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Coping with Hydrological Extremes

Zbigniew W. Kundzewicz , *Research Centre of Agriculture and Forest Environment, Polish Academy of Sciences, Poznan, Poland, and* **Zdzislaw Kaczmarek**, *Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland*

Abstract: *Coping with hydrological extremes, floods, and droughts has been a major concern since the dawn of human civilization. Freshwater, a necessary condition of life and a raw material used in very high volumes in virtually every human activity, is becoming increasingly scarce. Water use has risen considerably in the last hundred years at a pace exceeding the population growth. Therefore, societies are increasingly vulnerable to droughts and water deficits. Although the 21st century is heralded as the age of water scarcity, flood losses continue to grow. Increasing global vulnerability results to a large extent from soaring anthropopressure: settlements in hazardous locations and adverse land use changes. Deforestation and urbanization lead to reduction of the storage volume and higher values of runoff coefficient. In more wealthy countries, it is the material flood losses that continue to grow, while the number of fatalities goes down. Advanced flood preparedness systems can save lives and reduce human suffering. In some regions of the world, long-term forecasts (e.g., ENSO) help improve the preparedness for hydrological extremes, both floods and droughts, and hopefully will even more so in the future. Scenarios for future climate indicate the possibility of sharpening the extremes and changes of their seasonality. For instance, in Western Scotland and Norway, an increase of winter floods has already been observed. According to recent assessments, there is a growing risk of summer droughts in the Mediterranean region: less precipitation in summer and higher temperature will coincide, causing higher evapotranspiration and less runoff. Fighting with floods and droughts has not been quite successful. Humans have to get used to the fact that extreme hydrological events are natural phenomena that will continue to occur. While doing one's best to improve the preparedness systems, it is necessary to learn to live with hydrological extremes.*

Keywords: *Natural disasters, floods, droughts, climate change, extreme events.*

Introduction

Hydrological extremes, floods and droughts, have always been a major concern. Despite the fascinating achievements of science and technology in the 20th century, floods and droughts 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 continue to rise, soaring to tens of billions of dollars (US) in material damage and to thousands of flood fatalities a year.

Variables characterizing processes of the hydrological cycle are subject to variability. From time to time, they take values in their low or high ranges, including hydrological extremes. When there is too little or too much water, the problem becomes spectacular and of concern to the general public. River flow is the hydrological variable of most direct practical importance. Episodes of streamflow droughts and floods can be seen in the framework of threshold crossing, as excursions below a threshold of low flow, and over a threshold of high flow, respectively.

Floods and droughts are described by two sets of characteristics: hydrological (geophysical) and socio-economic. The former is illustrated in Figure 1 as threshold crossing-related characteristics of the river flow process: maximum and minimum flow, total volume, and duration time of an excursion. For floods, inundated area is another direct characteristic, and for droughts, starting date is important, as winter low flow is not as bad as in the vegetation season. Complex indicators of drought severity (e.g., Palmer's index) are also available. Another class of hydrological indicators is of an indirect, derived nature, such as statistics, return period, and probability of exceedence. Examples of socio-economic characteristics for floods are: measures of human losses (number of fatalities, number of evacuees) and measures of material damage (total level of material losses (Figure 2), insured losses, etc.). For droughts, socio-economic characteristics express losses due to water deficit in agriculture, industry, and navigation, and aggregated charac-

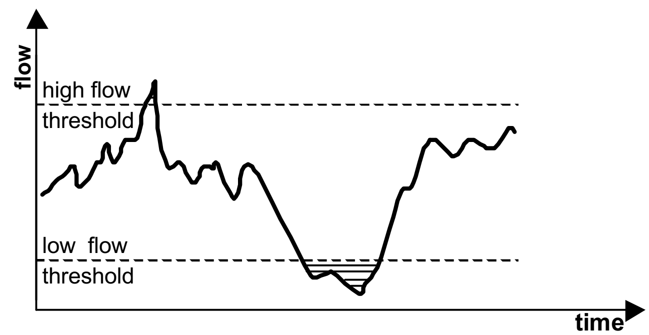

Figure 1. Definitional sketch of threshold crossing.

teristics, such as the total level of material losses or insured losses.

There is no uniform and broadly agreed upon definition of droughts and floods. Such notions always involve a degree of subjectivity and arbitrariness. There is no way to objectively choose a threshold of drought or flood. The drought can be defined as the naturally occurring phenomenon when the natural water availability is significantly below the normally recorded level. The cause of drought is typically a significant reduction in the amount of precipitation, possibly accompanied by high temperature and evapotranspiration. The notion of drought should not be confused with aridity, where water is always in short supply, that is, where a "permanent drought" is a normal condition. The ratio of the long-term mean precipitation to potential evapotranspiration determines a climate's classification. In a hyper-arid climate, two years with no rain may be a normal state, whereas in a humid area several weeks without rain indicate a drought. Droughts may hit large areas (up to sub-continental scale), and spatial coverage is one of the most important drought characteristics. By their nature, droughts extend in time for months, years, or decades.

Droughts have been considered and treated from different angles. Longer time intervals of no, or very little, rain are typically referred to as meteorological drought. A hydrological drought implies low flows and low levels of surface water (rivers, lakes) and of groundwater. An agricultural drought refers to low soil moisture and its effect on cultivated vegetation. The term "environmental drought" is used to emphasize adverse consequences of water deficits on ecosystems. To an economist, a drought would mean losses in the product value, while to a social scientist it would mean impacts on the society.

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

Most flood damages result from extreme floods caused by intense or long-duration rainfall, as well as by snowmelt, or by a mixture of these meteorological phenomena. Some treat the notion of flood as equivalent to high flow (e.g., the term "flood routing" covers propagation of a flow disturbance in a channel). Others understand flood as inundation, when a channel cannot carry the total flood flow and water must spill beyond the channel (flow higher than bank-full). In order to assess potential flood damages, information is required on hydrology (maximum discharge, water levels), the use of floodplains, and loss functions for each category of economic activities on areas exposed to the risk of flood.

Devastating droughts and floods can be viewed as enemies of sustainable development. They cause damage to crops and agricultural farms and induce the threat of famine. Floods bring destruction to cultural landscapes such as towns, settlements, buildings, historical monuments, bridges, roads, and railways inherited from former generations. In short, extreme hydrological events destroy human heritage and undermine development by breaking continuity. People have interacted with these features with varying degrees of success since history began. Sometimes it has been a failure, as floods and droughts (and desertification) have wiped out whole civilizations.

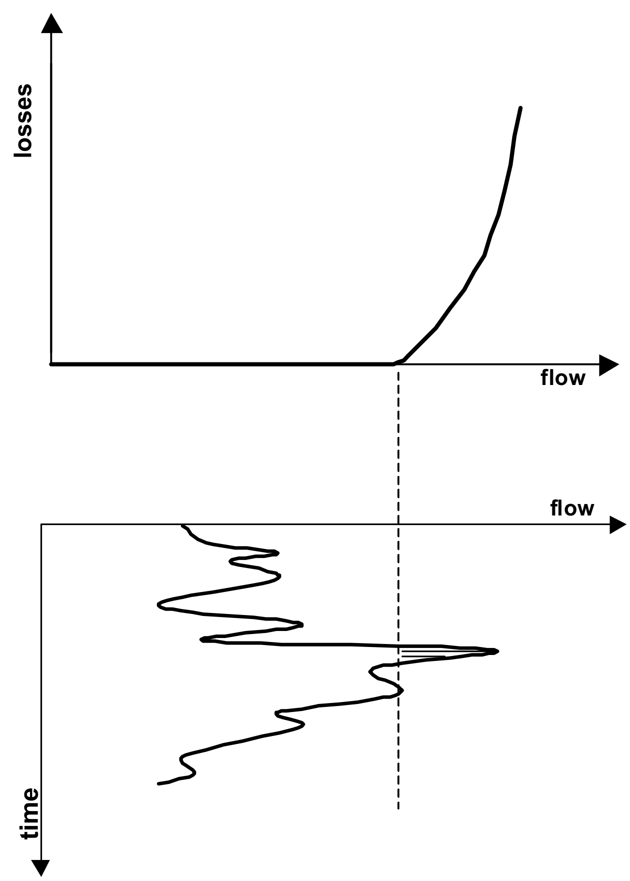

Figure 2. Flood flow vs. losses.

Dramatic Recent Experiences

There have been a number of severe recent floods worldwide, including seven floods in the 1990s, with the total number of deaths in excess of a thousand. The highest death toll was registered during a storm surge flood in Bangladesh when, in the course of two days in April 1991, 140,000 people were killed. There have been over 20 flood events in the 1990s that caused total losses in excess of one billion dollars each. The highest flood losses in the order of US$30 and 26.5 billion were recorded in China in 1996 and 1998, respectively. Regional distribution of the largest floods shows that the majority of these catastrophes have occurred in the countries of Asia, although several have occurred in North America and Europe. Recently, catastrophic floods have also hit arid and semi-arid areas (e.g., Tunisia, Malawi, Egypt, South Africa, and Yemen). The majority of recent catastrophic flood events have been caused by intensive rainfall, sometimes combined with a tropical cyclone, typhoon, or monsoon. In a number of floods, snowmelt and rain-on-snow mechanisms were active. Some floods, including the most disastrous one in Bangladesh in 1991, have been caused by storm surges.

It is not uncommon that floods repeatedly visit the same country in short time intervals. For example, North Korea suffered from disastrous floods in summer 1995 (68 deaths, US$15 billion total losses). A year later, in summer 1996, another flood extending to South Korea claimed the lives of 67 people and caused US$1.7 billion in material losses. It is interesting to note that large floods on the order of a 100-year flood size occurred on the Rhine twice within 13 months. In December 1993, the level of the Rhine in Cologne reached 1,063 cm, while in the beginning of 1995 it went up to 1,069 cm. In both Korea and Germany, the material losses during the second flood were far lower than during the first one. This illustrates that lessons were learned from the first disaster.

The Midwest Flood of 1993 in the USA has been labeled as a hydrometeorological event unprecedented in recent times (IFMRC, 1994). The recurrence interval of the flood ranged from 100 years in many locations to nearly 500 years in the upper segments of the Mississippi and Missouri Rivers. In St. Louis, at the confluence of the Missouri, the previous record stage was exceeded for more than three weeks, while the historical flood records on the main stem of the Missouri were broken at several observation stations by up to 122 cm (Natural Disaster Survey Report, 1994). The death toll amounted to 40 and the material losses to US$12–16 billion, with agriculture accounting for over half of the damages. More than 85,000 residences were flooded.

One of the most devastating recent floods in Europe was the July 1997 flood on the Odra (name in Polish and Czech, Oder in German), the international river whose drainage basin is shared by the Czech Republic, Poland and Germany. The flood, caused by a sequence of intensive and long-lasting precipitation events covering a large area, reached disastrous levels in terms of both river stage and flow rate and socio-economic consequences, with over 100 fatalities. Historic maximums of stage and flow were considerably exceeded at some locations. At the gauge Racibórz-Miedonia on the Polish stretch of the Odra, water reached over two meters higher than the maximum observed so far, and the corresponding flow was twice as high as the historical record. From the hydrological point of view, this flood was a very rare event with return periods in some river cross-sections of several hundreds of years. In Poland alone, the nation-wide toll for both Odra and Vistula floods of summer 1997 was an all-time high as far as economic losses are concerned (Kundzewicz et al., 1999). The material losses were estimated in the range of US$2–4 billion, of much significance to the national economy. Around 665,000 ha of land were flooded, of which over 450,000 ha were agricultural fields. The number of evacuees was 162,000.

Also, droughts have recently hit several developed and developing countries. In developed countries, an extreme drought may cause considerable disturbances: environmental, economic, and social losses. It is estimated that the 1988 drought in the USA may have caused direct agricultural losses of US$13 billion. The more recent 1999 drought, which started during the summer of 1998, seriously affected the eastern region of the country. The growing season in 1999 was the driest on record for four states: New Jersey, Delaware, Maryland, and Rhode Island (Showstack, 1999).

Yet, developed countries can cope with droughts without fatalities. In developing countries, and in particular in Africa, drought-induced agricultural losses may kill through hunger, or through infections and disease in weakened, undernourished organisms. Sometimes, drought is an element of a “complex emergency,” including a civil war.

In the last three decades, the African continent suffered an extraordinary drought without precedence in the records. A significant drop in precipitation, and in consequence a decreasing flow tendency, has been observed in the last decades over large areas in Africa (Sehmi and Kundzewicz, 1997). For example, since 1970, the mean discharge of the River Niger at Koulikoro is nearly half its level in the 1960s. The river nearly 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 the absolute minimum of 42 km^3 observed in 1984 (Howell and Allan, 1994).

Global Change and Hydrological Extremes

A flood risk estimation integrates frequency analysis of extreme hydrological phenomena and evaluation of flood damages. The probabilistic analysis usually includes estimation of the expected annual probability of the critical discharge being exceeded, and the equivalent long-term risk of exceedance over the next T years. If, however, the process is non-stationary, the T-year risk of flood damage may strongly depend on the change of the hydrological processes.

Water resources management has been traditionally based on the assumption of stationarity, that is, one of unchanging climate and land-use conditions. Yet, it is indeed a simplifying assumption. In geological scale, one can clearly distinguish wetter and drier periods. A number of recent floods of exceptional severity and a long-lasting drought in the Sahel make many specialists question the stationarity assumption at a smaller, human, time scale, raising the concern of the insurance industry worldwide.

A number of existing case studies allowed the following statement to be included in the scientific review for the Second Assessment Report of the Intergovernmental Panel on Climate Change: “magnitude and timing of runoff and the intensity of floods and droughts” will be affected, though, “specific regional effects are uncertain” (IPCC, 1996: 8). Further, “there is evidence from climate models that flood figures are likely to increase with global warming” (IPCC, 1996: 338). This is so because rainfall intensity is “likely to increase with increasing greenhouse gases concentrations” and the mass of rainfall may be distributed over fewer rain days (IPCC, 1996: 337). More intensive rainfall may increase runoff and the risk of floods. Yet, in the changing climate, there is a tendency for higher dryness during the vegetation season. According to recent assessment, there is a considerable risk of increasing summer droughts in the Mediterranean region; less precipitation in summer and higher temperatures will coincide, causing higher evapotranspiration and less runoff.

Scenarios for future climate indicate the possibility of sharpening the extremes and changes of seasonality. The amount of precipitation falling as snow may decrease, causing a widespread shift from spring to winter runoff. For instance, in Western Scotland and Norway, an increase of winter floods has already been observed, and this tendency is likely to continue. Local shortening of recurrence interval of a given flood magnitude was reported by Beran and Arnell (1995) who found that a ten percent increase of the mean would cause a ten-year flood to occur on average every seven years. Yet, caution is needed with generalization of such findings, as there is, indeed, no hard evidence of a general tendency. Therefore, no clear and unambiguous signal to the practitioners can be issued.

Since the 1980s in most of the Central European lowlands, one may observe a decrease of peak discharges during spring floods. Potential linkages between changes of statistical properties of snowmelt-induced floods and large-scale meteorological phenomena, like atmospheric circulation processes, were considered. In particular, a possible teleconnection between spring snowmelt-induced floods and the North Atlantic Oscillation (NAO) were investigated (Kaczmarek, 1999). The NAO is a large-scale alternation of atmospheric mass with centres of action near the Iceland Low and the Azores High. Changes in the hemispheric meridional heat transport are linked to the high variability of the North Atlantic Oscillation (Hurrel and Van Loon, 1997). High values of the NAO index indicate strong mid-latitude westerlies in the Northern Hemisphere, contributing to warm winters over much of Europe, and influencing snow accumulation and snow melting processes. They may have a significant impact on spring floods, particularly in Central and Eastern Europe. Spatial distribution of correlation coefficients between NAO and temperature, as well as NAO and precipitation, shows that differences in the impact of NAO on meteorological variables in various parts of Europe are significant. In the northern part of the region, the temperature and precipitation rise with the increase of the NAO index, while in the South just the opposite is likely. An analysis made for several catchments in Poland allows one to conclude that with increasing value of the NAO index, the yearly maximums of snow water equivalent values decrease, causing lower spring flood discharges.

The question of non-stationarity of spring flood characteristics may, therefore, be linked with stochastic properties of the NAO time series in a straightforward way. Yet, various mechanisms responsible for long-term variations of NAO are poorly understood at present. It is, therefore, difficult to judge whether the high values and positive trend of the NAO index, observed in the last two decades, will continue as a result of global change processes. From the hydrological point of view, study of possible long-term changes of the NAO index due to increased concentration of greenhouse gases offers an immediate challenge. Yet, the present level of understanding and predictability of large-scale atmospheric circulation cannot be of practical use for flood risk assessment.

If studies of climate change come to predict a significant increase in the severity of hydrological extremes in the warmer world, then the consequences for design codes would be severe. It would be necessary to design bigger water storage volumes at higher costs to accommodate larger flood waves and to better fulfill the growing demand for water during the prolonged and more frequent droughts of increasing severity. Existing infrastructure may not guarantee an adequate level of reliability in meeting targets and may need to be re-developed. In several regions (e.g., Japan), it is not possible to accommodate larger hydrological variation only by reservoirs. Comprehensive and integrated land and water management is, therefore, increasingly important.

Yet, it is extremely difficult to assess the possible impact of climate change on the occurrence of flood disasters. The reason is that ". . .it is difficult to define credible scenarios for changes in flood-producing climate events" (IPCC, 1996: 483). One recent study indicates that the design discharge of the Lower Rhine may increase in the order of five to eight percent by the year 2050 (Impact of Climate Change, 1997). The possibility of changes in the frequency and intensity of floods in response to global warming was also explored for Australia (Whetton et al., 1993). The conclusion was that change in the frequency of design events would require more expensive structures to cope with increased volumes of runoff.

Apart from eventual climate change impacts, there is a significant increase in risks and losses caused by extreme hydrological events due to soaring human pressure. Massive deforestation, urbanization, and river regulation reduce the available catchment water storage capacity and accelerate and amplify flood waves, shortening the time lag between precipitation and peak river runoff. Water runs off faster to the sea and may be acutely missed in a period of low flow. Another reason for the rise of flood losses is a plethora of locational decisions related to settlements and economic development of flood-prone areas. Human pressure and shortage of land cause the tendency of encroaching infrastructure and investments into floodplains due to their flatness, soil fertility, and proximity to water. There are mushrooming illegal settlements (squatter towns) in dangerous zones (e.g., floodplains) around mega-cities in developing countries.

Flood damage potential is increasing because of overreliance on the safety provided by flood control works such as levees, reservoirs, etc. In reality, no flood defense offers complete security against floods. Levees, a common structural defense designed typically for events smaller than a design flood of a specific exceedence probability, provide satisfactory protection for small and medium floods. Yet, if a catastrophically high flood arrives and a levee is damaged or destroyed, the losses can be very high, higher than they would have been in a levee-free case. This is because of a false sense of security of those inhabiting the floodplain. People move into areas protected with levees and invest in development there.

Different social and economic problems arise in cases of drought phenomena. A recent study (Kulshreshtha, 1993) has shown that food insecurity is a major water resources related issue in the arid and semi-arid lands of Africa, where about a third of the population of the continent live. The study showed that over a dozen countries in Africa were already affected by water stress or water scarcity, notwithstanding the goal of food self-sufficiency or the growth of the population. 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. Importing virtual water (incorporated in food and other products) from water-endowed countries may be more viable.

An extreme example of a man-made hydrological drought is the Aral Sea basin, where excessive water withdrawals from the tributaries Syr Darya and Amu Darya cause them to run dry in some years, leading to a dramatic reduction in the size of the Aral Sea.

Climate change may exacerbate the water stresses caused by population growth and increased demand due to economic development. For example, European simulations show a widespread increase in drought frequency across much of Europe (Impact of Climate Change, 1997). Similar results were obtained by Whetton et al. (1993) for some regions in Australia. A sensitivity analysis of the impact of changes in precipitation and evapotranspiration variability for three catchments in Poland (Kaczmarek et al., 1997) led to the conclusion that the increase of rainfall variance has a significant impact on reliability of water supply. There are many possibilities for adaptation measures to combat climate-induced drought enhancement. In order to establish a long-term strategy, analysis of a series of plausible climate scenarios together with different combinations of population growth and economic assumptions is needed (IPCC, 1996).

It is instructive to look at the system of preparedness to hydrological extremes in the context of load and resistance analogy stemming from mechanics. The satisfactory situation is when load is lower than resistance. Figure 3 shows probability density functions of load and resistance, plotted in a solid line. Examples of load and resistance analogies for the case of floods are water level and height of dikes, and for droughts, water demand and water availability, respectively. That is, load exceeds resistance if the water level is higher than the level of dikes or if water demand is higher than water availability. It can be noted that, in the future (dotted line), the incidence of a critical region, i.e., a situation when the load exceeds resistance, is likely to grow, both in the droughts and floods context. For droughts, the load (water demand) may rise with population growth and human aspiration for better living conditions, while resistance (water availabil-

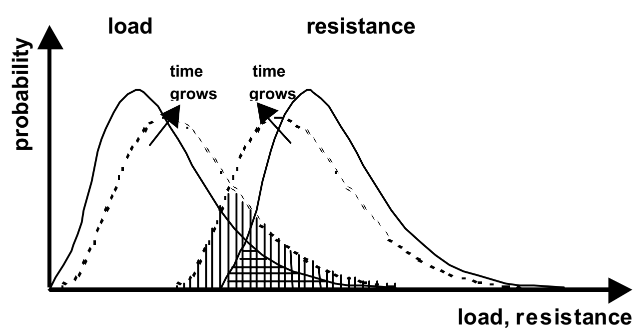

Figure 3. Load-resistance analogy in a changing world.

ity) may decrease through adverse climate changes. For floods, load (water level) may grow due to adverse climate changes and soaring human pressure.

Building Protection Strategies

Flood Preparedness

There is no single universal remedy against floods, and site-specific measures are necessary. A need for comprehensive flood control management has been clearly recognized in areas hit by floods protected by costly physical defenses. After dike collapses in three consecutive years at three major rivers in Japan, it was realized that the physical control works alone cannot completely overcome the floods (Kundzewicz and Takeuchi, 1999).

Important discussion of strategy of flood protection dates back to the mid-1800s in the US (Williams, 1994), when the US Congress looked into the problem of the Mississippi floods. One expert recommended that large areas of the Mississippi floodplains be used as flood storage and overflow areas. Yet, the US Congress accepted the advice of another expert who recommended embanking the Mississippi River in a single channel isolated from its floodplain. This decision largely influenced flood protection policy in the US and worldwide, leading to transformation of rivers and reduction of wetlands. In 1936, the US federal government assumed primary responsibility for flood damage reduction across the nation and over the next 40 years embarked on a multi-billion dollar program of structural defenses: levees, floodwalls, floodways, reservoirs, and channels (Galloway, 1999).

Flood mitigation systems typically contain several elements. They can be categorized in a number of ways. One is the division into "hard" (physical, including structural) and "soft" (non-physical, non-structural) means. Another division of strategies for flood protection and management is: modification of susceptibility to flood damage, modification of floodwaters, and modification of impact of flooding (Thomas, 1995).

There exist a number of "hard" means for flood protection, such as dams and flood control reservoirs, diversions, floodways, and improvements of channel capacity to convey a flood wave. Other "hard" means include distributed physical approaches, such as off-stream reservoirs (polders or flood retardation ponds) consisting of a floodplain and dike, providing small distributed storage for excess water, promoting water storage and infiltration by extending permeable areas (limiting pavement), and flood proofing.

Yet, there are also a number of useful "soft," non-structural, ways to alleviate floods, such as: zoning (delineation of areas where certain land uses are restricted or prohibited, controlling development of flood hazard areas leaving flood plains with low-value infrastructure and building codes (e.g., elevated house foundations). Flood insurance, that is, division of risks and losses among a higher number of people over a long time, is another "soft" measure. However, existence of generous government aid or subsidized insurance schemes may enhance settlement in hazardous zones, encouraging the affected individuals to stay in vulnerable areas. Without such an incentive, they may consider leaving, especially if there is a program to buy flood plains for reconstruction of wetlands. Indeed, permanent evacuation of the existing infrastructure from flood prone areas can be envisaged as the ultimate measure in some risk areas.

Effective flood mitigation systems consisting of forecasting, warning, dissemination, evacuation, relief, and post-flood recovery can substantially reduce losses. Improvement of strategies for reservoir operation during floods is also a point in case. An example based on an online distributed flood forecasting model was presented by Göppert et al. (1997).

It is essential to undertake damage mitigation measures together with physical control measures for flood management in an integrated approach, using a mix of "hard" and "soft" means. More disaster-conscious societies need to be built with better preparedness and safe-fail (safe in failure, i.e., systems that fail in a safe way), rather than unrealistic, fail-safe (safe from failure, i.e., systems that never fail) designed systems. Since a flood protection system guaranteeing absolute safety is an illusion, a change of paradigm is needed: it is necessary to live with awareness of the possibility of floods. No matter how high a design flood is, there is a possibility of having floods greater than the design flood that will cause losses.

There are a number of examples of technical infrastructure related to flood protection that are being criticized in the context of sustainable development because they close options for future generations and introduce unacceptable disturbances in ecosystems. Large structural flood defenses like dams, storage reservoirs, and embankments are often listed in this category. However, despite the criticism of structural flood protection means, they are indispensable to safeguard existing developments, particularly in urban areas.

A common interpretation of sustainable development, applicable also in the flood context, is that society, wealth, and the environment should be relayed to future generations in a non-depleted condition. A related aspect of the definition is that, while flood protection is necessary for the present generation to attain a fair degree of freedom from disastrous events, it must be done in such a way that future generations are not adversely affected. As stated by Brooks (1992): "a minimum requirement for sustainability is that one not paint oneself into a corner from which retreat is either impossible or unaffordable." A definition of sustainable flood defense schemes given by the UK Environment Agency (1998: 9) describes them as avoiding "as far as possible committing future generations to inappropriate options for defense." Curing problems that result from a non-sustainable policy can be more expensive than avoiding this problem in the first place (e.g., enforcing a ban on development of flood plains rather than providing flood protection to vulnerable areas).

Source control and watershed management are important means of modifying formation of flood waters. The idea of catching water where it falls is implemented by such measures as artificial infiltration and retardation facilities: reduced impermeable area, pervious pavements and parking lots and local storage: ponds, building storage, groundwater cisterns (Kundzewicz and Takeuchi, 1999). It also includes increase of storage in the river system (floodplains, polders, and wetlands). By promoting infiltration and storage, thus trapping more water in the catchment, flood peaks can be lowered. Enhancing retention and other runoff-reducing means counteracts the adverse effects of urbanization (growth of flood peak, drop in time-to-peak of a hydrograph, drop in roughness coefficient and in storage potential) and of channelization (faster flood conveyance through shortened and straightened rivers).

Gardiner (1995) compared options of flood defense such as source control, bypass channels, far flood banks and near flood banks, and channelized rivers and assessed their performance from the sustainable development viewpoint by using four groups of criteria. In his rating, source control received very good marks in all categories, while a channelized river was rated as being "bad" in some categories and "very bad" in others. Gardiner (1995) noted that, among the many advantages of source control, it conserves resources, buffers systems from possible climate change impacts, conserves energy through increasing storage "at source," promotes biodiversity by retaining water, improves self-sufficiency, and recharges groundwater.

Drought Preparedness

There are commonly known means of combating drought and promoting development (UNCED, 1992) such as:

- Improving national capabilities, including training and human resource development, for assessing water resources and determining water use on a continuing basis and for the planning and management of these resources;
- Conserving water resources and optimizing their use;
- Augmenting the supply of water locally by exploiting surface water and groundwater that might be available in the area, taking into account long-terms trends, the future demands of the local communities, and other needs;
- Augmenting the supply of water by transfers from more permanent surface water sources (lakes and rivers) and from groundwater resources within arid and semi-arid lands and/or long distance transfers from humid areas if practically and economically possible (and environmentally acceptable).

On the global scale, an essential self-sustaining option is benign population growth management, attainable by family planning and fertility reduction through improved living standards. If there were less population pressure, then activities that increase vulnerability to drought and desertification in less developed countries (over-cultivation, overgrazing, deforestation) could be more constrained.

All action plans to combat drought must be geared toward the possibilities of extending the availability of water and reducing water demand. Improvements in efficiency of existing supplies are essential. Some of the measures of water conservation and augmentation are improved land-use practices, conjunctive use of surface and groundwater, watershed management, rainwater/runoff harvesting, recycling water, and development of water allocation strategies among competing demands. Storing water in groundwater reservoirs (aquifers) when available can be more advantageous, despite the pumping costs, than surface water storage that may be subject to very high evaporation loss. Drought contingency planning, including restrictions of water use, rationing programs, special water tariffs, and reduction of low-value uses (agriculture), require thorough consideration. Reduction of wastage, improvement of water conservation via reduction of the non-accounted for water, and examination of the system of water pricing and subsidies deserve attention. Emphasis is being increasingly shifted from water development and providing water in required quantities to the management of finite, scarce freshwater resources. Improvement in efficiency of existing supplies is essential.

In emergencies, (i.e., during drought) a concerted action is necessary, requiring cooperation between water users, water providers (water agencies), and authorities. There are a number of short-term options that could be used. Glantz (1982) described the many activities triggered by a drought forecast in the catchment of the Yakima River (USA), such as drilling additional wells, trading water rights, systems of subsidies (e.g., subsidizing farmers with annual crops to leave their land fallow) and tax breaks (for drought-forced cattle sales), launching a water bank, transplanting high-value perennial plants, cloud seeding, encouraging water conservation practices, enhanced studies of options for long-distance water transfer, and using water from the dead storage zone of reservoirs. There are success stories about implementation of measures limiting water use in the time of drought: sharp water price increases and bans on watering lawns or washing cars.

Poverty, Wealth, and Protection Strategies

Human poverty is an important factor aggravating hazards due to hydrological extremes. Hope to overcome poverty drives poor people to migrate into informal urban settlements, frequently in places vulnerable to floods where effective flood protection cannot be assured. In fact, in many cities such places are often uninhabited and available for informal settlement by squatters precisely because they are flood-prone (Kundzewicz, 1999).

Although wealthy societies are willing to pay a high price to avoid low-probability disasters, they are still hit by floods. In developed countries, it is the material flood losses that continue to grow, while the number of fatalities goes down. Advanced flood preparedness systems can save lives. It was found in Japan, a country very vulnerable to floods, that the key to reducing the number of flood-related fatalities is information dissemination and warning. However, it is difficult to reduce the damage to property.

Kundzewicz and Takeuchi (1999) looked at the most severe floods worldwide in the period 1990–1996 (data from Munich Re, 1997). They analyzed the ratio of material losses to number of deaths as a function of GNP per capita. As expected, there is a general pattern in this relationship. In wealthy countries, catastrophic floods cause immense material losses but far fewer fatalities than would be the case in a less developed country. For catastrophic floods in developing countries, the ratio of material losses to the number of fatalities can be as low as US$21,000 (Bangladesh), while in developed countries it can go up to US$400 million.

In the developed world, droughts do not kill. There are numerous drought mitigation measures that work in a developed country, yet do not help in much of Africa. That is why Glantz (1977) gave a gloomy, yet realistic statement on the situation in the West African Sahel: "even 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."

Prospects for the Future and Concluding Remarks

A vision is needed as to how to adjust to the challenges facing the water resources community at the turn of the millennium. Floods and droughts are recurrent natural phenomena that have always been part of mankind's experience. They have hit, and will continue to hit, every generation of human beings. The overall objective of reducing losses, as measured by the number of fatalities and material damage, will be increasingly difficult to reach at the global scale due to the adversely changing conditions, such as soaring human population pressure, intensive development encroaching on hazardous areas, increased urbanization, and reduced natural water storage. Mushrooming megacities with largely informal satellite settlements encroaching on high risk areas do not offer adequate flood protection. Climate change may exacerbate the problems.

Enhancing water storage, not necessarily behind gigantic dams, 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 in underground retention (through enhancing infiltration), including storing water in the soil. This presents challenges to watershed management.

Integration of hard and soft approaches to mitigation of floods and droughts is needed, but a single set of remedies does not exist. The best solution may be condition-specific and may depend on such factors as the climate, topography, soils, geology, and human level of development and awareness. There is a growing opposition against develoment of structural defenses in several countries, yet they are indispensable to protect densely populated and high value urban areas such as in Japan, so superdikes are being built (Kundzewicz and Takeuchi, 1999). However, soft approaches are increasingly needed, such as enhancing hydrological information, flood and drought forecasting and warning systems, zoning, rational regional planning, and rasing awareness through improving education and promoting a participatory approach.

Because of possible non-stationarities of climatic and hydrological processes, progress in the hydrological sciences and water management practice highly depends on collecting hydrological data, better-organised archives of information, and better mechanisms of data distribution and exchange. Hydrological information is a prerequisite in the design and operation phase of systems of protection against hydrological extremes. Long time series of data are also needed to detect slow perturbances in hydrological processes (e.g., those caused by climate change or land use change). Yet, due to financial constraints in many countries, hydrological services are shrinking and are not able to provide information needed for water resources planning and operation. Networks of observing stations are in dramatic decline in Africa, and the database necessary to assess drought and desertification risks and to plan for their abatement is not adequate. It is of extreme importance to change this adverse tendency.

The immediate challenge is to improve flood and drought forecasting for a whole range of time horizons of concern. Despite substantial progress in short-term weather forecasting, the reliability of real-time flood predictions, particularly in small and middle-size river catchments, has not reached the level desired by water managers. An important problem is to learn more about the underlying dynamics of meteorological, hydrological, and oceanological processes and their sensitivity to initial conditions. It has been found that extreme hydrological events in several locations accompany particular phases of oceanic oscillations. There is a potential for development of long-term forecasts related to the El Nino-Southern Oscillation (ENSO) or North Atlantic Oscillation (NAO). For example, Cordery et al. (1999) developed a drought forecasting scheme capable of explaining 65 percent of the variance for areas of up to 500,000 km^2 one season ahead and 50 percent of the variance up to one year ahead. Advancing this form of prediction will certainly help improve human preparedness for extremes.

Prospects for the future of human mitigation of hydrological extremes differ greatly between developed and less developed countries. A number of recent investigations of the vulnerability of societies to extreme hydrological situations resulted in policy recommendations. For example, after the catastrophic 1993 flood, the US Interagency Floodplain Management Review Committee (Galloway, 1999) recommended 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. Analyzing possible consequences of water scarcity, the German Advisory Council on Global Change recommended that the German government "adopt and support, as part of the new environment research program, a broadly based and viable approach to the integrated analysis of freshwater problems against the background of global change" (German Advisory Council, 1997). Shortly after the largest flood in this century, the Norwegian government established a Commission on Flood Protection Measures in order "to reduce society's vulnerability to the hazards and damage caused by floods" (RIBAMOD, 1998). The conclusion to be drawn from these activities is that governments in developed countries understand their duty to undertake appropriate actions to mimimize negative consequences of hydrological extremes. However, less developed countries do not have adequate financial and manpower resources. Financial barriers also mean lack of financial sustainability and poor prospects for cost recovery. Less developed countries cannot cope with hydrological extremes without foreign and international assistance. In this connection, national and international professional associations have an important and eminent role to play.

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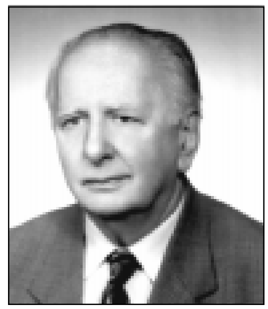
About the Authors

Dr. Zbigniew W. Kundzewicz has been working in the Research Centre of Agricultural and Forest Environment, Polish Academy of Sciences in Poznan, since 1990. He has also served as Scientific Officer in the World Meteorological Organization, Geneva, Switzerland. Professor Kundzewicz has published 113 papers and several books in hydrology and water resources and serves as Editor of the International Association of Hydrological

Sciences and bi-monthly *Hydrological Sciences Journal.* In 1987 he was awarded the Tison Prize (IAHS). His recent research interests include sustainable development and water resources systems, and impacts of climate on water resources. He can be reached at the Research Centre of Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19, 60-809 Poznan, Poland. Email: zkundze@man.poznan.pl. **Dr. Zdzislaw Kaczmarek** has been the Head of Water Resources Department at the Institute of Geophysics, Polish



Academy of Sciences in Warsaw since 1981. He is a member of the Polish Academy of Sciences, and has served as the Academy's Scientific Secretary (1981–1988). Professor Kacz-marek has published over 120 papers and several books in hydrology and water resources. In 1990 he was awarded the International Hydrological Prize. His research interests include stochastic hydrology, theory of water resources systems, and impact of climate on water resources. He can be contacted at the Institute of Geophysics, Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warsaw, Poland. Email: kaczmar@ igf.edu.pl.

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