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Adaptation to climate change in international river basins in Africa: a review

MARISA GOULDEN[1,2], DECLAN CONWAY[2,1] & AURELIE PERSECHINO[2,3]

1 *Tyndall Centre for Climate Change Research, University of East Anglia, Norwich NR4 7TJ, UK*
m.goulden@uea.ac.uk

2 *School of International Development, University of East Anglia, Norwich NR4 7TJ, UK*

3 *National Oceanography Centre, University of Southampton, Southampton SO14 3ZH, UK*

Abstract This paper reviews current knowledge of the potential impacts of climate change on water resources in Africa and the possible limits, barriers or opportunities for adaptation to climate change in internationally-shared river basins. Africa faces significant challenges to water resources management in the form of high variability and regional scarcity, set within the context of generally weak institutional capacity. Management is further challenged by the transboundary nature of many of its river basins. Climate change, despite uncertainty about the detail of its impacts on water resources, is likely to exacerbate many of these challenges. River basins, and the riparian states that share them, differ in their capacities to adapt. Without appropriate cooperation adaptation may be limited and uneven. Further research to examine the factors and processes that are important for cooperation to lead to positive adaptation outcomes and the increased adaptive capacity of water management institutions is suggested.

Key words climate change; adaptation; water resources; Africa; transboundary water; international river basins; conflict; cooperation

Adaptation au changement climatique dans les bassins fluviaux internationaux en Afrique: une revue

Résumé Cet article passe en revue les connaissances actuelles des impacts potentiels du changement climatique sur les ressources en eau en Afrique, ainsi que les limites et opportunités d'adaptation au changement climatique des bassins fluviaux internationaux. Avec une capacité institutionnelle généralement faible, l'Afrique fait face à d'importants défis concernant la forte variabilité des ressources en eau et les pénuries régionales. La gestion est d'autant plus compliquée en raison de la nature transfrontalière de plusieurs de ces bassins fluviaux. Malgré les incertitudes vis-à-vis des impacts précis du changement climatique sur les ressources en eau, il est probable qu'il exacerbe plusieurs de ces défis. Les bassins fluviaux ainsi que les états riverains qui se les partagent diffèrent par leurs capacités d'adaptation. Sans une coopération appropriée, les moyens d'adaptation peuvent être limités et inégaux. Des recherches approfondies sont proposées, qui examineraient les facteurs et procédés fondamentaux pour une coopération efficace en termes de résultats d'adaptation et d'une plus grande capacité d'adaptation des institutions de gestion des ressources en eau.

Mots clefs changement climatique; adaptation; ressources en eau; Afrique; fleuves transfrontaliers; bassins fluviaux internationaux; conflit; coopération

INTRODUCTION

Africa's freshwater resources are vital to the support of livelihoods (particularly agriculture and fisheries-based livelihoods), food security and power generation as well as growing domestic and industrial needs. Water resources are under pressure from increasing demand and competing uses. Climate change threatens to put further pressure on water resources due to a possible increase in the already high variability in rainfall and river flows and changes to the geographical distribution of water resources, some areas possibly becoming drier, and others becoming wetter (Kundzewicz *et al.*, 2007). Water users and water resource management institutions have to adapt to this variability, to changes in demand and to the effects of climate change. Whilst these may be significant in the future, they are also uncertain.

Adaptation in Africa may be complicated by the transboundary nature of water resources. An estimated 90% of all Africa's surface freshwater resources are located in river basins and lakes that are shared between two or more countries (UNDP, 2006). There are 60 international river basins

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within Africa, covering 62% of the continent's area, and five of these are shared by eight or more countries (Congo, Niger, Nile, Zambezi and Lake Chad; Wolf *et al.*, 1999).

International rivers in Africa pose particular management challenges because of competing national interests and limited mechanisms for cooperative action between nations that share major river basins. Water management has on occasion been compromised by climate variability and competing transboundary needs for water (or power generation from water); for example, the Manantali Dam in Senegal (Magistro & Lo, 2001), the Mtera Dam in Tanzania (Lankford *et al.*, 2004) and the current low levels in Lake Victoria (Pearce, 2006).

The transboundary nature of many of the world's great rivers and increasing global water scarcity have led to ideas of "water wars" or conflict over water resources (Gleick, 1993). However, nations that share international river basins have histories of both conflict and cooperation over water resources (Yoffe *et al.*, 2003). In this paper we use the term conflict to refer not just to armed violent conflict between nations, but also to a range negative interactions that encompass mild verbally-expressed discord and cold interstate relationships, as well as hostile military acts or declarations of war (Yoffe *et al.*, 2003). Conflict can also refer to negative interactions between societal groups at a sub-state scale. Similarly, the term cooperation encompasses a range of positive interactions that can take many forms (see Yoffe *et al.*, 2003) and occur between different actors at different scales. Keohane (2005) describes how "cooperation occurs when actors adjust their behaviour to the actual or anticipated preferences of others, through a process of policy coordination" (p. 51), and distinguishes it from harmony, where no adjustments are needed. He goes on to say that "cooperation should not be viewed as the absence of conflict, but rather as a reaction to conflict or potential conflict" (p. 54). Despite the benefits proposed from cooperation over shared resources, there are many barriers to cooperative action.

This paper reviews literature on: (a) climate change and its impacts on water resources in Africa; (b) adaptation to climate change for water resources management; and (c) conflict and cooperation in international or transboundary river basins. The review identifies the challenges that climate change presents to water resources management in the context of cooperative and non-cooperative behaviour of river basin nation states and their institutions. The aims of the paper are:

(i) to identify what is known about the need and the potential for adaptation to climate change in international river basins, and the processes and factors that may either constrain or enhance adaptation, and
(ii) to identify opportunities for further research to enhance our understanding of how to promote appropriate adaptation to both current climatic variations and future climate change in international river basins.

The next section reviews current understanding of water resources in Africa, how they change as climate changes and interactions with socio-economic change. We then explore processes of managing change in river basins, framed around ideas of adaptation to climate change. There then follows a section that examines barriers and opportunities for adapting to climate change in the context of theory and observation of cooperative and conflictive behaviour around internationally shared water resources. The final section uses insights from the review to identify areas of understanding and highlight opportunities for further study.

CLIMATE CHANGE AND WATER RESOURCES IN AFRICA

Water resources in Africa

Africa is characterised by a wide variety of climate systems ranging from humid equatorial, through seasonally-arid tropical, to sub-tropical Mediterranean-type climates. Annual precipitation in Africa is estimated at about 20 360 km^3 (Aquastat Survey, 2005). Disparities between countries and regions are very important: the central region receives 37% of all precipitation in Africa in an area that accounts for less than 20% of the total, in contrast to the northern region, which has a similar area but receives less than 3% of total precipitation (Aquastat Survey, 2005). Although a

dry regime (rainfall <400 mm year^{-1}) covers 41% of the continent, the intermediate regime (between 400 and 1000 mm year^{-1}) covering 25% of the continent attracts greater concern than the other regimes, as changes in precipitation would result in serious changes in surface and groundwater supply. The intermediate regime shows high seasonality and includes three densely populated regions: southern Africa (including the Orange and Limpopo basins); most of East Africa (including a large section of the Upper Nile basin); and the East–West band stretching from Senegal to Sudan (broadly similar to the Sahel) which crosses a number of important river basins (including Lake Chad, the Niger, the Upper Volta and the Senegal).

This review concentrates primarily on surface water resources in international river basins, whilst recognizing the importance of groundwater, estimated as 15% of Africa's water resources (AfDB *et al.*, 2000). Carter & Parker (2009) estimate that shallow or deep groundwater provides the daily water supply for about half of Africa's population of almost one billion. Green water, present in soil moisture reserves and evaporated to the atmosphere from soil and vegetation (Falkenmark, 1995), is vital in supporting natural ecosystems and rainfed agricultural production systems. Potential evaporation rates are high throughout Africa and, along with precipitation patterns and land cover, are important for determining seasonal variations in soil moisture and groundwater recharge as well as surface water availability (Carter & Parker, 2009; Kundzewicz & Döll, 2009). In some instances riparian states in international basins may use basin precipitation as the basis for calculating total water availability so that accounting for green and blue water flows (and changes thereof) is relevant to discussions and agreements on water allocation.

African water resources are unevenly distributed throughout the continent. There are 11 rivers with catchment areas greater than 250 000 km^2 in area (see Table 1) and more than 160 lakes larger than 27 km^2, most of which are located around the equatorial region and sub-humid East African highlands within the Rift Valley (AfDB *et al.*, 2000). River channels and basin watersheds make up almost 40% of Africa's international borders, and all of the major African rivers traverse one or more international boundaries (de Wit & Stankiewicz, 2006). Table 1 shows the number of countries sharing and the total area of each of the 11 largest international river basins in Africa (all over 250 000 km^2 in area and shared by between three and 13 countries). The basin discharge varies greatly according to region and specific characteristics of the rivers, with the highest discharge being in the Congo basin and lowest in the Orange basin in southern Africa. All of these river basins have high levels of variability, in particular the rivers of West and southern Africa for which the coefficient of variation at the gauging stations shown in Table 1 were over 20% for the period 1961–1990.

Three of the basins in Table 1 can be described as experiencing water stress (defined by UNDP, 2006, as less than 1700 m^3 per person per year), whilst two of these, the Orange and the Limpopo, both in southern Africa, experience water scarcity (defined as less than 1000 m^3 of water per person per year, UNDP, 2006). The Nile and Volta basins have the highest average population densities and are approaching situations of water stress. These statistics mask considerable variability within the basins and refer only to renewable water resources and not to people's ability to access water (Rijsberman, 2006).

Non-renewable groundwater resources are widely used in North Africa; for example the Great Man-Made River Project in Libya (Kundzewicz & Döll, 2009; Scheumann & Alker, 2009). Globally, there are large uncertainties in estimates of renewable groundwater resources and groundwater recharge (Kundzewicz & Döll, 2009). This is particularly the case for Africa where monitoring networks are inadequate (*Groundwater and Climate in Africa*, 2008). In addition much of the groundwater resources are located in an estimated 40 aquifer systems that are shared by several countries (Scheumann & Alker, 2009). The hydrological monitoring network for surface water in Africa is more developed than that for groundwater, but has generally sparse coverage and short fragmentary records, although some reliable long records exist for parts of the Nile basin and on major rivers in West Africa (Conway *et al.*, 2009). Soil water is not generally monitored.

The high levels of variability in rainfall and river flows in Africa across a range of spatial and temporal scales have important consequences for the management of water resource systems

Table 1 Comparison table for 11 international river basins in Africa.

Basin name	Number of countries *	Total area of basin * (km^2)	Basin discharge * (km^3 $year^{-1}$)	Gauging station †	River flow (at gauging station) † (m^3 s^{-1})	Coefficient of variation of river flow † (%)	Population * ($\times 10^3$)	Population density * (persons/ km^2)	Water stress * (m^3 $year^{-1}$) per person
West Africa:									
Lake Chad	8	2 388 700	100	N'djamena (River Chari)	892	42	37 300	16	2 800
Niger	11	2 113 200	330	Dire	870	29	82 100	39	4 100
Senegal	4	436 000	30	Bakel	549	48	4 420	10	5 800
Volta	6	412 800	40	Senshi Hal.	1 044	68	20 100	49	1 900
Central Africa:									
Congo/Zaire	13	3 691 000	1270	Kinshasa	42 418	13	63 200	17	20 000
East Africa:									
Nile	11	3 031 700	330	El Deim (Blue Nile)	1 454	20	160 000	53	2 000
Juba-Shibeli	3	803 500	20	-	-	-	14 600	18	1 100
Southern Africa:									
Zambezi	9	1 385 300	330	Victoria Falls	1 183	38	28 800	21	11 300
Orange	4	945 500	7	-	-	-	13 100	14	540
Okavango	4	706 900	30	Mohembo	869	22	973	1	30 700
Limpopo	4	414 800	10	-	-	-	11 800	28	890

* Data source: Transboundary Freshwater Spatial Database (http://www.transboundarywaters.orst.edu/database/transfreshspatdata.html).
† Data source: Conway *et al*. (2009).

(Peel *et al.*, 2004; Conway *et al.*, 2009). Throughout Africa, this variability brings significant implications for society and causes widespread acute human suffering and economic damage (Conway & Hulme, 1996). Although most of the African population (roughly 69%) lives, on average, in conditions of relative water abundance, this does not reflect the poor access to clean drinking water and sanitation (Vörösmarty *et al.*, 2005). Only 62% of Africans had access to improved water supply in 2000, despite considerable improvements during the 1990s (WHO/UNICEF, 2000). Current population trends and patterns of water use indicate that more African countries will exceed the limits of their "economically usable, land-based water resources before 2025" (Ashton, 2002).

Climate change in Africa

Against a backdrop of existing high levels of variability, climate change will alter the timing, distribution and quantity of water resources. The IPCC Fourth Assessment Report provides a comprehensive review of climate model projections for different regions in Africa. These are based on a set of 21 models from their Multi-Model Data (MMD) set using the A1B emissions scenario focusing on the change in climate between the period 1980–1999 (to represent the current climate) and 2080–2099 (to represent the future); cf. Christensen *et al.* (2007). Emissions scenario A1B represents a mid-range emission profile for a future world scenario characterised by rapid economic growth, a global population that peaks in the mid-21st century with a balanced use of fossil and non-fossil fuel energy sources (Nakićenović & Swart, 2000). Although A1B has been chosen as a "best-guess" scenario, by 2007 there were indications that we had already exceeded both this and the higher emissions scenarios used by the IPCC (Raupach *et al*., 2007).

Table 2 summarises, for each sub-region of Africa, the main changes in temperature and precipitation between the present and future periods. Results are presented as changes in mean temperature and precipitation for the mean of all the climate models and their range (differences exist in the projections produced by different climate models). The climate models show a consistent response in both mean annual and seasonal temperature change in all sub-regions, projecting warmer conditions ranging from +3.2°C (East Africa) to +3.6°C (Sahara) by the 2080s. Nearly all models project wetter conditions in West and East Africa (+2% and +7%, respectively) while drier conditions are projected in southern Africa and the Sahara (–4% and –6%, respectively). It is important to note that individual models generate large, but disparate, responses in the Sahel, such that, at present, there is no clear signal of future rainfall patterns in this region.

Table 2 Changes in mean temperature and precipitation between present day and 2080s. Multi-model means and model range shown, based on Christensen *et al*. (2007).

Region	Temperature: Annual (inter-model range)	Seasonal *	Precipitation: Annual (inter-model range)	Seasonal *
West Africa (12°S, 20°W to 22°N, 18°E)	+3.3°C (+1.8 to +4.7°C)	Warming in all seasons: +3.0°C (DJF) to +3.5°C (MAM)	Increase of 2% (–9 to +13%)	Increase in all seasons (1–6%) except for MAM where a slight decrease is projected (–3%)
East Africa (12°S, 22°E to 18°N, 52°E)	+3.2°C (+1.8 to +4.3°C)	Warming in all seasons: +3.1°C (DJF, SON) to +3.4°C (JJA)	Increase of 7% (–3 to +25%)	Increase in all seasons: 4% (JJA) to 13% (DJF)
Southern Africa (35°S, 10°E to 12°S, 52°E)	+3.4°C (+1.9 to +4.8°C)	Warming in all seasons: +3.1°C (DJF, MAM) to +3.7°C (SON)	Decrease of 4% (–12 to +6%)	Decrease in JJA (–23%) and SON (–13%). No changes in DJF and MAM
Sahara (18°N, 20°E to 30°N, 65°E)	+3.6°C (+2.6 to +5.4°C)	Warming in all seasons: +3.2°C (DJF) to +4.1°C (JJA)	Decrease of 6% (–44 to +57%)	Decrease in all seasons (–4 to –18%) except SON where a slight increase is projected (+6%)

* DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November.

According to Christensen *et al.* (2007) projections concerning extreme events in the tropics remain uncertain. There is a tendency for monsoonal circulations to result in increased precipitation despite a tendency towards weakening of the monsoonal flows themselves. The main and most understood climate drivers of inter-annual and decadal rainfall variability in Africa are Atlantic (and other) Ocean SST patterns (West Africa and the Sahel), ENSO behaviour (West, southern and East Africa) and Indian Ocean dynamics (East and southern Africa). At present, model simulations of future climate do not show clear tendencies in the future behaviour of these large-scale drivers (Merryfield, 2006; Conway *et al.*, 2007).

Overall, these results suggest that warming is very likely to be larger than the global annual mean warming throughout the continent and in all seasons. On balance, higher temperatures are likely to increase evaporative demand throughout Africa. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara. Rainfall in southern Africa is likely to decrease in much of the Southern Hemisphere winter rainfall region and western margins. Annual rainfall in East Africa is likely to increase, but it is unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve.

Climate change impacts, socio-economic change and water resources in Africa

During the coming century, increasing population, changing patterns of water use, and concentration of population and economic activities in urban areas will further pressurise Africa's freshwater resources (Arnell, 2006). In addition, changes in land cover and land use, the construction of upstream reservoirs, and pollution from domestic, industrial and agricultural sources will exacerbate problems related to timing and quality of water supplies. The high spatial and temporal variability of water resource availability and its uneven spatial distribution means that water scarcity is a major concern in some parts of Africa. Vörösmarty *et al.* (2005) estimate water stress to be high for 25% of Africa's population with a further 13% experiencing water stress due to drought once a generation. Climate change threatens to put further pressure on water resources already under pressure. Arnell (2004) estimates the population at risk of increased water stress in Africa to be 75–250 million and 350–600 million people by the 2020s and 2050s, respectively. The results from a selection of climate impact studies of surface water resources in Africa are presented in Table 3. Most of these studies combine climate change scenarios (derived from global climate models) with hydrological models to simulate river flow response to changes in temperature, potential evaporation (PE) and rainfall (see Gleick, 1986). Such studies generally demonstrate greater proportional changes in river flows than in precipitation and fairly modest responses to increasing temperature or PE. The overall effects on river flows show a wide range of outcomes, even for the same rivers, primarily due to differences in future precipitation scenarios between climate models.

These studies rarely incorporate sophisticated representation of PE, soil moisture dynamics and land cover, or a focus on changes in the frequency/magnitude of extreme events. In many of the most socio-economically important basins in Africa, evaporative losses are high and, other things being equal, likely to increase as the climate warms. Understanding future patterns of evaporation and transpiration and their interaction with land cover change is a key area for further research.

In the future, the demand for groundwater is likely to increase as total water use increases (Kundzewicz *et al.*, 2007). Demand may also increase in response to changes in surface water availability. Although groundwater systems generally respond more slowly to climate change than surface water systems, climate change will affect groundwater recharge rates and groundwater levels, i.e. the renewable groundwater resource (Kundzewicz *et al.*, 2007). However, knowledge of current recharge and levels in both developed and developing countries is poor and few studies have considered the effects of climate change on groundwater, particularly in Africa. Kundzewicz & Döll (2009) suggest that modelling results published by Döll & Fiedler (2008), which predict larger percentage decreases in groundwater recharge than in runoff for some areas of the globe, including southwestern Africa, may be overestimates, since increased daily rainfall variability is

Table 3 Summary of studies on climate change impacts on surface water resources in Africa.

Region	Projected changes in water resources *	References
Africa	By 2050, water stress will increase over 62.0–75.8% of total river basin area and will decrease over 19.7–29.0% of this area.	Alcamo *et al.*, 2007
	Decrease in perennial drainage will significantly affect present surface water access across 25% of Africa by 2100.	de Wit & Stankiewicz, 2006
East Africa	Runoff in eastern Africa is projected to possibly increase by 2050.	Arnell, 2003; Strzepek & McCluskey, 2006
	Increase in runoff of 20–40% by 2050 in eastern equatorial Africa.	Milly *et al.*, 2005
	Except during the 2001–2005 period, the total average annual inflow volume of Lake Ziway might decline by up to 19.5% for A2a and 27.4% for B2a scenarios.	Abraham, 2006
	Future Nile discharge (up to 2100) will decrease slightly (–2%) or will remain relatively stable compared to the current situation (average over 1750–2000 AD).	Aerts *et al.*, 2006
	Lake Tana: if the temperature is increased by 2°C and: (1) no change in rainfall → decrease in annual flow by 11.3%; (2) decrease in rainfall by 10–20% → decrease in runoff by 29.3–44.6%; (3) increase in rainfall by 10–20% → increase in runoff by 6.6–32.5%.	Tarekegn, 2000
	Reduction in runoff in Nile by 2050 (around 3%).	Manabe *et al.*, 2004
	Increase in water withdrawals in the Nile by 2025, mainly because of population and economic growth (application to a business-as-usual scenario).	Alcamo *et al.*, 2003
	By 2025, propensity for lower Nile flows (in eight out of eight scenarios).	Strzepek *et al.*, 2001
	White Nile flows sensitive to changes in Lake Victoria levels.	Sene, 2000
	Five out of six climate models produced an increase in Nile flows at Aswan, with only one showing a small decrease.	Yates & Strzepek, 1998
	Range (due to differences between GCM scenarios) of –9% to +12% change in mean annual Nile flows for 2025.	Conway & Hulme, 1996
	Divergence between climate model results for the Nile basin; two produced increases and two produced decreases in flows.	Strzepek & Yates, 1996
	By 2050, the combined effects of climate change, land-use change, and water resources management on future water availability in Egypt range from a large water surplus to a large water deficit.	Conway *et al.*, 1996
Southern Africa	Decrease in runoff of 10–30% by 2050 in southern Africa.	Arnell, 2003; Milly *et al.*, 2005
	Change in discharge relatively small in the Zambezi by 2050.	Manabe *et al.*, 2004
	Increase in water withdrawals in the Limpopo mainly because of population and economic growth (for a business-as-usual scenario).	Alcamo *et al.*, 2003
	Decrease in annual mean water flow in Okavango River by 14% (B2 scenario) or 20% (A2 scenario) for the 2050 to 2080 period.	Andersson *et al.*, 2006
North Africa	Runoff is projected to possibly decrease by 2050.	Arnell, 2003
	Most of North Africa: stabilization or decrease in water withdrawals between 1995 and 2025.	Alcamo *et al.*, 2003
Central Africa	Runoff is projected to possibly decrease by 2050.	Arnell, 2003
	Increase in runoff of 12% in Congo by 2099 compared to the recent discharge values.	Aerts *et al.*, 2006
	Increase in water withdrawals in the Congo mainly because of population and economic growth (for a business-as-usual scenario).	Alcamo *et al.*, 2003
West Africa	Significant increase in runoff in regions of heavy rainfall (e.g. coastal region of Africa around the Gulf of Guinea) by 2050.	Manabe *et al.*, 2004
	Increase in runoff of 61% in Volta by 2099 compared to the recent discharge values.	Aerts *et al.*, 2006

* These studies use a number of different climate change scenarios.

not accounted for by the model. Carter & Parker (2009) suggest that a study by Cavé *et al.* (2003) also overestimates reductions in groundwater recharge due to projected reductions in annual rainfall in southern Africa. Carter & Parker (2009) suggest that, for dry regions, groundwater recharge can depend as much on land use and land management as on climate. This point is illustrated by the study by Mahé (2009), which shows two river basins in West Africa responding differently to decadal-scale rainfall reductions in the 1970s and 1980s. In the Bani River basin, a tributary of the Niger River, the lowering of the groundwater table corresponded to reduced rainfall and contributed to the reduction in river discharges, whilst in the drier Nakambe River

basin in the Upper Volta basin, increases in river discharge—despite rainfall reductions and lowered groundwater tables—are explained by changes in land cover and land degradation.

Despite the uncertainty, because of the importance of groundwater in water supply in Africa, changes in availability could have disproportionately large effects on human wellbeing and stability of supply in regions with strongly seasonal precipitation regimes.

It is important to include changes in water availability and demand due to non-climatic factors such as population growth, and changes in *per capita* and agricultural water demand (Conway *et al.*, 1996; Vörösmarty *et al.*, 2000; Alcamo *et al.*, 2003, 2007; Arnell, 2004). Economically- and demographically-driven growth in demand generally leads to large changes in *per capita* water availability and often outweighs climatically-induced changes. For example, Alcamo *et al.* (2007) found that, in around 90% of the area of river basins, the main cause of increasing water stress was growth in water withdrawals, whereas in only the remaining 10% it was a decrease in water availability due to climate change. Carter & Parker (2009) examine the impacts of demographic trends on groundwater recharge and conclude that, for Africa, the massive increase in demand for water resources, including groundwater resources, due to rapid population rise and urbanisation is likely to far outweigh any reductions in water resources due to climate change. These analyses reveal that the interaction of underlying drivers of demand is moving many countries and international basins inexorably towards increasing water scarcity and river basin closure (Molle, 2003). *Per capita* indicators of water scarcity tend to be lower in areas with high population density and high water use. Many of these areas also experience high inter-annual variability, and surface flows show high sensitivity to climatic perturbations (Vörösmarty *et al.*, 2005; Conway *et al.*, 2009). It is these areas (much of southern and northern Africa) where climate change is most likely to exacerbate the challenge of achieving sustainable and equitable water resource management. In water-scarce areas, where precipitation is projected to increase (e.g. East Africa), scarcity may be alleviated if increases in precipitation are large enough to offset increases in PE. Indeed, the sub-basin-scale dynamics of rainfall–runoff relationships, soil moisture, groundwater recharge and the role of increased PE will be critical in determining water availability in many areas.

Climate change will affect demand for water through direct physical effects and socio-economic effects, such as behavioural changes in water consumption in response to higher temperatures. In most countries, agriculture is by far the largest sector of water use (especially the large irrigators, Egypt, Sudan and South Africa) and irrigation will be directly affected, for example due to higher rates of evaporation. Climate change may reinforce moves to expand irrigation (small and large scale) in Africa as a means of supporting economic growth through the agricultural sector (e.g. Andah *et al.*, 2004; Commission for Africa, 2005). Whether such developments will be maladaptive from a climate change perspective will depend upon what happens to surface water availability, primarily driven by the overall changes in precipitation. In the next section we discuss potential adaptations and their possible transboundary implications.

Changes in precipitation patterns and river flow regimes will cause changes in the frequency and magnitude of floods and droughts across Africa. In coastal areas, increasing flood risk will be exacerbated by sea-level rise, also caused by climate change. Flooding and drought will have wide-ranging secondary impacts on, for example, food security, hydroelectric power generation and domestic water supply (Kundzewicz *et al.*, 2007). Few studies have considered the effects of changes in variability and magnitude/frequency of extreme events on river flows or on the recharge of groundwater. This is primarily due to the difficulty of generating reliable scenarios from climate models at the scale required for impacts modelling. However, Kundzewicz & Döll (2009) suggest that, in semi-arid and arid areas of Africa, increased intensity of precipitation and flood frequency may increase the recharge of groundwater by reducing evaporation losses (except for areas with compacted soils), whilst the opposite is true for sub-humid and humid areas. In the past, extreme events have brought significant challenges to management and also played a key role in prompting *ex post* management and policy responses, such as in the Nile (Conway, 2005) and South Africa (Schulze, 1997).

ADAPTATION TO CLIMATE CHANGE IN RIVER BASINS

The impacts of climate change and other stresses on water resources and changes to flooding risks in the future will require adaptation on the part of water resource management institutions and water users. In this section we examine the challenges of adaptation in the water sector, evidence for types of adaptation that are already occurring and factors that might influence the success of adaptation in river basins. The majority of the literature on adaptation in the water sector originates from North America and Europe. We draw on this literature and ask what might be the additional challenges to adaptation in the African continent where the institutional capacity of management institutions, water scarcity and the transboundary nature of many of the river basins may all have an impact on the ability to adapt. The terms adaptation and adaptive capacity are used in this paper in the sense used by the IPCC, where *adaptation* describes "changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change" (Smit & Pilifosova, 2001, p. 879) and *adaptive capacity* refers to "the potential, or ability of a system to adapt to climate change stimuli or their effects or impacts" (Smit & Pilifosova, 2001, p. 894).

Challenges of adaptation to climate change: decision making under uncertainty

Water resource and flood-plain management systems used in developed countries assume a stationary climate where probabilities for hydrological variables can be estimated from observations. However, this assumption of stationarity is no longer valid with recent and expected changes in climate (Olsen, 2006; Milly *et al.*, 2008).

Different future climate scenarios have been used in impact assessments for planning adaptation (e.g. Warwick *et al.*, 2003). However, the scenario approach can be problematic because different climate models produce a wide range of different scenarios (Stakhiv, 1998) and yet may still underestimate the full range of possibilities, whilst the credibility of individual scenarios is hard to evaluate (Kundzewicz *et al.*, 2007). The use of subjective probabilities, or probability distribution functions, has been experimented with (Kundzewicz *et al.*, 2007), but, according to Olsen (2006), the difficulty of experts reaching agreement on subjective probabilities can be a drawback to this approach. New *et al.* (2007) demonstrate for the River Thames in the UK, as an example, that probabilistic climate change impacts information generated from a large ensemble global climate model can enable the estimation of the potential risk associated with different adaptation options. However, they recognise that this method requires a detailed analysis of different sources of uncertainty in the impacts model, perhaps beyond the scope of many organisations.

Olsen (2006) suggests the need for new approaches, such as minimizing the regret of making a wrong decision or minimizing vulnerability. An example of this is provided by Dessai & Hulme (2007), who analyse the robustness of adaptation decisions taken by a water service provider in the UK to uncertainties in climate change. Aerts & Droogers (2004) emphasize that adaptation measures are related to a number of stressors in addition to climate change, including, for example, land-use change, population growth, competition between sectors, etc. Dessai *et al*. (2009) conclude that, given the deep uncertainties in climate prediction and the reality that climate is only one factor influencing adaptation decisions, an approach that avoids heavy reliance on climate prediction and, instead, assesses the robustness of adaptation decisions to a range of plausible futures is preferable. Stakhiv (1998) recommends that a "no-regrets" strategy could be provided by the use of the adaptive management principle for water resource management.

Experience of adaptations in the water sector

Several different frameworks have been used to distinguish between different types of adaptation in the water sector. Drawing on the work of the UK Climate Impacts Programme (http://www.ukcip.org.uk/resources/tools/database.asp), Tompkins *et al.* (2009) distinguish between responses that *build adaptive capacity* and those that *deliver adaptation actions*. They also distinguish *planned* adaptations, specifically implemented to respond to climate change, from *unplanned* adaptation, not specifically designed with climate change in mind. De Loë *et al*. (2001) use a framework developed from the hazards literature (Burton *et al.*, 1993) to categorise the three

main types of adaptations available to the Canadian water sector: *accepting losses*, *preventing effects* or *changing uses or locations*. *Supply-side* and *demand-side* are terms used to distinguish adaptations that increase water supply from those that reduce demand (Kundzewicz *et al.*, 2007). In their "Adaptation Methodology for River Basins" Aerts & Droogers (2004) use a stakeholder participation approach to define factors influencing water resources and management decisions, identify adaptation options and decide evaluation criteria.

Adaptation options listed by Kundzewicz *et al.* (2007) as supply-side adaptations include: exploiting groundwater; increasing storage in reservoirs; desalination of seawater, rainwater harvesting and water transfers between river basins. Demand-side adaptations include: improvement of water-use efficiency and recycling of water, reduction of demand for irrigation by changing crops or cultivation practices, reduction of demand by importing agricultural products (use of "virtual water"; Allan, 1998), sustainable water-use practices, use of water markets to re-allocate water between uses, and use of economic incentives such as metering and pricing. Kundzewicz *et al.* (2007) describe two main approaches for adaptation to increased flood risk: either modify the floodwater or modify the system's susceptibility to flood damage, the relative benefits of each approach depending on local circumstances.

Tompkins *et al.* (2009) find that both planned and unplanned adaptation is already happening in the UK for changes in water supply and demand, and for flood risk management. Adaptation is occurring in the public and private sectors but focuses more on building adaptive capacity than on adaptation action. They also find that legislation and regulation are important drivers of adaptation in the UK water sector, for example, the EU Water Framework Directive.

Adaptations may involve trade-offs between different sectors, for example, maintaining power production or in-stream flows for fish (Payne *et al.*, 2004, in Kundzewicz *et al.*, 2007). Tanaka *et al.* (2006) find that adaptation of California's water supply system will involve significant transfers among water users, changes in the operation of groundwater storage and adoption of new technologies. Water markets, already existing in the USA, Canada, Chile and Australia, and developing in several other regions of the world, provide a way of achieving such transfers of water (Kundzewicz *et al.*, 2007).

Examples of adaptations to climate change in the water sector in developing countries are less documented, perhaps because developing countries have many other pressing issues to tackle (Kabat *et al.*, 2002). Ragab & Prudhomme (2002) suggest adaptations for arid and semi-arid regions that include conventional solutions, such as developing storage dams and irrigation schemes, inter-basin transfers of water through networks of pipes and canals, and further development of groundwater resources. They also suggest more innovative solutions, such as rainwater harvesting, desalination, cloud seeding, water storage in underground reservoirs, and the development of salt tolerant crops to make use of brackish water and, alternatively, solutions that reduce the demand for water, such as reducing leaks and evaporation, improving efficiency of irrigation, and recycling of water. Some of these measures are already being implemented in African river basins, for example, in the Nile basin (Conway, 2005) and Orange basin (Kistin & Ashton, 2008), although actions may not be specifically taken to deal with climate change risks. Where water resource management decisions are taken without considering possible future climate change impacts, then maladaptation may result, as vulnerabilities to future climate change are increased.

Groundwater exploitation provides more reliable and improved-quality water supplies for rural communities in many parts of Africa and elsewhere (Hiscock *et al.*, 2002). Adaptation by increasing the use of groundwater has been suggested (Kundzewicz *et al.*, 2007). However, Hiscock *et al.* (2002) warn of unsustainable use of groundwater and suggest that strategies to develop groundwater should be compatible with future scenarios, including climate change.

Determinants of adaptive capacity and factors influencing the success or limitations of adaptations

Studies of adaptive capacity to stresses in a variety of systems have identified a number of different determinants of adaptive capacity that are specific to the system, sector and location and can

also vary over time (Yohe & Tol, 2002; Smit & Wandel, 2006). Examples include: the range of technological options available for adaptation; the availability of resources and their distribution; institutional structures and the decision-making criteria of institutions; human capital; social capital; access to risk spreading mechanisms; the management of information; and the public's attribution of, and exposure to, the stress (Yohe & Tol, 2002).

Adaptation options and the constraints on water management are specific to the context in which they occur (Ivey *et al.*, 2004; Arnell & Delaney, 2006; Shepherd *et al.*, 2006). In addition, the goals of adaptation are important for determining whether adaptation is successful or whether limits to adaptation exist (Adger *et al.*, 2009). To be effective, adaptation should fit with existing management systems and objectives.

Four different types of limits or barriers to adaptation to changes in water quantity and quality have been identified (Kundzewicz *et al.*, 2007; Arnell & Charlton, 2009). Firstly, there may be physical barriers that constrain the performance of a particular adaptation option. Secondly, there may be economic constraints when some adaptations are considered too costly. There may be socio-political barriers to adaptation according to the attitudes of stakeholders to proposed adaptation options and, finally, the capacity of water management institutions may limit the ability to promote or implement adaptations (Kundzewicz *et al.*, 2007; Arnell & Charlton, 2009).

Physical barriers are geographically specific; for example, some adaptation options may be unavailable in "closed" river basins, those where there is no dry season outflow of usable water and where additional withdrawal of water by one user decreases the amount of water available to other users (Seckler *et al.*, 1998; Turton, 2003). There may also be a physical limit to the reduction in water demand that is possible without harming the health and livelihoods of the population (for example, see Kundzewicz *et al.*, 2007). The highly variable flows in many African rivers basins also provide barriers or challenges to their management (Lankford & Beale, 2007).

Socio-political barriers exist where adaptations are subject to conflict (Miller *et al.*, 1997), or are considered undesirable by some stakeholders; for example, the metering of water to reduce demand (Shepherd *et al.*, 2006). Changes in expectations of water services may be necessary or society may have to accept trade-offs between different uses of water (Kundzewicz *et al.*, 2007). Socio-political barriers to adaptation can sometimes be overcome; for example, Penning-Rowsell *et al.* (2006) found that flooding events can create windows of opportunity for policy change. Similarly, Arnell & Delaney (2006) found that extreme events triggered an improved awareness of climate change, which provided incentives for building adaptive capacity for public water supply in the UK. Economic barriers to adaptation arise because adaptation is often costly (Miller *et al.*, 1997; Tanaka *et al.*, 2006). However, the costs of not adapting to climate change can be far greater than the adaptation costs (Stern, 2007), as Boko *et al.* (2007) illustrate for the Berg River basin in South Africa.

Moser (2009) draws attention to the many ways in which the decisions, actors, processes, institutional structures and mechanisms that make up governance can be involved in determining adaptation actions. Institutions and governance structures in the water sector differ significantly both within and between countries (Kundzewicz *et al.*, 2007) and can either facilitate or hinder adaptation by different stakeholders at different scales (Ivey *et al.*, 2004; Naess *et al.*, 2005). Whilst water governance structures in the UK (Tompkins *et al.,* 2009) and the USA (Frederick *et al.*, 1997; Stakhiv, 1998) are able to promote adaptation, in developing countries existing legal frameworks and institutions are often too weak to address the challenges currently faced by the water sector (Levina, 2006). Given that, over the short to medium term, future climate change is likely to exacerbate existing challenges to water resources management (scarcity, flood risk), there are many situations where adaptation will fit closely with current management objectives. This has been referred to as a "no-regrets" strategy (Stakhiv, 1998; de Loë *et al.*, 2001). A significant objective for many countries in Africa is to reduce the large adaptation gap that already exists in many situations.

Integrated Water Resources Management (IWRM) and Adaptive Water Management are seen by some as suitable approaches for enhancing adaptive capacity in the water sector (Stakhiv, 1998;

Pahl-Wostl *et al.*, 2005; Kundzewicz *et al.*, 2007). However, developing countries face considerable barriers to implementing IWRM and adaptive management, since it is reliant on the adaptive capacity of national institutions (Allan *et al.*, 2002).

Adaptation in international river basins in Africa

Few studies address adaptation to climate change in international river basins. The transboundary issue is not discussed in the Water chapter of the IPCC Fourth Assessment Report, and appears only briefly in the Africa chapter in relation to cross-border management of floods in Mozambique and mention of the international nature of water management in West Africa and the Okavango. Neither does the chapter on Managing Transboundary Waters in the 2006 Human Development Report consider climate change adaptation. Aerts & Droogers (2004) examine adaptive strategies to climate change in seven case studies of river basins including the Volta in West Africa. A major ongoing European Union funded research project on adaptive water management, called NeWater, consists of seven case studies of international river basins in Europe, Asia and Africa (including the Nile and Orange basins (Pahl-Wostl *et al.*, 2005).

International river basins in Africa differ with respect to the opportunities available for, or barriers to, adaptation. Table 4 shows relevant indicators for potential adaptive capacity for 11 African international river basins (see also Table 1). The gross domestic product (GDP) can be taken as an indication of national economic resources available for adaptation and the human development index (HDI) as an indication of differential social vulnerability to climate change impacts, although these are only two of several possible indicators of adaptive capacity and social vulnerability (Brooks *et al.*, 2005). Basins with a higher mean GDP, such as the Orange basin in southern Africa, might be expected to have a higher adaptive capacity, because they are more likely to have the financial resources to address transboundary water resources management issues. Those basins with a large range of GDP and HDI values within the basin indicate situations of great inequality, where adaptive capacity is likely to vary greatly within the basin, and some countries may be better placed to adapt than others, such as the Lake Chad, Congo and Zambezi basins. Without effective basin-wide institutions and agreements, this could result in uneven adaptation, e.g. one country's adaptation potentially causing negative impacts on another country within the basin. This could also occur in internationally shared groundwater resources, which are found in an estimated 40 transboundary aquifers in Africa (Scheumann & Alker, 2009). Scheumann & Alker (2009) examine the transboundary impacts of groundwater development in five cases of transboundary aquifers in Africa. They conclude that transboundary impacts already occur in some of the cases and could potentially increase with planned development projects.

The institutional arrangements for managing transboundary water resources are therefore important for adaptive capacity. The number of treaties (Table 4) reflects, in part, the number of countries sharing a river basin and the history of cooperation between them. For example, the Nile basin has a large number of treaties, which go back to the colonial era (see Waterbury, 2002). Not all of the treaties in African international river basins are exclusively related to water resource management, and many of them are bi-lateral or multi-lateral agreements that do not involve all riparian countries. Different institutional arrangements accompany these treaties. Some provide flexibility mechanisms or transboundary institutions that could assist adaptation, whilst others have conditions that may limit adaptation (Fischhendler, 2004; Drieschova *et al.*, 2008; Kistin & Ashton, 2008). Some river basin institutions, for example the Lake Chad Basin Commission and the Orange-Senqu River Basin Commission, have expanded their remit to include transboundary groundwater resources as well as surface water (Scheumann & Alker, 2009). In addition to treaties, there are other forms of cooperation which can add to adaptive capacity and may either be enshrined in formal agreements or occur informally. These are discussed in the next section.

The "Basins at Risk" indicator in Table 4 is taken from a global-scale analysis of international river basins by Yoffe *et al.* (2003), who identified a number of factors contributing to risk of future conflict over freshwater resources, including: high population density, low *per capita* GDP, overall unfriendly relationships (as derived from a database of events), the presence of politically

Table 4 Comparison of indicators of adaptive capacity for international river basins (see footnotes for data sources).

Basin name	Number of countries[a]	Number of dams[a], *n* (dam density = *n*/1 × 10^6 km^2)	Irrigated area[a] (km^2)	Irrigable area[a] (10^3 km^2)	Number of treaties[b]	GDP *per capita* (2005) basin mean[c] (max–min)	HDI (2005) basin mean[c] (max – min)	Basins at Risk code[d]	Change in future basin runoff with climate change[e]
West Africa:									
Lake Chad	8	1 (0)	1130	1600	2	1677 (244–6621)	0.53 (0.37–0.82)	2	-
Niger	11	10 (0.1)	2980	2060	10	769 (216–3112)	0.45 (0.34–0.73)	0	Small increase[f]
Senegal	4	0 (0)	367	383	5	513 (350–707)	0.47 (0.38–0.55)	2	-
Volta	6	3 (0.2)	386	508	3	506 (358–900)	0.45 (0.37–0.55)	0	Large[f] or very large[g] increase
Central Africa:									
Congo/Zaire	13	22 (0.4)	69	4200	2	1012 (106–5821)	0.48 (0.38–0.68)	0	Either small[f] to moderate[g] increase, or decrease[h]
East Africa:									
Nile	11	12 (0.1)	52200	2710	18	392 (106–1207)	0.48 (0.38–0.71)	1	Small decrease[f,g] or large increase[h,i]
Juba-Shibeli	3	0 (0)	2270	861	1	352 (157–547)	0.46 (0.41–0.52)	0	-
Southern Africa:									
Zambezi	9	35 (1.2)	1430	1530	9	1415 (123–5846)	0.49 (0.38–0.65)	3	Small[f] or moderate to large[h,i] decrease
Orange	4	33 (2.5)	6820	1260	5	3695 (808–5846)	0.63 (0.55–0.67)	0	Moderate to large decrease[h,i]
Okavango	4	1 (1)	-	932	1	2795 (259–5846)	0.57 0.45–0.65)	2	Moderate to large decrease[h,i]
Limpopo	4	40 (3.4)	4750	542	1	2887 (259–5846)	0.56 (0.38–0.67)	3	Moderate to large decrease[h,i]

[a] Transboundary Freshwater Spatial Database: http://www.transboundarywaters.orst.edu/database/transfreshspatdata.html
[b] The African Transboundary Water Law Page: http://www.africanwaterlaw.org/html/default.asp
[c] UNDP (2006). Unit of GDP = US$.
[d] Basins at Risk: 0 = not at risk; 1 = negotiating current conflict; 2 = indicators and protests over water; 3 = indicators only (Yoffe *et al*., 2003).
[e] Small: 0–5%; moderate: >5 to <20%; large: 20 to <50%; very large: 50% and over.
[f] Runoff change by 2050 (Manabe *et al.*, 2004).
[g] Change in discharge 2001–2099 (Aerts *et al.*, 2006).
[h] Runoff change by 2050 (Arnell, 2003).
[I] Runoff change by 2050 (Milly *et al*., 2005).

active minority groups, and limited or no freshwater treaties. These factors were then combined in a single "Basins at Risk" indicator with three categories. Type 1 basins are those that are "negotiating current conflict", do not have basin-wide treaties, and have a high potential for disputes (e.g. the Nile basin). Type 2 basins are those with the potential for future conflict and existing issues that have raised protests or tensions within the basin (e.g. Lake Chad, Senegal and Okavango basins). Type 3 basins have similar factors to Type 2, but without evidence for existing tensions or protests (e.g. Zambezi and Limpopo basins). The remainder of the basins listed in Table 4 were not identified as being "at risk" by Yoffe *et al.* (2003).

The more highly developed basins are those that have a high number of dams, a high density of dams and a larger irrigated area in comparison to other river basins, such as the Zambezi, Orange and Limpopo. The Orange and Limpopo river basins are already water scarce, as indicated in Table 1. Expansion of existing water use in these basins is limited and they are regarded as "closed" river basins (Turton, 2003). These basins are also likely to be exposed to serious climate change impacts as they are projected to experience decreasing runoff in the future with climate change (see Table 4). This suggests that there may be physical limits to some types of adaptation, such as increased storage and expansion of irrigation systems. Adaptations based on demand management are likely to be particularly important in these water-scarce basins. In southern Africa, adaptations to water scarcity also involve inter-basin transfers of water, and more of these are contemplated for the future, for example between the Orange, Limpopo and Zambezi river basins (Kistin & Ashton, 2008).

Socio-political barriers to adaptation are likely to be influenced by the power relationships and politics between riparian states and are apparent in the often competing priorities and interests for water development amongst different riparian states, for example in the Nile River basin. Adaptations to changing water demand and to climate change impacts may have transboundary implications. For example, expansion of water storage and irrigation facilities may reduce flow to downstream riparian states, especially if their design does not incorporate the likelihood of changing river flows with climate variability and future climate change. This is already an issue of concern in Mozambique, the downstream riparian in the Limpopo and Zambezi basins (Wirkus & Böge, 2006) and could become important in other river basins, such as the Volta (Andah *et al.*, 2004), the Nile (Conway, 2005), and the Orange (Heyns *et al.*, 2008). Basin-wide or bilateral agreements that allow for proportional allocation of water to different states or users are one possible solution to this problem (Lankford & Beale, 2007; Drieschova *et al.*, 2008). It is possible that small-scale programmes of rainwater harvesting, which may be supported as adaptations (for example, through National Adaptation Plans of Action), if adopted on a very large scale, could have transboundary implications, as has been speculated for the Ethiopian Highlands in the Nile basin (Whittington, 1997). Adaptations to changing demand or supply of water may occur in the wider political economy, outside the immediate sphere of water resources management, for example through trade in agricultural products, or "virtual water" trade (Allan, 1998, 2006).

The impacts of extreme climate events and responses to them can have a transboundary dimension; for instance, Benson & Clay (1998) describe an example of water mismanagement at Lake Kariba in the Zambezi basin during the 1991/92 drought in southeastern Africa. Fluctuations of the level of Lake Victoria in the Nile basin, such as the floods of 1997 and 1998 and the large decline in levels between 2005 and 2007, have impacted upon lake-shore communities in Kenya, Tanzania and Uganda (Conway *et al.*, 2005; Pearce, 2006). Both climate variability and management of the lake outflow in Uganda for hydroelectric power are likely to have been responsible for the recent decline in lake levels (Goulden, 2006; Pearce, 2006; Sutcliffe & Petersen, 2007). If climate change is manifest as higher variability and magnitude/frequency of extremes, then they are likely to become important triggers of adaptation in water resource management. However, their role as contributors to cooperative action between river basin states is poorly understood.

Further research is needed on what adaptations are occurring at both national and international scales in African international river basins and what factors are driving these adaptations. Also, further research could identify the particular limitations to adaptation due to the transboundary

nature of the resource and the existing institutional arrangements. We propose that the nature of interactions between countries in international river basins has an important influence on adaptive capacity. These interactions, in particular the role of conflict and cooperation in international river basins, are explored in the next section.

COOPERATION AND CONFLICT IN INTERNATIONAL RIVER BASINS

Climate change and conflict in the literature

The international nature of many of the world's great rivers and increasing scarcity of water has led to discussions in the academic literature of the growing potential for violent conflict, or "water wars", between nations over shared water resources (Gleick, 1993; Toset *et al.*, 2000; Swain, 2001; Gleditsch *et al.*, 2006). A related body of literature links environmental scarcity in broader terms with conflict (Homer-Dixon, 1991, 1994; Gleditsch, 1998). The potential for security problems or violent conflict at an international or sub-national level has also been discussed in relation to the impacts of climate change by Gleick (1989) and, more recently, in a special issue of *Political Geography* (Gleick, 1989; Barnett & Adger, 2007; Hendrix & Glaser, 2007; Meier *et al.*, 2007; Nordas & Gleditsch, 2007; Raleigh & Urdal, 2007).

Nordas & Gleditsch (2007) find that the links between climate change, national security and armed conflict have increasingly been made by governmental and international organisations in recent years without reference to sufficient empirical evidence. The papers of the *Political Geography* special issue highlight two causal links between climate and conflict: fighting over resources, such as food and water, diminished by climate change impacts; and tensions caused by migration of large numbers of people fleeing climate impacts (Barnett & Adger, 2007; Nordas & Gleditsch, 2007; Reuveny, 2007). Little evidence is presented for organised armed conflict but more for unorganised violence. Nordas & Gleditsch (2007) highlight a need for more systematic studies and more sophisticated conflict models that consider both the kinds of violence that could be expected and the links to specific impacts of climate change, both positive and negative, as well as likely adaptation measures. Few studies link security or conflict with the impacts of climate change on water resources in international river basins (Gleick, 1988; van der Molen & Hildering, 2005).

A contrasting perspective on conflict is provided by literature on international river basins. Wolf (1998) suggests that there have been few examples of wars over water historically, and that international water is more likely to induce cooperation than violent conflict due to a number of factors including the shared interests of riparian states, the resilience of institutions where co-operative water regimes have been established and the high economic cost of war compared to the cost of water. Yoffe *et al.* (2003) examine a database of historical incidents over international waters between 1948 and 1999 and find that, for 122 international river basins, the number of cooperative incidents (67%) far exceeds the number of conflictive events (28%).

Forms of conflict and cooperation

Yoffe *et al.* (2003) developed a Water Event Intensity Scale, which draws from the International Cooperation and Conflict Scale of Azar (1980). The scale ranges from extreme conflict at –7, for a formal declaration of war, through to extreme cooperation at 7 for voluntary unification into one nation. In this scale, conflictive interactions include hostile verbal expressions (official or unofficial) and hostile diplomatic, economic or military acts. Cooperative interactions include official verbal expressions of support and cultural, scientific, economic, technological, industrial or military support or agreement. This scale is taken up by Zeitoun & Warner (2006), who combine it with the NATO conflict-development scale (NATO 1999) to produce a Conflict Intensity Frame (shown in Fig. 1) that differentiates between three main categories of conflict: no significant conflict, cold conflict and violent conflict. Zeitoun & Warner (2006) demonstrate how relationships between states can undergo various degrees of intensity of conflict over time and that

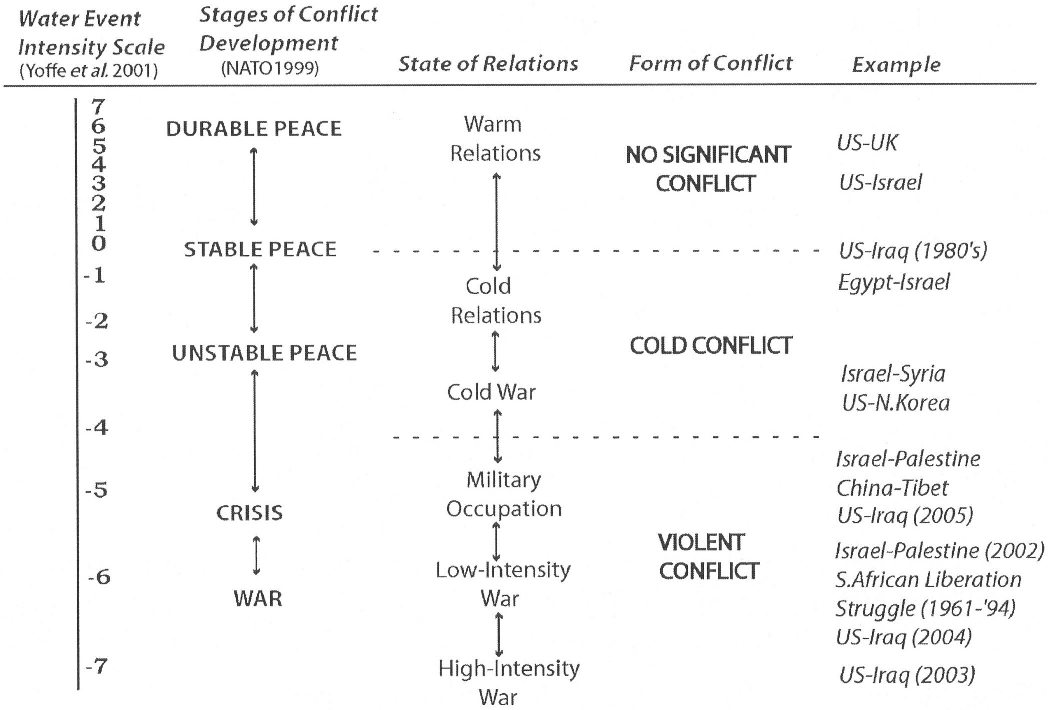

Fig. 1 Conflict Intensity Frame by Zeitoun & Warner (2006) (Reproduced with permission from IWA).

conflict should not just be understood as violent conflict between nation states: less-intense conflicts are still forms of conflict. Recent theorising on conflict over transboundary water resources by Zeitoun (2007) has expressed the dynamics between states in terms of the securitization of the issue, described as the framing of "the issue in terms of security … drawing on perceptions of national, local or individual (in)security" (Zeitoun, 2007, p. 115). The level of securitization ranges from non-politicised (no conflict and some cooperation) through to politicised, securitised and armed (violent conflict). Here, it is the perceptions of states as to how water sharing issues relate to threats to national security that define the level of securitisation.

Until recently, cooperation has been less theorised than conflict (Mirumachi, 2007; Allan, personal communication). Kistin (2006) warns against employing a simplistic dichotomy of conflict and cooperation to describe relationships between riparian states and that cooperation should not be seen just as the absence of conflict. Mirumachi (2007) develops a typology of levels of cooperation adapted from Tuomela (2000): confrontation of an issue; *ad hoc* collaboration; technical collaboration; risk-averting cooperation; and risk-taking cooperation. This has been combined with the securitisation scale (Zeitoun, 2007) to produce a matrix for analysis of interactions over transboundary water resources, referred to as the Transboundary Waters Interaction Nexus (TWINS; Zeitoun & Mirumachi, 2008).

Cooperation over internationally-shared water resources can occur through a number of different formal or informal mechanisms. Formal mechanisms include international conventions, bilateral or multilateral treaties, or agreements involving some or all riparian states, joint river management institutions and joint projects. Informal mechanisms can include knowledge or data sharing. Formal institutions involved in cooperation in African river basins include institutions of the African Union: the African Ministerial Council on Water (AMCOW); and the New Partnership for Africa's Development (NEPAD), and also the UN Economic Commission for Africa (UNECA). There are several important regional institutions, such as the Southern African Development Community (SADC) and the East African Community (EAC), that have a remit that includes transboundary resource management amongst other goals of political, economic and environmental cooperation and regional integration (Wirkus & Böge, 2006). In SADC these goals

are implemented through the SADC Protocol on Shared Water Resources (Kistin & Ashton, 2008). Several African river basins have a river basin organisation as well as a number of bilateral or multilateral agreements, for example the Senegal, Niger, Lake Chad, Okavango, Limpopo, Orange and Zambezi basins (UNECA, 2000; Wirkus & Böge, 2006). The Nile basin does not have a river basin organisation or any agreements involving all riparian countries, although there are several disputed bilateral treaties that date back as far as 1891 (UNECA, 2000), and a number of cooperative programmes, the latest of which is the Nile Basin Initiative started in 1999, which aims to build trust between the ten basin countries (Wirkus & Böge, 2006; Nile Basin Initiative, 2007).

Freshwater treaties use a number of different principles, many of which are enshrined in the 1997 Watercourses Convention: universal participation, equitable use, avoiding significant harm, sovereign equality and territorial integrity, information exchange, consultation, prior notification, environmental protection, and peaceful dispute resolution (Conca, 2006). However, Conca (2006) finds that there are tensions between some of the principles, such as those of "no significant harm" and "equitable use". For example, Waterbury (2002) describes how Egypt gives prominence to the principal of significant harm to defend its existing uses of Nile water, whilst Ethiopia argues for equitable use to allow it to develop its use of Nile water.

Wolf *et al*. (2003) found that cooperation occurs over a wide range of issues in international river basins, including joint management, water quantity, water quality, infrastructure, hydropower and economic development. However, most water disputes revolve around three issues: quantity, quality and timing (Wolf, 2007). Emphasis on benefit sharing as a mechanism for cooperative river basin management can lead to a broader range of issues being included in negotiations and agreements between riparian states, for example, including issues of trade, immigration and environmental protection, as well as issues of water use for irrigation, domestic water supply or hydropower generation (e.g. Sadoff *et al*., 2002).

Whilst extreme conflict (i.e. war) over water, or other renewable resources, is seen as unlikely at the international scale by Wolf (1998), there is evidence for regional disputes over water and other natural resources (Homer-Dixon, 1994; Wolf, 1998; Meier *et al*., 2007). Wolf finds that "geographic scale and intensity of conflict are inversely related" (1998, p. 261) and asserts that there is the highest potential for violence at the regional scale (within-countries), whilst there is little potential for violence between states (Wolf, 2007). Evidence of climate-related conflict is also more common at the regional scale (Meier *et al*., 2007; Raleigh & Urdal, 2007).

Although nation states are the key stakeholders considered in the international relations approach to the study of international rivers, several different stakeholders are involved in these interactions, including the executive authorities and policy-making elites of the riparian states at national and local government level, and non-state actors, such as international donor institutions, multi-national firms, civil society and the environment (Waterbury, 2002; Wolf *et al*., 2003; Furlong, 2006). Engagement with different stakeholders can be important for the public acceptance of proposed measures of cooperation (Huisman *et al*., 2000).

Benefits, conditions and limitations of cooperation

Cooperation in international river basins is seen as desirable (Sadoff & Grey, 2002; Waterbury, 2002; UNDP, 2006). Sadoff & Grey (2002) describe four types of benefits: firstly, benefits *to the river* from cooperative basin-wide environmental management, such as improvements in water quality and maintenance of biodiversity; and secondly, benefits *from the river*, such as hydropower, irrigation, flood and drought management and navigation. Thirdly, they hypothesise benefits *because of the river*, for example reduced risk of conflict between riparian nations and increased food and energy security, and fourthly, benefits *beyond the river*, such as integration of regional infrastructure, markets and trade. Sadoff & Grey (2002) suggest that there are costs to non-cooperation, as well as to cooperation and that, depending on the particular circumstance, the scale of benefits may or may not outweigh the costs of cooperation. In the absence of strong cooperation, Zeitoun & Warner (2006) assert that the varying intensities of conflict that commonly

exist, but fall short of violent conflict, nevertheless have negative consequences on the less powerful riparian states.

The literature cites a number of conditions necessary for, and barriers or limitations to, cooperation that can be political, institutional or geographical. Wolf (1998) refers to geographical determinants of conflict and cooperation by suggesting that conflict is more likely where the downstream nation is the hegemon, or nation with most power, and upstream countries launch projects that reduce water quantity or quality. Other factors thought to have influence on whether cooperation or conflict occurs include the hydroclimatology, particularly the nature of variability and extremes, the institutional capacity to absorb change and the political situation in the riparian countries, in particular whether countries are democracies or not (Wolf *et al.*, 2003; Yoffe *et al.*, 2003). Van der Zaag & Savenije (2000) describe the foundation for balanced and equitable sharing of international water resources as IWRM, supported by three pillars: technical cooperation; an enabling political environment; and adequate institutions. Wolf (1998) suggests that riparian countries need incentives for cooperation, such as strong third-party encouragement and extensive funding from the international community.

The political aspects of transboundary relationships are examined by Zeitoun & Warner (2006) and Zeitoun & Allan (2008), who develop a framework of hydro-hegemony, in which the key factor determining the outcome of competition for water in international river basins is the relative power wielded by each riparian state. They find that the upstream/downstream positions of the riparian states and their potential to exploit water through infrastructure and technical capacity also play a role in determining outcomes. Zeitoun & Warner (2006) argue that the hydro-hegemon, the riparian state with most power, determines the nature of interactions over water resources and whether they are cooperative or competitive, and whether the benefits from the river will reach weaker riparian states or not. Recent research in the Nile basin, applying the hydro-hegemony framework, has investigated the "counter-hegemonic" strategies used by weaker riparian states, such as Ethiopia, to oppose or challenge the *status quo* maintained by the hydro-hegemon, in this case Egypt (Cascao, 2008).

The idea that cooperation is inherently good has been questioned (Kistin, 2006; Kistin & Phillips, 2007; Zeitoun & Mirumachi, 2008). Zeitoun & Mirumachi (2008) describe how token cooperation can mask and perpetuate conflict, and coercive cooperation can deepen conflict. Kistin & Phillips (2007) find that many of the existing arrangements for cooperation in international agreements are flawed because of factors relating to inclusivity, data quality and transparency, flexibility, equitability, environmental sustainability, implementation and enforcement. An example of limitations to cooperation related to flexibility is provided by Fischhendler (2004), who finds that treaties often lack mechanisms to deal with climate variability and that this impedes the ability of treaties and institutions to manage a crisis, such as a drought situation. Drieschova *et al.* (2008), in a review of 50 agreements for international river basins, find that there are trade-offs between flexibility in treaties and the enforceability of the agreements. Nevertheless, there are documented examples of cooperation that incorporates flexibility in response to water variability for African river basins, for example in the Nile basin (Conway, 2005) and the Orange basin (Kistin & Ashton, 2008).

In the context of climate change, an important question is whether barriers to cooperation can be overcome following an emergency, such as an extreme climate event that has an impact on one or more country in an international river basin. Huisman *et al.* (2000), in a study of European international river basins, found that disasters with international impacts can lead to a breakthrough that improves transboundary cooperation. However, Waterbury (2002) suggests that "crisis in the quantity or quality of supply may drive users toward cooperation or, alternatively to conflict" (p. 166).

CONCLUSIONS

In this paper, we have reviewed evidence for climate change and its possible impacts on water resources in Africa, the challenges of adaptation to climate change impacts on water resources,

particularly in international river basins, and the role of cooperation in water resource management in international river basins.

Africa faces significant challenges to water resources management in the form of high variability and regional scarcity, set within the context of generally weak institutional capacity. Management is further challenged by the transboundary nature of many river basins. Climate change, despite uncertainty about the detail of its impacts on water resources, is likely to exacerbate many of these challenges. Empirical and modelling analyses demonstrate that river flows are highly sensitive to climate perturbations. Studies that project changes in average surface runoff conditions from climate and hydrological models show increases in runoff during the 21st century for some regions of Africa, for example in the West African river basins of the Niger and Volta, whilst in Central and East Africa the studies disagree on the direction and magnitude of change. In southern Africa, a region that is already prone to water scarcity, the model projections show decreasing surface runoff in the future. However, these projections are uncertain and, for the majority of river basins, economically- and demographically-driven growth in demand is expected to outweigh climate-induced changes.

Globally, adaptation in the water sector is beginning to emerge, although evidence suggests this is primarily in the form of building adaptive capacity and no-regret type activities in response to multiple factors. The combination of uncertainty and the need to consider non-climate factors is leading to a greater emphasis on flexibility, adaptive management and responses that are robust to uncertainty (e.g. Frederick *et al.*, 1997; Stakhiv, 1998; Pahl-Wostl *et al.*, 2005; Dessai & Hulme, 2007). The nuances of such approaches and their requirements for sophisticated levels of policy and institutional capacity means that their application in an African context requires careful consideration and good understanding of local complexities.

The transboundary nature of the resource and its role in these processes is poorly understood, as is the role that climate extremes and future climate change play. International river basins and their riparian states differ in their capacity to adapt to changing water availability and demand, and extreme climate events, as indicated by their differing economic resources, social vulnerability, institutional arrangements and levels of inequality within the basin. This raises concerns that one country's adaptation may cause a negative impact on another country's ability to adapt, and emphasises the need for cooperative responses to climate change and other drivers of change in water resources. Our review highlights several features of cooperation in transboundary water resource management that are relevant to climate change adaptation. Cooperation is seen to have multiple benefits, including benefits for water resource management and potentially benefits for adaptation, but there are costs to cooperation as well as costs of non-cooperation (Sadoff & Grey, 2002). Interactions that are cooperative and conflictive occur at varying intensities and geographical scales, over a number of issues, through both formal and informal mechanisms, fluctuate over time and frequently co-exist (Yoffe *et al.*, 2003; Kistin, 2006; Zeitoun & Warner, 2006; Zeitoun & Mirumachi, 2008). The power relationships between states sharing a river basin have a major influence on the nature of interactions between states and the outcome of competition for water resources (Zeitoun & Warner, 2006). In addition, the perceptions of states as to how water sharing issues relate to threats to national security define the level of securitisation (Zeitoun, 2007), and this in turn influences interactions. Crisis situations or international emergencies, for example due to flooding or drought, have the potential to either prompt enhanced cooperation or, alternatively, they may exacerbate conflict (Huisman *et al.*, 2000; Waterbury, 2002).

Following on from this review, we suggest an agenda for further research on adaptation to climate change in African international river basins. Research is needed to identify current adaptations occurring at both national and international scales, and what factors are driving these adaptations. The range of water scarcity conditions and levels of adaptive capacity suggest that different combinations of adaptation options will need to be considered, including *inter alia*, storage, supply/demand management and the potential for intra-basin virtual water transfers. The specific physical, economic and political situations in African international basins also deserve more attention, in particular, how they mediate processes of adaptation and cooperation. For both

African and other international basins there is a need to review the appropriateness of existing institutional structures and frameworks for treaties in the context of climate change, and to research new approaches that are better suited to non-stationary hydrological conditions.

There is some evidence that cooperative mechanisms may enhance water resource management in international river basins and may therefore also enhance adaptation to climate variability, climate change and other pressures on water. However, cooperation needs to be examined carefully for how it contributes to adaptation to climate change for different states in river basins. It cannot be assumed that cooperation will facilitate adaptation for all riparian countries due to asymmetric power relationships between countries. Research is needed to examine the factors and processes that are important for cooperation to lead to positive adaptation outcomes and increasing adaptive capacity of water management institutions. For example, is the threat of climate change or experiences of past climatic disasters providing an impetus for cooperation or perhaps a justification for counter-hegemony strategies by weaker riparian states? The role of experience of extreme climate events in triggering cooperation or conflict could be examined for specific African international river basins. In addition, where indicators of conflict do exist between riparian states, does this conflict present a limit to adaptation to climate extremes and future climate change?

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