragmented. Water affairs are being dealt with by a number of agencies established for various purposes and under different laws and regulations. Sometimes their functions and powers overlap. Problems emerge with information exchange, coordination, cooperation, distribution of competences, responsibility and accountability.

#### 4.5. *Capacity building, stakeholders and gender issues*

Capacity building, an essential step in flood and drought mitigation, is a burning need especially in less developed

countries. It includes education, awareness raising, and the creation of a legal framework and well-designed institutions, with a clear mandate, that enable people to access information and participate in decision-making.

The ability to reduce the impact of water-related disasters also depends on the state of science and technology of each country. Many countries lack the capacity to acquire new technology applicable to disaster reduction and prevention. The international community needs to share its experience to narrow the gap between current knowledge and policy making.

Appropriate procedures need to be established to evaluate economic, social, and environmental damages due to floods and droughts, as well as for risk assessment and planning of preparedness systems.

A comprehensive disaster risk management (CDRM) strategy for water-related extremes requires that key agencies collaborate in a coordinated way in pursuing the recommended management actions. Early consideration should be given to institutional arrangements suitable for assuring that decisions are taken with appropriate consultation, and that the responsibility for implementing each action is assigned to the most appropriate agent.

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

Any decision-making in flood and drought relief strategies should include broad public participation from all sectors in society. In many developing countries, women and girls are frequently the main providers of water for household uses. Drought alleviation could reduce the daily burden on women to carry water from distant sources. Women also play a central role in the 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., in some countries, married women may not respond to flood warnings if their husbands are absent from the home).

## 5. Concluding remarks

The risk of water-related extreme events, floods and droughts, is likely to grow. Although the 21<sup>st</sup> century has been called ‘the age of water scarcity’, losses from floods are, at the same time, increasing. The cost of extreme weather events has indeed exhibited a rapid upward trend in recent decades, partly linked to socio-economic factors, but also to climatic factors, such as the observed changes in precipitation.

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

Preparedness systems should be designed to protect as far as technically possible and affordable, and accommodate, i.e., prepare to live with water-related extremes. If the necessary level of protection cannot be provided and accommodation is not possible, retreat could be a solution. This applies, for instance, to vulnerable informal settlements that are often scattered around large cities, especially in developing countries; such areas can be seriously affected by water-related extremes and neither adequate water supply nor flood protection may be provided.

To reduce human vulnerability to water-related extreme events, a general change of paradigms is needed. Anticipation and prevention are more effective and less expensive than emergency response. There is no such thing as perfect security, as all defences may fail in the 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 the interacting pressures that cause water-related extremes, a holistic perspective should be taken and integrated preparedness systems sought. There is no single universal remedy against water-related extremes and it is necessary to devise a site-specific mix of measures, both structural and non-structural.

A holistic perspective calls for:

- Joint consideration of data collection, availability and use;
- A forecasting, warning/response system; and
- A system for strengthening the weakest elements of this chain.

Hydrological information is a prerequisite for the design and operation of preparedness systems for water-related extremes. Advances in protective systems depend on the capacity to collect and analyze hydrological data, maintaining archives of information, and efficient data distribution and exchange.

Other important activities that can strengthen preparedness systems are:

- Improvement in flood and drought forecasting;
- Risk assessment;
- Watershed management (source control); and
- Increasing water storage (though not necessarily in large reservoirs) serving to protect against both droughts and floods.

Enhancing water storage is a remedy for both types of hydrological extremes: floods and droughts. Catching water when abundant and storing it for the times of need can be realized with reservoirs of all scales and also by underground

retention (e.g., by enhancing infiltration). However, in several countries, there is growing opposition against building large structural defences.

Water-related emergencies illustrate the need for concerted action, effectively coordinated across sectors. A number of institutional and organizational issues have been identified that can strengthen preparedness systems. These include:

- Enhancing coordination;
- Dividing competence, tasks and responsibilities among different agencies;
- Acting at watershed level rather than within administrative boundaries; and
- Engaging the participation of stakeholders.

Developing countries often do not have adequate financial resources or qualified human resources to be able to cope with hydrological extremes without international assistance. An increase in effective assistance to vulnerable developing countries is badly needed.

## Acknowledgements

This article is based on the thematic background paper presented at the International Conference on Freshwater, Bonn, 4–8 December 2001 (Kundzewicz et al., 2001). Useful, constructive comments made by an anonymous referee of *Natural Resources Forum* are gratefully acknowledged.

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