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MANAGEMENT OF CLIMATIC EXTREMES WITH FOCUS ON FLOODS AND DROUGHTS IN AGRICULTURE[†]

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ABSTRACT

A changing climate leads to changes in the frequency, intensity, spatial extent, duration and timing of weather and climate extremes, and can result in unprecedented extremes. These climate extremes have significant impacts on human and ecological systems, which are influenced by changes in climate, vulnerability and exposure, resulting in increased fatalities and economic losses especially in developing countries.

To reduce disaster risks, the global and local society or community need to assess weather and climate events with the interaction of these hazards, the exposure of society to these events and the vulnerability of the region and society to these extremes. On the other hand, the future projection of events and their impacts is expected to be more uncertain. Under the given uncertainties in climate change impact projections, improving resilience by reinforcing the capability of societies to cope better with extreme events is one of the most favoured approaches. The adaptation includes practical measures that not only reduce the disaster risk but also reinforce the base system.

This paper aims at summarizing the current practices of managing extreme climate events, assessment of impact under climate change scenarios, and development of adaptation strategies. Copyright © 2017 John Wiley & Sons, Ltd.

KEY WORDS: climate change; extreme events; flood and drought; irrigation and drainage; impact assessment; adaptation

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RÉSUMÉ

Sous hypothèse de changements climatiques imminents, l'amélioration des systèmes d'irrigation et de drainage ainsi que le développement rural joueront un rôle clé dans la l'utilisation de l'eau et la sécurité alimentaire en milieu rural, en particulier dans les pays en développement. Un climat changeant entraîne des changements dans la fréquence, l'intensité, l'étendue spatiale, la durée et l'occurrence des extrêmes climatiques ou météorologiques, et peut même conduire à des extrêmes sans précédents. Ces extrêmes climatiques posent des impacts importants sur les systèmes humains et écologiques, qui sont influencés par des changements de climat, de vulnérabilité et d'exposition, entraînant une augmentation des décès et des pertes économiques, en particulier dans les pays en développement.

Pour réduire les risques de catastrophe, la société locale ou la communauté mondiale doit évaluer les événements météorologiques et climatiques avec l'interaction de ces dangers, l'exposition de la société à ces événements et la vulnérabilité de la région et de la société à ces extrêmes. D'autre part, la projection future des événements et leurs impacts devraient être plus incertains. Aux incertitudes près dans les projections d'impact des changements climatiques, l'amélioration de la résilience en renforçant la capacité des sociétés à mieux faire face aux événements extrêmes est l'une des approches les plus favorisées.

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L’adaptation comprend des mesures pratiques qui réduisent non seulement le risque de catastrophe, mais aussi renforcent le système de base.

Cet article vise à résumer les pratiques actuelles de gestion des événements climatiques extrêmes, l’évaluation de l’impact dans les scénarios de changement climatique et l’élaboration de stratégies d’adaptation. Copyright © 2017 John Wiley & Sons, Ltd.

MOTS CLÉS: changement climatique; événements extrêmes; inondations et sécheresses; irrigation et drainage; évaluation d’impact; adaptation

INTRODUCTION

Climate change is recognized as one of the most serious and urgent issues for human society and the global environment. A recent report by the World Bank finds that the most severe impact of a changing climate would be the effect on water supplies. The report suggested that by 2050, an inadequate supply of water could knock down economic growth in some parts of the world by a figure as high as 6% of gross domestic product (GDP), *sending them into sustained negative growth*. Regions facing this risk can at least partly avert this by better water management (World Bank Group, 2016).

Climate change hits water supplies in multiple ways. Warm temperatures can cause more evaporation of water from landscapes, while changes in precipitation can lead to both more intense individual downpours but also swings into drought conditions (e.g. Trenberth, 2011; Dai, 2013). The human activity that consumes the most water is agriculture. In the context of agriculture, the International Commission on Irrigation and Drainage (ICID) believes that improving irrigation and drainage systems and building rural resilience will play a key role in achieving rural water and food security under impending climate change, especially in developing countries. Also recent studies have suggested that irrigation and drainage technologies have an important role in climate change adaptation (Rosenzweig *et al.,* 2004; Nelson *et al.,* 2010).

Irrigation and drainage are fundamentally the human activity that manages the variability or fluctuation of natural hydrological regimes for better agricultural production. They have been continuously developed to function to adapt climate variability and change to some extent. Then, the current problem concerns *extreme events* beyond thresholds or expectations. The challenges due to climate change would have to be considered as another driving force to improve the irrigation and drainage system.

Accordingly, ICID deliberated on the theme *Securing water for food and rural community under climate change* at its 22nd Congress held in Gwangju, Republic of Korea, in September 2014. Two Congress Questions raised included one that was directly related to climate change: *How do irrigation and drainage play an important role in climate change adaptation?*

Discussions during the Congress highlighted that climate change needs to be recognized as an added stress on the increasingly uncertain complex and interlinked issues of rural development and food security under demographic changes due to environmental concerns and limited natural resources. Intervention to mitigate the impacts of climate change and consequent extreme climate events, such as floods and drought, must therefore be considered in the entire decision-making processes in irrigation and drainage activities (ICID, 2014).

A changing climate is expected to lead to changes in the frequency, intensity, spatial extent, duration and timing of weather and climate extremes. These climate extremes are expected to have significant impacts on human and ecological systems, which are, among other changes, influenced by changes in climate, vulnerability and exposure, resulting in increased fatalities and economic losses especially in developing countries. These impacts are seen as additional, and hard, stresses on regions currently facing the problem of losing sustainability. An example could be seen in coastal and deltaic areas, where negative impacts of future sea level rise and increase in flood inundation due to climate change are expected, while currently human-induced land degradation and land subsidence are increasing (Schultz, 2016). Increasing exposure of people and economic assets to climate extremes has been an important cause of long-term increases in economic losses from weather- and climate-related disasters. Extreme events have greater impacts on sectors with closer links to climate, such as water, agriculture and food security, forestry, health and tourism. As the general findings and outcomes, it was reiterated that intervention to mitigate the impacts of climate change and consequent extreme climate events have to be factored in all irrigation and drainage-related decision-making processes (Watanabe, 2016).

Based on this recognition and discussion history on climate change and consequent extreme events, one of the sub-themes adopted for the Second World Irrigation Forum (WIF2) was *Management of climatic extremes with focus on floods and droughts* (*sub-theme 2*) to facilitate discussion on various related topics such as adaptation of design and operation criteria for irrigation and drainage schemes in light of climate change impacts, managing impacts of extreme events—floods and droughts, dealing with climate change impacts on food security, and regional water management. The objective of this Background Paper was to present the framework for discussion and information exchange on sub-theme 2, including the current world context, the development of impact assessment and adaptation strategy, and the challenges in managing extreme events on floods and droughts, with some introduction of past approaches and outcomes as well as state-of-the-art technologies.

GLOBAL CLIMATE, EXTREMES AND AGRICULTURE

The latest report of the Intergovernmental Panel on Climate Change (IPCC) (2014) indicates, once again, that the future climate will depend on the combined influence of warming caused by already emitted greenhouse gases, as well as future emissions on one hand and natural climate variability on the other. A current analysis of greenhouse gas emissions shows that, based on our current understanding of global warming mechanisms, humanity can continue to emit for 12–15 years at the current rate to surpass the threshold that marks the 2°C warning at the end of the century with 0.66 probability (WMO and GWP, 2016).

Although a higher mean annual temperature, in combination with an increased CO_2 level, will have a positive impact on crop yields in parts of the world, in general climate change is expected to have negative impacts on the production of major traditional food crops. In addition, farmers remain concerned about the increasing intensity of extreme weather events that is expected to occur as a result of climate change. Weather-related events which have an impact on agriculture include:

- more frequent heatwaves;
- erratic rainfall;
- prolonged drought;
- more intensive rainfall spells;
- increased winter storms and hurricanes;
- rising sea level rise and increased salinization.

The IPCC Fifth Assessment Report with medium confidence reported that climate trends have negatively affected wheat and maize production in many regions, and estimated negative impacts on these crops. It also reported with medium evidence and high agreement that effects on rice and soybean yields have been small in major production regions and globally. With high confidence, it reported that warming has benefited crop production in some high-latitude regions, such as north-east China or the United Kingdom. The report identifies the difficulty to quantify with models the impact of very extreme events on cropping systems, reasons for which are that by definition extreme events occur very infrequently and models for projection of future changes are not adequately calibrated and tested (IPCC, 2014).

While the impacts of future climatic extremes are difficult to project with greater accuracy, extreme events are expected surely to increase the vulnerability of food production and affect natural resources such as soil fertility; availability of water resulting in water stress; and land degradation and desertification. It is expected that changing weather patterns, manifesting in changes in average temperatures and rainfall, will make it increasingly difficult to plan for activities such as sowing, planting, fertilizing and spraying. Rainfed agriculture is especially vulnerable to changing weather patterns and the impacts of variable water availability. It is also expected that some regions will experience excess water resulting in flooding and others will experience severe water scarcity. Annual average river runoff and water availability are projected to increase by 10–40% at high latitudes and in some wet tropical areas, and decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics.

The changes in hydrological regime will be a matter of great concern for agriculture and rural society. Not only at farm level, climate change and consequent extreme floods and droughts are also expected to affect agricultural systems at basin level. The IPCC Fifth Assessment Report stresses that major future rural impacts are expected through impacts on water availability and supply, food security and agricultural incomes, including shifts in production areas of food and non-food crops across the world. These impacts are expected to disproportionately affect the welfare of the poor in rural areas, such as female-headed households and those with limited access to land, modern agricultural inputs, infrastructure and education.

The risk of extreme events for agriculture (or for that matter any socio-economic activity) is not only caused by the magnitude and extent of the hazards, like the duration of floods and droughts, but is also governed by exposure to the hazards and the vulnerability of the system to that event. This framework is clearly described in the Fifth Assessment Report of the IPCC. In this context, vulnerability means *the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*. And exposure means *the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected*. This interaction related to extreme flood and drought can be depicted as in Figure 1, just modifying the figure for a general framework for various events introduced in that IPCC report (IPCC, 2014).

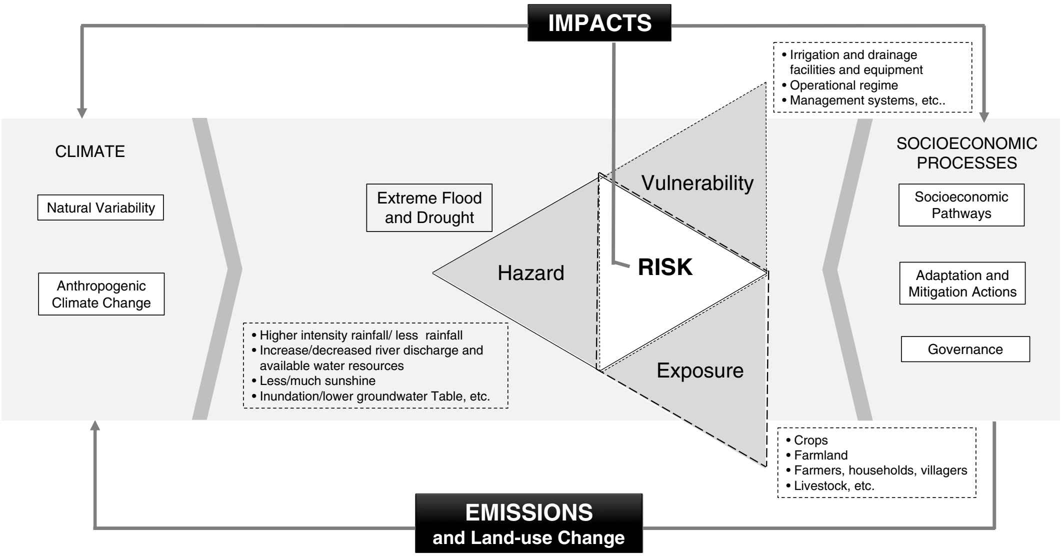

Figure 1. Risk of impact results from the interaction of hazards of extreme floods and droughts with the vulnerability and exposure of human and natural systems (after IPCC, 2014).

This recognition of the risk and impacts of climate change and consequent events is now becoming common in global society. When we think of extreme floods and droughts as a result of climate change, this framework is essential. The impacts are subject to the special and temporal scale of floods and droughts, the function and potential of water management systems in rural society, and crops, farmland, infrastructures as well as farmers and people in rural areas. From the point of view of irrigation and drainage management, which is recognized as adaptation with mitigating actions, the assessment of local structure with regard to the risk of extremes of floods and droughts is to be the base for its improvement under a changing climate.

DEVELOPMENT OF IMPACT ASSESSMENT AND ADAPTATION STRATEGY

In order to reduce the impact of climate extremes it is essential to develop strategies for disaster risk management in the context of climate change, which may include coping and adaptation mechanisms, informed by and customized to specific local circumstances. Adaptation to climate change and disaster risk management provides a range of complementary approaches. An iterative process of monitoring, research, evaluation, learning and innovation can reduce disaster risk and promote adaptive management in the context of climate extremes.

While we have been integrating local knowledge with additional scientific and technical knowledge, disaster risk reduction and climate change adaptation can be improved. However, there is a lack of sufficient scientific knowledge to better understand what is going on and what can be predicted about climate change with reasonable accuracy. Meanwhile, we cannot wait until understanding of future climate change is clear and its impacts are known. It is therefore necessary to factor known impacts of climate change into all processes of planning, design, implementation, operation, maintenance and management of irrigation and drainage activities.

Development of impact assessment

Climate extremes can result in droughts and floods through an accumulation of weather or climate events and may not be caused by a single individual extreme event.

Evidence of the impact of climate change on sea level rise, change of frequency and severity of tropical cyclones or extreme water-related disasters and prolonged drought periods are being studied by scientists all over the world. To understand how climate change may influence over the long term the risk landscape that governments, businesses and citizens need to prepare for, it needs to be weighed against other major trends influencing our exposure to these hazards and threats and our capacities to deal with them. Climate change is expected to influence other risk factors beyond natural hazards themselves. Water, food and energy security could be affected in a number of regions or countries, making these areas more vulnerable to hazards and threats, affecting their economic development, the well-being of their citizens and eventually their stability, which could lead to undesirable impacts on humanity.

There are many interconnected climate risks such as prolonged droughts that increase the risks of forest fires.

Droughts can also lead to more catastrophic floods when water management practices adapt to the trend of reduced water resources without considering that high flows can still reach the highest levels. The Brisbane floods in Australia in 2011 and United Kingdom floods in the winter of 2013 followed prolonged drought periods. Droughts also impact on aquifers whose depletion can affect soil stability, leading to subsidence in urban areas and reduced structural resilience to earthquakes.

Thus, these climate extremes have a significant impact on the earth's environment. Extreme events have greater impacts on many elements of the environment and human systems, including water, ecology, sedimentation, forestry, flora and fauna and human health. Impacts of climate extremes on the environment are mostly observed at the river basin level, whereas impacts on human systems are experienced at the regional and local level. In order to understand and determine the qualitative and quantitative impacts of climate extremes over the short term (5–10 years) and long term (10–50 years), impact assessment on environmental and human systems needs to be developed. Impact assessment for the environmental system could include rainfall, snowpack, evapotranspiration, natural and man-made surface water storage, surface water flow, groundwater storage and recharge as well as other elements. These assessments need to be completed and are expected at regional or river basin level.

Studies indicate that gross irrigation water requirements may increase or decrease depending on the future efficiency of irrigation and conveyance systems, the effect of population growth on food (and water) demand and the climate change impacts; the first two seem to have the greatest influence (Fader *et al.,* 2016). The Mediterranean area as a whole may require increased gross irrigation between 4 and 18% due to climate change alone. Population growth increases these numbers to 22 and 74%, respectively.

Studies show that the changes in projected future peak flows due to snowmelt fall outside the range of natural variability compared with current natural variability in southern Britain but not in the north (Bell *et al.,* 2016). In recent research (Clark *et al.,* 2016) on important sources of uncertainty, it has been reported that these are commonly neglected by the water management community, especially uncertainties associated with internal climate system variability and hydrologic modelling. It also articulated issues with widely used climate downscaling methods.

Studies on the effects of climate change on groundwater recharge of the upper Tiber River Basin in Central Italy (Behulu *et al.,* 2016) presented summaries and overviews of several climate change studies over Italian territory. Specifically, they presented studies on a calibrated and validated SWAT river basin model that used the climate model outputs obtained from three dynamically downscaled regional climate models in order to evaluate the groundwater recharge characteristics of the basin.

A review of existing multi-risk assessment concepts and tools applied by organizations and projects providing the basis for the development of a multi-risk methodology from a climate change perspective has been carried out (Gallina *et al.,* 2016). It developed the assessment of multiple natural hazards—floods, storm surges and droughts affecting a given area for the year, season and decade time frame. Several methodologies were used to assess the vulnerability of multiple targets to specific natural hazards by means of vulnerability functions and indicators at the regional and local scale. It recommended that climate impact assessors should develop cross-sectoral collaboration among people with different expertise (for example modellers, natural scientists, economists), integrating information on climate change scenarios with sectoral climate impact assessment, towards the development of a comprehensive multi-risk assessment process.

When planning for the long term and assessing risks, it is important to integrate how the different trends interact in a comprehensive manner to identify risk scenarios for the future. These trends influence and reinforce each other, and determine risk levels through interconnected processes that are difficult to separate in order to get a real sense of future risks, and policies that need to be set up to reduce them.

Development of adaptation strategy

Synergy between adaptation and mitigation. Coordinated and effective adaptation strategies are essential to ensure the long-term sustainability of food production under changing climatic conditions. Adaptation to climate change is, however, inevitably a multidisciplinary problem, as it requires consideration of agro-climatological, technical and socio-economic issues. Thus adaptation management demands integration of methods from different disciplines (Howden *et al.,* 2007). Uncontrolled autonomous adaptation, defined as responses implemented by individual farmers and communities without the intervention of governments or international agreements, is projected to increase consumption of energy, water and land resources and lead to land degradation (Smith, 1997; Tubiello and van der Velde, 2010) which would potentially result in increased carbon losses. Thus synergy between adaptation and mitigation is needed as a part of adaptation strategies. The strategies would have to include practices which reinforce the climate change mitigation potential.

Adaptation to the changing climate is considered to be particularly challenging in the developing countries, as they are highly vulnerable to climate change due to their warm baseline temperatures, the predominance of agriculture in their economies, the relatively low amount of available capital and high exposure to extreme events (Tubiello and van der Velde, 2010). Despite the challenges, several technical response options are already available.

In temperate and tropical regions, management options are expected to have the potential to counterbalance climate change impacts in the low-to-moderate warming conditions (1–2°C), although they are expected to face limits under more severe climate warming (Howden *et al.,* 2007). These methods include: (i) adapting farm management; (ii) changing crop varieties and species; (iii) improving water management practices. The methods are mainly extensions of widely known farming practices and are more specifically introduced (Tubiello and van der Velde, 2010). Regarding agricultural water management specifically, the different adaptation requirements include: (i) changes in water availability; (ii) changes in irrigation requirements; (iii) improving resilience and adaptive capacity; (iv) responses to floods and droughts; (v) changes in other related parts of the environmental system, such as soil and biodiversity (Iglesias and Garrote, 2015). As listed by Iglesias and Garrote (2015), several mechanisms to overcome the impacts of climate change on agricultural water management are available and could be applied to region-specific challenges. On a global scale, improvements in irrigation efficiency and expansion of irrigated areas have been estimated to have the potential to compensate for a large part of the negative impacts of climate change (Nelson *et al.,* 2010). Irrigation methods also fundamentally require simultaneous application of proper drainage practices (Smedema *et al.,* 2000).

The impacts of existing management options have inter- and intra-regional variation and in some countries adaptation options may not be sufficient to offset the negative impacts of climate change (Butt *et al.,* 2005). Benefits of technical adaptation methods also vary with the type of crop and with the changes in temperature and rainfall (IPCC, 2007). Predictions of the adaptation potential also include uncertainties related, for example, to pest and disease incidence and the ability of farmers to adapt to increasing climate variability and frequency of extreme weather events. The expected future contribution of genetically modified crops is also considered controversial (Tubiello and van der Velde, 2010), although some novel findings can for example help to develop rice varieties, which can enhance rice production in flood-prone areas (Hattori *et al.,* 2009). Despite the prevailing uncertainties about the impacts of adaptation methods, technical adaptation options could also be supported by changes in resource allocations and alternative land-use and livelihood options to increase the adaptation potential of the regions.

Changing policies and adaptation to extreme weather events. Coordinated adaptation measures through changing policies are necessary to ensure the long-term benefits and social equity of the adopted measures. In order to build capacity for better collective understanding as well as to build stronger strategic and technical capability for adaptation, adaptation policies need to support information communication as well as research and analysis operations (Howden *et al.,* 2007). Training inhabitants for new jobs will be essential where climate change may lead to large land-use changes (Howden *et al.,* 2007). To have the capability to support new technical management and land-use arrangements, new infrastructure, funds and institutions are also essential (Tubiello *et al.,* 2009).

New policies may be needed and would also require the capacity to be able to continuously improve adaptation to include targeted monitoring of the costs, benefits and impacts of adapted policies (Howden *et al.,* 2007). Climate change and socio-economic pressures are expected to increase the demand for food as well as other resources.

Adapting to extreme weather events can be considered more challenging in comparison with the adaptation to increased mean temperatures, since extreme events may not have historical analogues. In general, adaptation to extreme events is, however, possible through reducing vulnerability and enhancing resilience of the food production systems. For example, practical capacity building rather than disaster relief would increase resilience to extreme events (Mirza, 2003) and improved flood forecasting and warning practices would reduce the vulnerability of agricultural systems. Flood plain management, improved irrigation and drainage, wetland restoration and hard defences are among the technical options to mitigate the adverse impacts of floods and droughts, whereas for example drought-resistant crops and insurance can offer a non-structural approach to reduce vulnerability (e.g. Iglesias and Garrote, 2015). Recent technical advances have increased the ability to adapt to extreme climate variation (Cane *et al.,* 1986). Also the early warning systems related to extreme events have improved (Dilley, 2000). However, social inequities can also prevent part of society from benefiting from these adaptation options and thus hinder the adaptive capacity of society (Pfaff *et al.,* 1999).

Costs and bottlenecks of adaptation. Costs of coordinated adaptation to climate change and the associated risks in developing countries have been estimated to require approximately US$100 billion annually, which markedly exceeds the projected financial flows in rural development in the coming decades (Tubiello *et al.,* 2009). Annual agricultural investment needs are estimated to be about US$7 billion (Nelson *et al.,* 2010). Potentially a large part of the required financial flow is expected to be generated through carbon markets by boosting activities related to both agriculture and forestry, including methods such as reducing deforestation (Tubiello and van der Velde, 2010). Without the carbon markets the funding needs are estimated to fall an order of magnitude short (Tubiello and van der Velde, 2010). Currently, clean development mechanism projects are, however, regionally unevenly distributed and only approximately 1% of their financial flow reaches Africa (Tubiello and van der Velde, 2010), which suggests that the geographic distribution of the projects needs to be widened.

Generally, further increasing the number of these projects includes both administrative and technical challenges, including investor risks, inadequate infrastructure and unclear land tenure (FAO, 2008). Further, more agricultural activities could be included in the list of clean development funding projects, and aggregation of different actors within a region could be one way to further scale up the projects and thus increase the attractiveness of the projects for investors (Tubiello and van der Velde, 2010).

CHALLENGES FOR MANAGEMENT OF THE EXTREME EVENTS

Flood management

Since the dawn of time, civilizations have prospered on floodplains, taking advantage of the benefits of floods, which are much more than just a hazard (WMO and GWP, 2006). Housing is often located in flood-prone areas, together with economic activities. These zones often represent a major source of income, livelihood and housing for thousands of communities, while floods play a key role in these processes (WMO and GWP, 2013).

Until 1927, the main flood policy of the US Army Corps of Engineers was *levees only*. After the great flood of 1927, flood management by reservoirs was also included. The concept of non-structural measures (NSMs) was first used in the context of flood control some 50 years ago, as a means to reduce the ever-increasing damage, without unduly expanding the costly infrastructure. In that sense, NSMs were perceived more as complementary additions to the essentially structural solutions to flood control, in order to reduce costs and enhance efficiency. This concept has changed in the last few decades with the introduction of new approaches as documented in the following publications:

- development of the new Swiss safety concept for dams in 1985;
- publication of the *Manual on Non-structural Approaches to Flood Management* by ICID (ICID, 1999);
- bulletin of the International Commission on Large Dams (ICOLD), *Non-structural Risk Reduction Measures; Benefits and Costs for Dams* in 2001 (ICOLD, 2001);
- Integrated flood management concept paper, WMO No. 1047, in 2003;
- publication of the US Army Corps of Engineers' manual *Adaptive Management for Water Resources Project Planning* in 2004;
- publication of the proceedings of Q53 of the ICID Congress *Harmonic Coexistence with Floods* in Beijing in 2005;
- United Nations (UN)-Water (2010) recognizes the integrated flood management approach as robust and adaptive for adaptation to climate change.

In the specific case of floods, there has been a recent paradigm shift, moving from *flood control* to *integrated flood management* (IFM) (WMO and GWP, 2006), that is, from the *need to master* floods from a technical standpoint to the *need to manage them* from every point of view—technical but also social, political and economic, by anticipating the event rather than undergoing it. In the twenty-first century, it is recognized that the approach to flood management has to be increasingly adaptive and be a combination of non-structural and structural measures.

Integrated flood management is the approach that promotes an integrated—rather than fragmented—approach to flood management. It integrates land and water resource development in a river basin, within the context of integrated water resource management (IWRM), and aims at maximizing the net benefits from the use of floodplains and minimizing loss of life from flooding. Uncertainty and risk management are defining characteristics of choice, and risk management is a necessary component of the development process in the integrated flood management approach, essential for achieving sustainable development.

The application of a risk management approach provides measures for preventing a hazard from becoming a disaster. Flood risk management consists of systematic actions in a cycle of preparedness, response and recovery, and should form a part of IWRM. The actions taken depend on the conditions of risk within the social, economic and physical setting, with the major focus on reducing vulnerability. The UN System (United Nations (UN)-Water, 2010) recommends integrated flood management as a robust and adaptive approach to manage floods. Flood risk assessments, which form an essential element in such approaches, need to incorporate climate change effects on the magnitude of floods and the vulnerability of populations.

An important aspect of evolving concepts of engineering practice is the way uncertainty is recognized and addressed. It is today widely appreciated that many consequences of civil engineering investments cannot be precisely forecasted. Whether the objective is to take advantage of new opportunities or to insure against bad outcomes, the goal is to create the capacity to respond appropriately as new situations may include unforeseen surprises. Flexibility over the life of the project is essential for effective development and functioning of civil engineering systems.

Public awareness of and education in flood risk are key elements for flood management in flood-prone areas. A high level of awareness of flood-related risks is required if we are to have effective and efficient flood risk reduction measures; for example, successful evacuations require awareness and planning among the population of what to do and where to go in a flood emergency (WMO, 2009). Flood maps are tools for visualizing flood information for decision makers and the general public. These maps form the basis for developing flood risk scenarios based on land use, various environmental and climate conditions; and they form the basis for the planning and implementation of development alternatives (WMO, 2013).

Adaptive management concepts and practices represent innovative, current thinking on resolving conflicting demands and adjusting to changing social preferences and priorities. Many of the benefits of adaptive management come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and therefore must improve management decisions. The benefits of better management decisions will be realized in the future. These benefits, however, are difficult to measure and translate into dollars, the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, upfront costs of adaptive management programmes, such as ecosystem monitoring programmes, scientific staff and institutional support. The strategies of adaptive flood management (AFM) are shown in Figure 2 (ICID, 2016).

As an example, in August 2016, a very strong El Niño was forecasted in Iran and subsequently a study was undertaken for six selected river basins in that country, which indicated a good teleconnection of strong El Niño–Southern Oscillation (ENSO) events and associated precipitation in autumn. These forecasts were used for real-time water management during the extreme floods in the southwest basins. In fact, the appropriate authorities issued large flood forecasts for the months of November and December (2015) several months in advance. These forecasts closely matched the observed floods and consequently reduced the devastating effects of the floods.

Drought management

Drought is a natural but temporary imbalance of water availability, originating from a deficiency of precipitation (e.g. persistent lower-than-average), of uncertain frequency, duration and severity, of unpredictable or difficult to predict occurrence, resulting in a reduced gap between water supply and demand, and reduced carrying capacity of the ecosystem (Wilhite and Glantz, 1985; Pereira *et al.,* 2009).

Drought is a relative, rather than absolute, condition, and occurs in all climatic regimes, from low- to high-rainfall areas. Although agriculture is the sector most affected by drought, in both developing and developed countries, other sectors such as energy production, transportation, tourism and recreation, urban water supply and the environment face significant impacts.

Some drought types are recognized (i.e. meteorological, agricultural, hydrological and socio-economic), depending on the interaction between the natural characteristics of the event and the specific human activities related to the water supplied by precipitation. When meteorological drought (e.g., a lack of precipitation over a region for a period of time) is adopted, precipitation is used for drought analysis

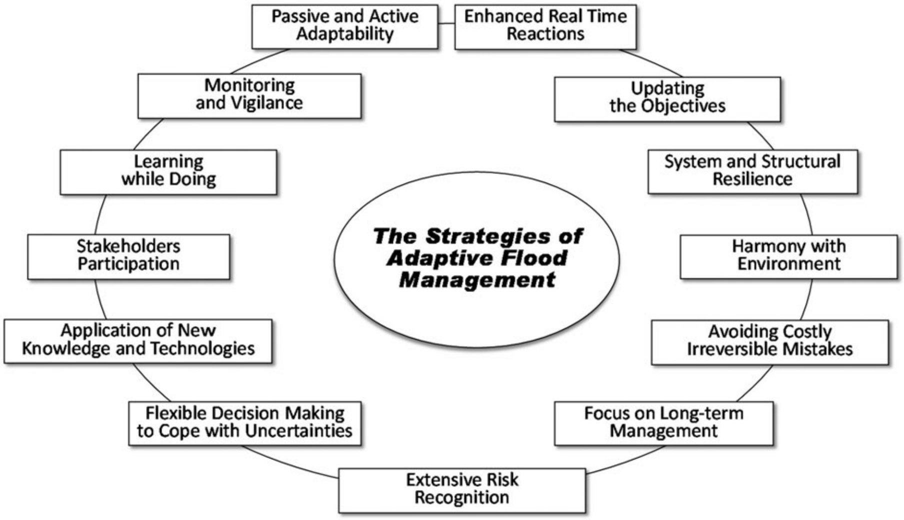

Figure 2. The strategies of adaptive flood management (AFM) (after ICID, 2016)

(Paulo *et al.,* 2012). Precipitation-based indices have been developed over time in order to quantify a drought as a departure of precipitation from the *normal*. Widely used indices, such as the Palmer drought severity index (PDSI), the National Oceanic and Atmospheric Administration (NOAA) drought index (NDI), and the standardized precipitation index (SPI), use precipitation either singly or in combination with other elements (Shatanawi *et al.,* 2013).

Satellite observations can supply *in situ* data at high spatial density. Indices, such as the normalized difference vegetation index (NDVI), the vegetation condition index (VCI), the temperature condition index (TCI) and the vegetation health index (VHI), can be derived (Kogan, 1995). They can profitably be used for monitoring drought events according to the vegetation response to environmental stress.

Different from other natural events, drought is a slow-onset hazard, whose effects accumulate slowly over a rather long period of time. Since duration of drought (i.e. onset and end) is difficult to determine, disagreements between researchers and policy makers can occur with respect to the actual length of a drought event. Drought has both a natural and social dimension, the latter being the factor that moves a hazard into disaster (Wilhite *et al.,* 2014). Due to the absence of a unique definition of drought, some confusion can arise on the existence and the degree of severity.

A critical feature of drought is that impacts are non-structural and can spread over areas larger than those hit by other natural hazards, often beyond national borders. This may lead to difficulty both in quantification of the impacts and in disaster relief. In addition, both economies and the environment can be affected for long time periods. Natural disasters originate from the interactions between climate extremes and the vulnerability of human and natural ecosystems to such extremes (WMO, 2013).

Responses to drought have been reactive in most parts of the world, largely adopting a crisis management approach. This approach is revealed to be ineffective in most cases, mainly because it does not reduce the risks associated with drought. It is imperative that a more risk-based approach to respond to drought, based on well-established national drought policies and preparedness plans, is adopted. Improving the level of preparedness for drought results in a reduction in societal vulnerability.

Impacts associated with drought are the result of a wide range of climatic and societal factors. Whether a drought event becomes an emergency or a disaster depends on the vulnerability of people and the environment to such an event (IPCC, 2012). In recent years, due to an increase in vulnerability, together with the incidence of drought, the approach to reduce the risks associated with drought is gaining emphasis.

Two main paths can be followed to deal with drought events: better planning to improve operational capabilities, and mitigation measures to reduce drought impacts. Mitigation of drought effects requires the use of all components of the cycle of disaster management (Figure 3), that is both risk and crisis management.

Post-impact interventions. When drought occurs, governments and donors normally follow the steps in the recovery section of the cycle. The return to a pre-disaster state with little attention given to risk management (i.e. preparedness, mitigation, early warning or other prediction actions) can address a short-term need but cannot avoid or reduce future impacts and lessen government and donor interventions. Countries with policies based on crisis management have little reduction in risk when moving from one drought event to another (WMO and GWP, 2014).

These responses to drought are generally reactive both at the national and regional scale (Wilhite and Pulwarty, 2005). Treatment of symptoms is often untimely, poorly

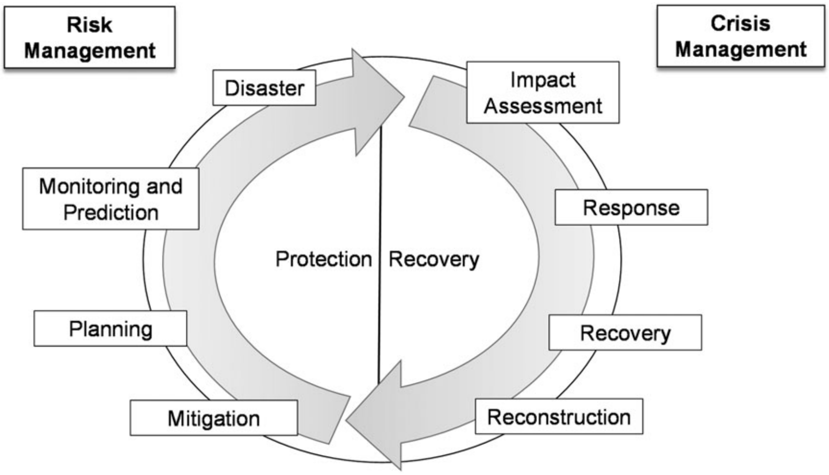

Figure 3. The cycle of disaster management (after Wilhite, 2000)

coordinated and ineffective to reduce the impacts of droughts, since it is driven by crisis rather than prevention. A reactive approach is partially due to the uncertainty and unpredictability of drought events, especially in the past. This situation has hindered development of different approaches to drought management, no longer based on reactive practices, but on the underlying causes of the vulnerability.

Post-impact interventions, carried out by both developing and developed nations worldwide, are normally in the form of emergency assistance programmes to the victims of the drought. This reactive approach does not sustain the reduction of vulnerability, since behaviour or resource management practices are not expected to change. This attitude does not encourage either self-reliance or coping capacity.

Pre-impact government programmes. Concern that droughts may be increasing in frequency, severity and duration due to climate change, together with available technologies to support drought early warning and information delivery systems, has stimulated governments throughout the world to switch from responses to drought based on crisis management towards national drought policies based on risk management. A drought policy is developed in advance of drought and maintained between drought events.

Pre-impact programmes aim to reduce vulnerability and impacts through a number of non-structural mitigation measures. Among others, they include seasonal forecasts, water conservation (demand reduction) and increased exploitation of groundwater, water reuse and recycle, construction of reservoirs, interconnection of water supplies between communities, drought planning and education (Wilhite and Rhodes, 1993). Insurance also can be categorized in this policy type.

Where vulnerabilities are identified (population groups, regions, sectors), measures that are able to reduce the risk associated with future drought events can also include adaptation measures (WMO and GWP, 2014). Vulnerability of a region is also a function of the sensitivity of water management that in turn is characterized by adaptation to changing circumstances. Many adaptations are reactive, but others are planned for the future. Adaptation to altered circumstances allows us to respond to some consequences of climate change (i.e. drought events). Adaptation in the water sector to cope with adverse impacts follows two approaches: supply side and demand side. Supply-side techniques include building new supply and distribution infrastructure, and more efficient management of existing sources. Demand-side techniques aim to reduce the demand for water resources through a wide range of measures, such as public awareness campaigns and statutory requirements for water use efficiency (Parry, 2000).

Some economic and agronomic adaptive options are available in agriculture. Most of the agronomic strategies are demand-side oriented and can be grouped into short-term adjustments and long-term adaptations. Short-term adjustments are the first defence tools for facing the event. They include changes in planting dates and cultivars (i.e. early planting), changes in external inputs (i.e. fertilizers and pesticides) and practices to conserve moisture (i.e. conservation tillage and irrigation management). Long-term adaptations include major changes to overcome adversity, such as changes in land allocation, introduction of more resistant crop varieties, substitution of crops, enhancement of irrigation efficiency and changes in farming systems.

Preparation of national drought policies and planning techniques. Drought events differ with respect to their physical characteristics between climatic conditions, resulting in local impacts defined by unique characteristics. Preparation of national drought policies and planning techniques need to define the key components of the policy, its objectives and the steps in the implementation process. This type of policy response includes organizational frameworks and operational arrangements developed in advance of drought and maintained between subsequent drought events. The goal of this approach is to create institutional capacity to improve coordination and collaboration within and between different levels of government and with stakeholders. A national drought policy has specific objectives, different from nation to nation. However, in principle these objectives intend to encourage vulnerable elements (i.e. economic sectors, population groups) to adopt measures promoting risk management, to promote sustainable use of agricultural and natural resources, in order to facilitate early recovery from drought according to actions consistent with national policy objectives (Wilhite *et al.,* 2014).

Integrated water resources management

Increasingly competing demands for finite water resources and the impacts of climate variability require a more holistic approach to resource management. *The Asian Water Development Outlook 2013* (Asian Development Bank (ADB, 2013)) estimates up to 75% of the Asia-Pacific region being water insecure. Combined with increasing demands, water can no longer be looked at through a single lens. The impacts of one user on another and the associated trade-offs need to be considered.

According to the definition of the Global Water Partnership, *Integrated water resources management (IWRM) is a process which promotes 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*. It is pertinent to note that IWRM is a process and not an end in itself.

IWRM strategies are based on the Dublin Principles which were presented at the World Summit in Rio de Janeiro in 1992. These include: (i) recognition of water as a finite resource with multiple uses; (ii) requirement for more holistic management based on supply and demand considerations; (iii) social and economic value of water; (iv) recognition of stakeholder participation in decision making; (v) women's role in water management.

Over the past decade much progress has been made with increasing awareness of the concept of IWRM in the Asia-Pacific region and subsequently embedding in the water policy framework of an increasing number of developing and middle-income countries. For example, in India the main objective of the National Water Mission is *conservation of water, minimizing wastage and ensuring its more equitable distribution both across and within States through integrated water resources development and management*. In the People's Republic of China, the 2002 Water Law reinforces the need to strengthen the responsibilities of river basin commissions and local water bureaux with respect to integrated water resources planning. Multilateral development banks like the Asian Development Bank have also endeavoured to embed IWRM through strategic and operational plans and support to regional knowledge partners like the Network for Asian River Basin Organizations.

Adaptation to climate change is closely linked to water and its role in sustainable development. To recognize this reality and to respond accordingly presents development opportunities; various necessary adaptation measures that deal with climate variability and build upon existing good land and water management practices have the potential to create resilience to climate change and enhance water security and thus directly contribute to sustainable development. Creating the infrastructure for water resources development and distribution has shown great human and macroeconomic benefits; conversely, countries lacking this capability have suffered damaging shocks from droughts and floods. More water storage is required to manage the increased variability of water resources (United Nations (UN)-Water, 2010).

A good example is the ADB-provided loan to the Karnataka Integrated and Sustainable Water Resources Management Investment Programme in India. The state of Karnataka is water-stressed, with increasing water demands from the urban and industrial sectors. This is exacerbated by an uneven spatial and temporal distribution of water resources and the predicted impacts of climate change. Overall, the investment programme area is found to be vulnerable to increased incidence of seasonal droughts. This increases the need for a well-planned and methodical approach to water resources management. An integrated approach to water resources management is a way to reconcile varied and changing water uses and demands since it provides greater flexibility and adaptive capacity than conventional water resources management approaches.

Adaptation to climate change to reduce vulnerability in the water sector should involve far more than just water managers. Increasing social vulnerability to water stress (in terms of drought and flood) in many parts of the world reflects a wide range of pressures, many of which are outside the responsibility of water managers. Reducing vulnerability to climate change-induced flood and drought will require decisions about issues such as development and planning control, fiscal incentives (such as subsidized insurance or government disaster relief) to occupy (and continue to occupy after loss) hazard-prone land, and wealth enhancement.

The fourth edition of the *World Water Development Report* (WWAP, 2012), *Managing Water under Uncertainty and Risk*, seeks to demonstrate, among other messages, that water underpins all aspects of development, and that a coordinated approach to managing and allocating water is critical. It highlights that more responsible action by all water users has enormous potential to lead to better outcomes—but requires political, social, economic and technical responses at all levels of government, businesses and communities, from local to international.

Over the past decades the translation of IWRM into water policy, planning and institutional development has also had the knock-on effect of a more prescriptive rather than location- or basin/sub-basin-specific approach. The latter would be based on understanding the goals or targets for basin/sub-basin water resources, for example improving agriculture water productivity and defining a prioritized set of actions to achieve. In certain cases, activities like performance benchmarking of a river basin organization may be regarded as a priority action—using a blueprint rather than tailored approach.

Rethinking IWRM in the context of water security and climate change adaptation may be a way to move forward. The Asian water development outlook (AWDO) has five key dimensions of water security, which would be affected by population dynamics and impacts of climate change.

As an adaptation action it would be useful to consider gradual improvements in the IWRM spiral as a reflection of enhanced water security (GWP, 2012). This would require planners and decision makers to consider the following:

- risks to the basin or sub-basin (including climate change impacts on hydrology);
- critical users within the basin (e.g. if domestic users then assess their water security status —under key

dimension 1 based on relevant indicators like access to piped water supply and sanitation);

- assess the basin or sub-basin targets or vision for the future—e.g. is there a net shift in allocations required between agriculture and domestic use, have water quality targets been set for improved domestic supply and river health and are there environmental base flow requirements;
- consider the risk of climate change impacts to ascertain the trade-offs required;
- based on the assessment consider the priority actions to increase water security in the sub-basin and to respond to adaptation requirements. For example, installation of river flow measurement devices, use of remote sensing to establish agriculture water productivity, strengthening institutional capacity for climate-proofed domestic water supply design, monitor water quality, stakeholder awareness raising, establishing performance targets for the basin, etc.;
- develop a road map with indicators, roles of agencies and timelines;
- review performance and achievements, and constraints and update road maps with continuous monitoring.

We are witnessing increasing frequency and magnitude of extreme events and regional climate variability in the Asia region. This not only introduces an element of disaster risk management into the overall equation of improved and integrated water resources management, but further reinforces the need for tailor-made adaptive solutions.

The past decade has demonstrated that moving from a concept of IWRM to applying the process in an operational context requires further contextualization. An example is the initiative for improved management of extreme events through ecosystem-based adaptation in watersheds (ECOSWat). The programme is commissioned by the German Federal Ministry for Environment, Nuclear Safety and Buildings (BMUB) and supported by the government of Thailand. It provides a more locally based approach with local water agencies (in pilot river basins) to plan and assess ecosystem-based adaptation measures for protection against the effects of extreme events. Lessons learned from the project have been fed into national-level adaptation strategies for the water sector.

Much of the base work has been accomplished in increasing regional understanding of a more integrated approach to water management. There is also an increasing awareness of the risks and impacts of climate variability and extreme events. What is more challenging is taking the lead in drilling down further into tailored solutions and approaches and highlighting their benefits to all stakeholders.

CONCLUSIONS

This paper overviews the background and structure of the issues about management of climatic extremes with special focus on floods and droughts, which aimed at facilitating the discussion on this topic for the Second World Irrigation Forum.

To reduce disaster risk, the global and local society or community need to assess weather and climate events with their magnitudes, frequencies and variabilities as well as the forces, the vulnerability of the region and society and the exposure to the events. Climate change, however, is not easy to predict and carries a high level of uncertainty.

Under the current uncertainties in climate change impact projections, improving the resilience of local systems is one approach to reinforce the capability of societies to better cope with extreme events. In this situation, one of the essential and significant attitudes is the adaptive approach. Since the factors associated with climate change and its apparent impacts are difficult to be projected and evaluated at the present level of scientific understanding, it would be more effective and feasible to manage the extreme flood and drought through integrated and adaptive approaches. In particular, coordinated adaptation measures are needed since autonomous adaptation might lead to an increase of emissions and degradation of ecosystems, which could further reinforce the negative impacts of climate change.

The concept and approach of adaptive management are found in many sections of this paper. Here, the main points of the sections are summarized.

Extreme events may affect natural resources such as soil fertility and available water resulting in the increased vulnerability of agricultural production to negative impacts, such as serious water stress, land degradation and desertification as well as waterlogging and land inundation. Extreme floods and droughts with changing temperature are expected to affect the hydrological conditions of a basin and farmland, which may make it increasingly difficult to plan for cultivation activities, such as exact farmworks including on-farm water management practices.

When planning for the long term and assessing climate change risks, it is important to integrate how different trends interact in a comprehensive manner to identify risk scenarios for the future. These trends may influence and reinforce each other, and determine risk levels through interconnected processes that are difficult to separate in order to get a real sense of future risks, and policies that need to be set up to reduce them. Coordinated and effective adaptation strategies are essential to ensure long-term food and water security under changing climatic conditions.

Adaptation to climate change is inevitably a multidisciplinary activity, and it requires the consideration of agro-climatological, technical and socio-economic issues.

Adaptation management demands integration of methods and synergies with mitigation of climate change. Innovative, coordinated and effective adaptation strategies require the capacity for adaptation to be continuously improved and targeted monitoring of the costs, benefits and impacts of the adapted policies.

Many of the benefits of adaptive management come in the form of better knowledge of ecosystem response to management actions. This improved knowledge reduces uncertainties and would therefore improve management decisions. These benefits are difficult to measure and translate into the standard metric of economic analysis. The intangible nature of these benefits stands in contrast to the direct, upfront costs of adaptive management programmes, such as ecosystem monitoring programmes, scientific staff and institutional support.

Responses to drought, which have been reactive in most parts of the world, have proved to be ineffective in most cases. Whether drought characteristics change or not, it is imperative to follow a more risk-based approach to respond to drought, based on developed national drought policies, preparedness plans and widely disseminated drought early warning systems.

Floods need to be recognized as a natural phenomenon that has multifaceted ecological benefits, but will turn into disasters if the vulnerable sections of society are exposed, particularly in extreme events. Integrated flood management approaches that draw on the maximum benefits of floodplains within the framework of water resources management, land-use planning and risk management principles need to be adopted.

Adaptation to climate change to reduce vulnerability in the water sector would have to involve far more than just water managers. Mechanisms for interaction between various stakeholders, coordination among various agencies and collaboration among various disciplines for establishing better management systems need to be promoted, not only against climate change but also for everlasting improvement of systems.

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