PRACTICES IN COPING WITH CLIMATIC HAZARDS: FLOODS AND DROUGHTS AT RIVER BASIN SCALE

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1 Introduction

Climatic hazards – floods and droughts – have always been a matter of concern to the human population. Though there have been significant achievements in science and technology in the 20th century, people still continue to suffer the consequences of severe floods and droughts on all continents. Floods endanger human life, and cause damage to settlements, roads and transport networks and destroy human heritage. Devastating droughts are harmful for agriculture and may create problems in water supply. Droughts can be connected with heat waves (an extended time interval of abnormally and uncomfortably hot weather lasting from several days to several weeks), which can be harmful for human health.

In view of the developing issue of climate change, floods and droughts may become more frequent. At the global scale, warming of the atmosphere will lead to an increased evaporation from the oceans, and as a result, to an increased precipitation. However, the Earth climate system functions in such a way that only some parts of the world (in high latitudes and tropical regions) would experience higher precipitation, whereas other regions would get lower amounts of rainfall (Climate change, 2001). Also, regional differences are probable due to local topographical conditions. Climate change therefore has the potential to increase the frequency of extreme events in many regions by increasing flood risk in some regions of the world, increasing drought risk in others, and even increasing the occurrence of both floods and droughts in some regions.

Set to this background, the paper focuses on practices coping with floods and droughts on example of seven large river basins: Amudarya, Elbe, Guadiana, Nile, Orange, Rhine and Tisza. Four of the basins: Elbe, Guadiana, Rhine and Tisza are located in Europe, Nile and Orange in Africa, and Amudarya in Central Asia.

2 General characteristics and climate change in seven river basins

This section gives an overview of seven case study basins with an emphasis on climate change. The major basin characteristics: drainage basin area, countries sharing the drainage basin areas, average annual precipitation, and occurrence of floods and droughts, are presented in Table 1.

Table 1 General characteristics of seven river basins

River basin (Continent)	*Countries sharing drainage basin area*	*Drainage area, km^2*	*Average annual precipitation*	*Flood risk?* *Recent flood events*	*Drought risk?* *Recent drought events*
Amudarya (Asia)	Uzbekistan, Tajikistan, Turkmenistan, Afganistan, Kyrgyz Republic	309,000	200 mm a^{-1} on average (from 50 to 800 mm a^{-1})	Yes 2005	Yes 2000/2001
Elbe (Europe)	Germany, Czech Republic, Austria and Poland	148,268	From 450 to 1600 mm a^{-1}	Yes 2002	Yes 2003
Guadiana (Europe)	Spain, Portugal	66,800	From 400 to 600 mm a^{-1}	Not very high 1997, 2004	Yes 1991-1995
Nile (Africa)	Burundi, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, Uganda, Congo	3,112,369	From 3 to 2000 mm a^{-1}	Yes 2002	Yes annual
Orange (Africa)	Lesotho, South Africa, Namibia, Botswana	896,368	From 25 to 2000 mm a^{-1}	Yes 2000	Yes 1991-93 Lesotho: 1994-1997
Rhine (Europe)	Austria, Germany, France, Luxembourg, Netherlands	185,000	From 700 to 1200 mm a^{-1}	Yes 1993, 1995, 1999 (Oberrhein)	Yes 2003, 2005, 2006
Tisza (Europe)	Ukraine, Slovakia, Hungary, Romania, Serbia, Montenegro	157,218	From 500 to 1700 mm a^{-1}	Yes 2001, 2005	Yes 1998, 2001

The observed trends and projected climate scenarios for the case study basins are outlined in Table 2 and shortly described below.

Amudarya. Instrumental observations indicate that there is an ongoing tendency to warmer climate over all territory of Central Asia. Climate models project a temperature increase of 1.8-2.9°C in the upstream areas by 2050 (Tajikistan, 2002) and 1-2°C in the lowlands by 2030 (Agaltseva 2005). Current precipitation patterns in the upstream areas are changing, however tendencies are less clear due to the complex mountainous terrain.

Observations have revealed a tendency of precipitation decrease in the foothills and increase at altitudes above 1500 m (Tajikistan, 2002). Besides, a change in the type of precipitation at different altitudes is expected. Mountain glaciers are very sensitive to climate warming. Currently, large-scale glacier degradation is taking place in the Amudarya basin: small glaciers are disappearing, and large glaciers are decreasing. The glacier area in the Amudarya basin has been reduced from 7144 km^2 in 1957 to 6205 km^2 in 1980 (Agaltseva, 2005).

The runoff of the major Central Asian rivers, including Amudarya, is generated by snow and glacier melt in the high altitudes of the Hindukush, Pamir and Tienshan mountains. Climate change will alter the relative runoff contributions from snow, glacier melt and rain (currently: 78% from snow and 14-16% from glacier melt) (Ososkova et al. 2000) towards larger contributions from glacier and rain and less from snowmelt. This will affect the flow patterns of the river such as the timing of peak flows.

Elbe. In the Elbe region an increase of average surface temperature of 1.1°K has been observed during the last 50 years. Seasonal estimation shows higher temperature increase in winter than in summer. Though a growing trend in precipitation has been observed in western and southern parts of Germany, a downward trend (or, locally, no significant trend) has been observed in the German part of the Elbe basin with more significant though opposite changes in summer and winter. According to the detailed investigation for the climate station Potsdam (located almost centrally in the Elbe basin) using time series from 1891 to 1991, summer rainfall shows a decreasing trend (-46 mm), whereas winter precipitation is increasing (+50 mm) (Table 2).

The climate scenario was produced by the statistical downscaling model STAR from the ECHAM4-OPYC3 signal, which was driven by the IPCC emission scenario A1 (F.-W. Gerstengarbe and P. Werner, see in Hattermann et al., 2006). The climate change scenario is characterized by an increase in temperature by 1.5°C until 2050, and a moderate decrease in mean annual precipitation in the basin corresponding to the observed regional climate trend with notable subregional differences.

Guadiana. The report of the European Environmental Agency (EEA 2004) suggests that Spain and Portugal are likely to be the EU member states most affected by climate change. This report states that while average temperatures in Europe have increased almost 1ºC more than in the rest of the world, global warning in these two countries has been higher. Cold winters are expected to disappear by 2080, while summer temperatures may increase by 10% in the area. Rising temperatures are expected to be felt particularly in continental areas during the summer months, and extremely high daily temperatures may become more frequent (MMA 2005).

Rainfall over the last two decades has been approximately 7% below the average of the last fifty years (Martinez-Santos et al 2004). Whether this can be considered a result of climate change or a consequence of the natural climate fluctuations is yet to be confirmed. Rainfall predictions are less reliable, with notable differences in the results of different General Circulation Models. Most of these, however, seem to point at a notable decrease in total annual precipitation for Spain and Portugal. Some authors quantify the average loss of water resources associated with increased temperatures and decreasing rainfall as 5-14% by 2030 and 22% by 2060 (Iglesias et al 2005).

Nile. There is evidence of ongoing climatic change in the Nile basin. Analysis has shown that there have been large-scale variations in rainfall in the last five hundred years, and the climate of the region cannot be considered as stable over this time scale (Farmer and Wigley, 1985). Estimates of the possible changes in temperature, rainfall, evaporation and runoff for the decade of the 2020s as simulated by GCMs were compared to the reference period 1961-90 (Meigh et al., 1998). The results showed fairly uniform increases in temperature of between 0.7 and 1.0°C across the whole basin. Changes in rainfall were much more variable, generally increasing by between 0 and 19%, but with decreases in some areas. The expected changes in runoff are minor in most of the equatorial lakes basin, but quite substantial increases of 30% or even more were projected for some parts of the Ethiopian highlands and southern Sudan. Conway and Hulme (1996) reported that annual rainfall change would vary from -1.9% to +7.4% for the Blue Nile basin and from -1.0% to +5.0% for the equatorial lakes basin, whereas annual runoff would vary from -8.5% to +15.3% for the Blue Nile and -9.2% to +11.8% for the equatorial lakes.

Orange. There is some evidence of existing gradual changes in climate throughout Africa with the imminent loss of the permanent snow from the top of Africa's highest peak, Kilimanjaro, being the most notorious. However, there are still many uncertainties with regard to the magnitude and direction of climate change.

Schulze et al. (2005) published an extensive review on climate change in South Africa, projecting that temperatures would rise considerably over the entire country especially in the interior (most of the upper Orange basin) where there could be up to a ten fold increase in the number of days with temperature >30°C by 2100. Using a Regional Climate Model C-CAM they predict that mean annual precipitation will decrease by approximately 15-25% in the western portion of the basin while the upper regions of the basin, including Lesotho, may experience an increase by up to 10% by 2100. Deviations from this trend are also set to increase, thus raising the risk of both droughts and floods. The range of rainfall events will also change seasonally, with an increase in the summer rainfall but a decrease in the dry season winter rainfall, thus again exacerbating the threats of climate change. There will also be an increase in the number of rainless days, while days of heavy precipitation will increase, again exacerbating flood events. Projections suggest that the west coast area will suffer up to 30% reduction of precipitation, which will be extreme for an area that is already a desert! However, projected precipitation trends are controversial, and depend on model used (see Tab. 2).

Rhine. General Circulation Models project an increase in temperature of 2-4 degrees, and an increase in winter precipitation of about 20% by the end of 21st century for the Rhine basin (see also Tab. 2). The climate scenarios for the Rhine basin can be summarized as '*more of everything*' (Water, Climate, 2003). Rainfall will increase throughout the year and will more often be concentrated in intense cloudbursts, and, hence, flood frequency will increase. However, higher summer temperatures will increase evaporation, so that, paradoxically, less fresh water will be available with consequent higher risk of droughts and heat waves. The sea level will continue to rise.

Although the exact consequences of climate change cannot be pinpointed for the basin, it is generally accepted that extreme conditions will become more frequent. It is expected that water discharge in the Rhine and Meuse will increase in winter, while the summer discharge will decrease (Gupta and Van Asselt, 2004). A rising sea level will hamper the discharge into the sea. Inundations and salt-water intrusion will become more common. However, there will be water shortage in summer season. Rising temperatures and lower precipitation in summer will affect the availability of cooling water for industry and the power plants.

Tisza. For the Tisza basin a temperature increase by approximately 1° C was detected during the last 50 years (IPCC, 2001). In addition to that, an upward trend in precipitation for the Zacarpathian part of the basin except the period between March-May was found. For major parts of the lowland basin, a downward trend in the overall precipitation has been detected, with main emphasis on the Hungarian part (Jolonkai et al., 2005). In terms of the future temperature development, an increase by 0.7-2.5° C by 2050 is expected according to the REMO-simulation (MPI Hamburg, 2006). Precipitation is assumed to increase in the Carpathians up to 30%, whereas a decrease of ~10-30% is expected in the spring period in Hungary and Ukraine by 2050 (REMO-simulation by MPI Hamburg, 2006).

3 Coping strategies in seven basins

Amudarya. Climate change will have a significant effect on water resources of the Amudarya river basin, however there is high uncertainty in the magnitude of changes. Changes in the hydrological regime will affect current rules for operational regimes of reservoirs and water availability for different water users. In low water years the region is currently operating in a water deficit regime, and thus is very vulnerable to future decrease in water availability. Mudslides and the breaking of natural dams on mountain lakes in the upstream areas pose serious threats for flooding and water availability in the entire basin.

Over many centuries water management strategies and policies have been developed to allocate the river's water resources for various uses, including irrigation. In the Amudarya river basin concepts and mechanisms to deal with droughts and floods are available and implemented. In the past decades there has been strong emphasis on technical measures. Current coping strategies for drought protection include:

- technical measures such as two single year storage reservoirs, development of small scale reservoirs in the wetlands of the river delta, use of former bays of the Aral Sea for water storage,
- water allocation planning measures such as reduction of allocation quotas to all regions by fixed percentages when a low water year is forecasted,
- development measures such as introduction of water saving technologies in irrigation to decrease water demand in agriculture and increase efficiency,

- social measures such as awareness raising among water users for water conservation;

and for flood protection:

- technical measures such as construction of overflow structures, storage reservoirs in the former wetlands and bays of the Aral Sea,
- management measures such as establishment of a transboundary flood emergency committee to ensure fast response to flooding risks.

However, some recent events (e.g. a severe drought in 2000/2001, a flood in 2005) have shown that they may be insufficient and fail to mitigate extreme situations, especially in the downstream areas. Single year reservoirs have only a limited potential for drought mitigation. Deteriorating infrastructure caused by lack of maintenance and investment over the past 20 years aggravates the situation.

Elbe. In the last three years, extreme hydrological situations were observed on the Elbe - a destructive flood in August 2002, and a severe drought and water deficit only one year afterwards, in 2003. The disastrous flood in August 2002 in the Elbe basin has strongly shifted general public attention to the flooding problem. Due to ongoing climate change the intensity of rainfall and, as a result of that, the frequency of extreme events are expected to increase in the basin (Becker and Grunewald 2003). The need to develop proper flood management measures and strategy is recognised.

Two main elements of flood risk management in the basin are reduction of flood risk and coping with floods. Preventative measures against flooding (Flood risk, 2004, p.10) combine engineering facilities, river basin planning along with financial and social measures. They include:

- technical flood protection: facilities for water retention such as dams, storage reservoirs and polders,
- river basin planning: increasing natural water retention in catchment areas,
- spatial planning: keeping constructional development as far as possible out of floodplains,
- constructional measures: ensuring appropriate construction methods in areas prone to flooding,
- risk reduction methods: financial provisions backed by insurance,
- behavioral or social measures: explaining, preparing for and practicing how to cope with flood-related dangerous situations,
- informational measures: alarming and warning systems.

Already in the present climate conditions, water is often scarce in the Elbe basin in summer season: precipitation is relatively low and so is the runoff coefficient. In future, higher temperatures and lower precipitation are projected for the summer, and this in turn would affect hydrological processes and lead to increased evapotranspiration, and decreased soil moisture, groundwater recharge and river flow. This indicates that the water scarcity problem will grow, with adverse consequences to several sectors, such as agriculture, forestry, water supply, navigation, recreation and nature conservation. Measures used in water management now, which are especially necessary in periods of droughts, are water saving technologies, water price mechanisms, and optimization of water resources use (Krysanova et al., 2006). In future, some other measures like land cover change, introduction of new crop varieties will be needed under drier climate, and water saving technologies along with optimization of water resources use will have to be enforced.

Guadiana. Agriculture is traditionally the main water user in the Guadiana basin, accounting for 90-95% of the total water consumption in the upper part, and 88% in the lower part of the catchment. Therefore, water use in the area is heavily conditioning the agricultural sector, which in turn, is the most likely one to suffer the potential effects of climate change.

While no specific strategies have yet been drafted for the Guadiana basin, the report on climate change of Spain's Ministry of the Environment already displays a series of adaptive alternatives for the whole country (MMA 2005). These include three main lines of action:

- demand management solutions, based mostly on water pricing, legal measures, water-efficient cropping patterns, public information and education;
- enhanced water management solutions, including improvements in monitoring networks, management models and databases, and the creation of centers for the exchange of water rights;
- supply-based solutions, such as increasing storage capacity, water transfers from wet to dry regions, groundwater development, water harvesting, afforestation, water reuse or desalination.

While the first two sets of strategies can only be looked upon with hope, it appears clear that opportunities to implement the third kind of solutions in the Guadiana basin are limited. The middle and lower reaches of the catchment already boast two of Europe's five largest reservoirs (*Alqueva* and *La Serena*), while intensive groundwater development is commonplace in the upper part of the basin.

It is precisely in the upper part of the basin where the main lessons could be learnt in regard to coping with climate hazards. A drought-prone region, the upper Guadiana basin (16,000 km^2) is underlain by aquifer formations whose saturated depth often exceeds 300 m. Estimated groundwater storage exceeds 15,000 Mm^3, while renewable resources amount to between 200-400 Mm^3 a^{-1}. Such large capacity makes this aquifer system akin to a macro reservoir, except for the huge evaporation losses that the later usually experience. Thus, as the events in the early 1980s and 1990s show, the area's aquifers are able to withstand several years of severe droughts in exchange for fairly small increases in pumping costs, even if the total irrigated surface exceeds 200,000 ha and accounts for over 90% of the area's water uses.

Therefore, the upper Guadiana basin offers an example of drought-proofing through intensive groundwater development. It is true, however, that this has come at an environmental cost, since groundwater-dependent ecosystems have been lost due to water table depletion. Making irrigation and wetland conservation compatible under more severe climate conditions remains the area's main challenge for the future.

Nile. The main withdrawals of water are for agricultural use, which are dominated by irrigation, especially in the northern part. Irrigation demands are by far the most important water use in this area (94% in Sudan and 97% in Egypt). Different levels of freshwater scarcity are experienced in the basin depending on the population densities, the level of water availability and water demand. In some areas with abundant water resources water is still used inefficiently.

The Nile River countries suffer from the effects of droughts, desertification and land degradation. Ethiopia suffers from recurrent drought and famine "War and drought" in 1984-85 caused a food crisis, during which around one million people died – a disaster from which Ethiopia never fully recovered. Widespread flooding throughout Kenya in May of 2002 hit seven of Kenya's eight provinces. A total of 175,000 people were affected by the flooding, up to 60,000 people were displaced, and 50 people were reported dead.

Coping with climate extremes in such a large basin is a very complex issue. In this paper it will be shortly outlined on example of Kenya (Mathur et al., 2004). The Kenyan government is undertaking reforms of the water sector that have the potential to improve the management of climate extremes in future. The improved management of climate variability can be grouped under three headings: improved prediction, improved protection and response.

The improved prediction includes emphasis on data acquisition, early warning systems, and flood forecasting modelling based on available climate scenarios.

The improved protection includes: reparation of existing infrastructure and development of new infrastructure to contain floodwater and provide surface and subsurface storages for the periods of drought, regular monitoring and evaluation of groundwater levels, water discharge and water quality, establishment and enforcement of standards, and development of groundwater programmes that are based on known recharge rates. Kenya has the potential to develop conjunctive use of surface and groundwater so that water from periods of excess flows is stored in aquifers for use during dry periods. A new land policy is under development, which is likely to include a land use component to prohibit certain land uses in sensitive areas.

Kenya's *response* to floods and droughts is partly based on the country's predictive capability. With sufficient time and sufficient certainty, people and livestock can be moved from flood or drought areas before the event occurs. Similarly, short-term, emergency responses can be provided more quickly with sufficient advanced warning and coordination between government and private sectors.

Orange. Current water management mechanisms and policies have been developed to ensure that the existing supply of water meets the growing demand. Some of the mechanisms may be appropriate to deal with the future shortage that will be brought about by climate variation, but robust long-term strategies are required to ensure that demand for water matches supply, even in times of reduced availability.

Three basic areas of adaptation have been suggested which are appropriate for this basin (Benioff et al. 1996 in Mukheibir & Sparks, 2003):

- Increased water supply: construction of reservoirs and dams, development of groundwater resources, utilization of inter-basin transfers, and modified vegetation cover to reduce evaporation;
- Demand-side management, water reuse and water recycling;
- Different management of supply and demand: e.g. crop substitution, conjunctive use of ground- and surface water, better climate forecast, more versatile inter-basin transfer schemes and more flexible operating rules for water systems.

Regarding flood protection, the emphasis in the basin was until recently still on structural mitigation measures, and little attention was given to hazard and risk assessment for different river reaches (Du Plessis, 2002). These authors suggested to develop a more effective flood mitigation and prevention strategy based on flood forecast, warning and response system (FFWRS), which should be a cost-effective option for flood damage reduction. Now a fairly sophisticated system operates in the Orange basin where an office is established during flood events, and several government departments now have policy in place to deal with disasters.

The National Disaster Management Centre of South Africa has established a number of working groups, to prepare components of the National Disaster Management Framework. The flood management policy will include proposals on guidelines and standards, and institutional responsibility with regard to the following:

- The optimized operation of large storage dams;
- The safe and sustainable use of the floodplains of rivers;
- Design criteria for services infrastructure such as roads, bridges and waterworks situated on or adjacent to rivers;
- Effective flood warning systems for all flood-prone areas;
- Interactions and co-operative relationships with countries with which South Africa shares river systems.

Rhine. The traditional strategy for water management in the basin was based on controlling water. Over the centuries, the dikes defending reclaimed land have been built and strengthened, while the rivers have been straightened and widened to allow water to be speedily discharged to the see. This approach provided a relatively high safety standard compared with that of many other countries.

However, after the high floods in the 1990's the International Commission for the Protection of the Rhine (ICPR) acknowledged that the existing strategy is not sufficient to maintain safety standards in the future. In view of climate change, when more intense precipitation rates and hence more runoff are expected, a new sustainable flood risk strategy is imperative. On 22 January 1998, the 12th Conference of Rhine Ministers adopted the "Action Plan on Floods Defense" in Rotterdam (IKSR, 1998) to be implemented within the next twenty years. The Action Plan aimed at the improvement of precautionary flood protection. It formulated five guiding principles for preventive flood protection: (1) *Water is part of the whole* and must be given due consideration in all policy fields; (2) *Store water*: retain it as long as possible in the catchment; (3) *Let the river expand*: give river enough room in order to delay runoff and reduce danger; (4) *Be aware of the danger*: a certain risk will remain, and people have to be aware of it; (5) *Integrated and concerted action* in the basin is a prerequisite for the success of the plan.

Dutch strategy. The Dutch strategy is based on minimizing the consequences of flooding: the new paradigm in water management is *'learning to live with the floods'*. Despite of upgrading the dike system in response to the 1993 and 1995 floods, the Dutch government announced a more radical policy for the longer term: *to create more room for the rivers* (Water, Climate…2003; Klijn et al., 2004). The country should create a flexible system that can deal with unpredictable events and be adapted to cope with future developments. In order to reduce flood damage caused by excessive rainfall, the new mantra is: "*first retain, then store, only then discharge*". This should not only reduce flood risk by reducing high water levels in canals and rivers, but also mitigate the effects of droughts in summer and reverse the degradation of nature due to over-drainage. Land along rivers will have to be set aside to widen flood plains and create retention basins for incidental inundation. The set-aside areas can still be used for agriculture or recreation (multifunctional use). Parts of polders will have to be designated for use as emergency storage areas. In coastal areas space will have to be found to strengthen the present defenses against the effects of sea level rise. However, several studies have shown that at the scale of the entire Rhine basin, climate change impacts cannot be compensated only by land use changes (Middelkoop et al, 2004), as the potential influence of climate change on water discharge and occurrence of extreme floods is much stronger than the compensatory influence of land use change measures.

German strategy. Similar developments are observed in Germany, where management is being addressed in new flood storage and retention areas by combination with nature areas. In April 1999 the water agencies of the German federal states Baden-Württemberg and Bavaria as well as the German Weather Service (DWD) have agreed on a joint long-term cooperation for regional studies on the subject "Climate change and consequences for water management" (project KLIWA, www.kliwa.de). For this purpose an Action Plan was initiated, which covers five main issues:

- Assessment of changes in climate and water to date ("retrospective analysis");
- Estimation of impacts of potential climate change on the water budget;
- Monitoring programme for climate parameters and water budget;
- Development of sustainable provision concepts for water management policy on account of climate-induced changes of the water budget;
- Distribution of results to the scientific community as well as to the general public.

It is acknowledged that the effect of new flood risk strategies in both countries can be further optimized if they are applied to the whole basin with improved cross-border cooperation.

Tisza. The technically advanced protection scheme seemed to be successful in both countries until the record-breaking floods happened recently (2001, 2005), causing enormous socio-economic damage due to several dyke breaches. As a result, alternative solutions such as creating emergency reservoirs and polders, providing a possibility for flood runoff through parts of the watershed, and adapted land use and management pattern are gaining more attention in both countries.

The increasing number of floods and their mounting cost convinced the government that constantly reinforcing and rebuilding dykes is not cost effective. For this reason, the new Vásárhelyi Plan was established by the Ministry of Environment and Water Management to address hydrological issues in the Tisza basin. The new Vásárhelyi plan aims at solving flood protection problem exclusively by building new reservoirs and leaving other options for future. The plan has been described as the most ambitious rural development programme of the last decades (Vásárhelyi Plan Intersectorial Committee Bulletin 2004). According to the plan, six emergency reservoirs will be constructed along the upper and middle Tisza sections to enhance flood safety and clear the flood bed to improve conveying capacity. Besides an increase of water storage capacity, complex flood control measures would be needed in the basin, including cleaning of flood channels (cutting flood passage ways), raising the dikes, integrated planning of land development and land use management within the floodplains, financial support of local farmers as well as other transboundary coordinated measures (Horvath et al., 2001). The same or similar strategies exist for the Ukrainian part of the Tisza basin.

Compared to the already developed and partially implemented strategies to cope with floods, measures of protection against droughts are nearly no existing. Although hot summer seasons and drought periods in the Hungarian part belong to the long-term and known climate features (Jolonkai, 2005), there is considerably more awareness on flood than on drought risk in the basin. In order to reduce the vulnerability of local farmers to be affected by spring and summer droughts, an improved storage and distribution strategy of the spring flood water for droughts during the vegetation period would be a significant step towards drought adaptability. Moreover, agricultural losses due to drought situations should be incorporated into the agro-environmental schemes by the EU (CAP), in particular for those regions endangered by droughts recently.

4 Comparison of coping strategies in seven basins

Structural measures for flood protection: dams, water storage reservoirs, dykes exist practically in all river basins. The dams are designed for flood security, and reservoirs serve for water storage. Maintenance and update of structural engineering constructions are needed everywhere, though realization of measures is sometimes difficult due to conflicting interests. The largest uncertainty related to climate change is whether the dams designed for historical floods will be able to withstand more intensive floods, possible under changed climatic conditions. It is very difficult to understand and predict the effects of climate change correctly due to many reasons, like natural variability of hydrological systems, short periods of available measurements, and restricted capabilities of climatic and hydrological models (Beven, 2000). Some of the uncertainties can be reduced, while others are unavoidable.

Some non-structural measures are also implemented in river basins, but they are mostly not very extensive. Increasing natural water retention is stated as necessary in the Elbe, Rhine and Amudarya. Improved land use schemes and new land use policy are needed in the Nile and Orange. Though the need for such measures seems to be well understood, sometimes they are even not included in newly developed management plans (e.g. Hungary, Tisza).

Social measures, such as advanced alarming and warning systems, publicity and education are ongoing in the Rhine, Elbe, Guadiana and Tisza, but there are few such measures in Amudarya and Orange. Improvement of social measures is needed in all basins.

Supply-side measures for drought protection (surface and groundwater reservoirs, water transfer schemes) exist practically everywhere. The need for improvement includes (a) increasing the storage potential in the Orange, (b) protection of groundwater aquifers in the Guadiana, (c) improvement of conjunctive use of surface water and groundwater in the Nile. In some basins, like Amudarya, there are not many options left for improvement on the supply-side.

Demand-side measures are quite good developed in the Elbe, Rhine, Guadiana. These measures need improvement practically everywhere, like better irrigation schemes in the Orange, control of illegal water abstraction in the Guadiana, water saving measures in the Amudarya.

Need for improved monitoring, more reliable scenarios of climate change, and prediction of flood and drought risks in a transboundary context is stated in all basins. Investigation and comparison of different mechanisms for adaptation to droughts and floods, their implementation and monitoring are necessary. For example, for the Amudarya basin research is needed to analyze potential changes in flow patterns in river, to assess their impacts on water supply and agriculture, and develop plans to cope with them. Modern approaches such as remote sensing analysis can be used to determine the degree of reduction of the glaciers in the Central Asia region, which are the main source of river runoff. The future challenge is to develop strategies and measures to guarantee adequate water supply to multiple users under potential change scenarios.

Acknowledgements

The authors acknowledge help of all data suppliers, especially Chris Dickens (Orange) and Markus Wrobel (climate scenarios data) The present contribution is a background publication within the NEWATER Project funded within the Sixth Framework Programme of the European Union (contract No. 511179).

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Table 2. Observed trends in climate and projected climate scenarios for six basins

	Indicators of climate change trends			*Projected climate scenarios for the basins*	
	Observed temperature trends	***Observed precipitation trends***	***Observed snow and glacier dynamics***	***Change in temperature***	***Change in precipitation***
Amudarya	Upper catchment[1]: 0.7-1.2°C temperature increase in the valleys; 0.1-0.7°C in high altitudes; Lower catchment[2]: small increase (ca. 0.5°C)	Seasonal redistribution of precipitation, mostly increase in higher altitudes, increase in extremes in lower; changes in type of precipitation (hard versus liquid).	Glacier degradation: 14% decrease from 1957 to 1980[3] Snow stock[1]: increase of 35% on average in areas up to 2000m, decrease by 35 % in areas 2000-3500m high	Upper catchment [1]: Increase by 1.8-2.9°C by 2050; Lower catchment[2]: Increase by 1-2°C by 2030; increase in temperature extremes.	Both increase in precipitation (3-26%) as well as decrease (3-5%) are projected by various models by 2050 [1], Change in distribution of precipitation.
Elbe (German part)	Temperature increase by 1.1° K during the last 50 years [4]	Decrease in summer precipitation (-46mm), increase in winter (+50mm) during the last 50 years [4]	No observations	Temperature increase by 1.5° C by 2051-2055 compared to 1961-1990 (model STAR) [4]	Small precipitation decrease (-5.6mm) according to model STAR by 2051-2055 compared to 1961-1990 (STAR) [4]
Guadiana	Average max. temperatures stable (upper basin): 21.1ºC 1904-1950; 21.0ºC 1904-2002; 21.2ºC 1980-2002 [5]	Decrease of 7% in the last two decades over the period 1950-2002 (upper basin) [5]	Not applicable	Temperature increase by 2070 (worst-case scenario): 1-2ºC in winter and 4-5ºC in summer [6]	Rainfall decrease by 2070 (worst-case scenario): -0.25 to +0.25mm d^{-1} in winter and +0.5mm d^{-1} in summer [6]
Rhine	0.8°C during the last century (with uncertainty it would be about +1°C) [12]	During 20th century winter precipitation has increased by about 10-20%. No significant trend in summer precipitation was detected[12]	In Switzerland: Since 1850 the surface covered with glaciers has decreased from 1800 km^2 to 1300 km^2. The volume has decreased from107 km^3 to 74 km^3 (13)	Temperature increase by 2.0-4.0º C by 2100[14]	Increase in winter precipitation by about 20% by 2100, depending on T increase[14]
Tisza	Temperature increase by approx. 1º C during the last 50 years [15]	Upward trend in precipitation (Ukrainian part); downward trend in precipitation (Hungarian part) [16]	No glacier environments in the basin	Temperature increase by 0.7-2.5º C by 2050 [17]	Precipitation increase in the Carpathians up to 30%; precipitation decrease in spring of ~10-30% in lowland by 2050 [17]
Orange	South Africa: Average increase of 0.2°C during 1990's.[1] Namibia: Increase of 1.15°C between 1950-2000[2] Botswana: Increasing trend of about 1°C over period 1900-1990 [10]	South Africa, Botswana: No overall trend [8,10] Namibia: variation in rainfall extremely high (in excess of 30% across country, rising to 70% in southern areas) [8]	Snow is common in the Lesotho portion of basin, but data not accessible.	South Africa: average temperature increase of 2.5-3º C over north-central parts by 2050 [11] Namibia: 2 - 6º C above 1961-1990 mean by 2100 [8] Lesotho, Botswana: 1.2 - 4.4°C increase by 2075.[9,10]	South Africa, Lesotho, Botswana: Both increases (5%-10%) and decreases (10%-25%) projected by various models.[3,10,11] Namibia: Decrease up to 200mm per year [8]

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