

From headwater tributaries to international river: Observing and adapting to climate variability and change in the Nile basin

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Received 1 April 2004; received in revised form 1 November 2004; accepted 22 December 2004

Abstract

Egypt is almost totally dependent upon water that originates from the upstream headwaters of the Nile in the humid Ethiopian and East African highlands. Analysis of rainfall and river flow records during the 20th century demonstrates high levels of interannual and interdecadal variability. This is experienced locally and regionally in the headwater regions of the Nile and internationally through its effects on downstream Nile flows in Sudan and Egypt. Examples of climate variability are presented from areas in the basin where it exerts a strong influence on society; the Ethiopian highlands (links with food security), Lake Victoria (management of non-stationary lake levels) and Egypt (exposure to interdecadal variability of Nile flows). These examples reveal adaptations across various scales by individuals and institutions acting alongside other social and economic considerations.

Water resources management in the downstream riparian Egypt has involved institutional level reactive adaptations to prolonged periods of low and high Nile flows. Observed responses include the establishment of more robust contingency planning and early warning systems alongside strategic assessment of water use and planning in response to low flows during the 1980s. In the 1990s high flows have enabled Egypt to pursue opportunistic policies to expand irrigation. These policies are embedded in wider socio-political and economic considerations but increase Egypt's exposure and sensitivity to climate driven fluctuations in Nile flows. Analysis of climate change projections for the region shows there is no clear indication of how Nile flows will be affected because of uncertainty about future rainfall patterns in the basin. In many instances the most appropriate entry point for adaptation to climate change will be coping with climate variability and will play out against the certainty of looming national water scarcity in Egypt due to rapid population growth and its possible exacerbation by water demands from upstream riparians.

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Keywords: Nile basin; Adaptation; Climate variability; Climate change

1. Introduction

River basins integrate the interaction of environmental change and human activities across a range of scales. The temporal and spatial scales at which processes of change occur are important for understanding the downstream consequences of upstream change. In a physical sense incremental changes across time and space may cancel out certain effects or begin to cumulatively affect runoff and river flow characteristics

at detectable levels against baseline conditions. In this paper, I use the Nile basin as a unit of analysis to explore processes of climate variability, climate change and adaptation acting across a range of spatial and temporal scales. The aim is to use empirical observation to inform practical approaches to adaptation in the basin. The analysis considers variability during the recent past, beginning around the 1860s, when regular measurement of Nile flows began at Aswan. I focus primarily on the two main headwater areas of the Nile: the Ethiopian highlands which contribute around 70% of overall Nile flow and Lake Victoria which contributes most of the rest; and the downstream riparian Egypt

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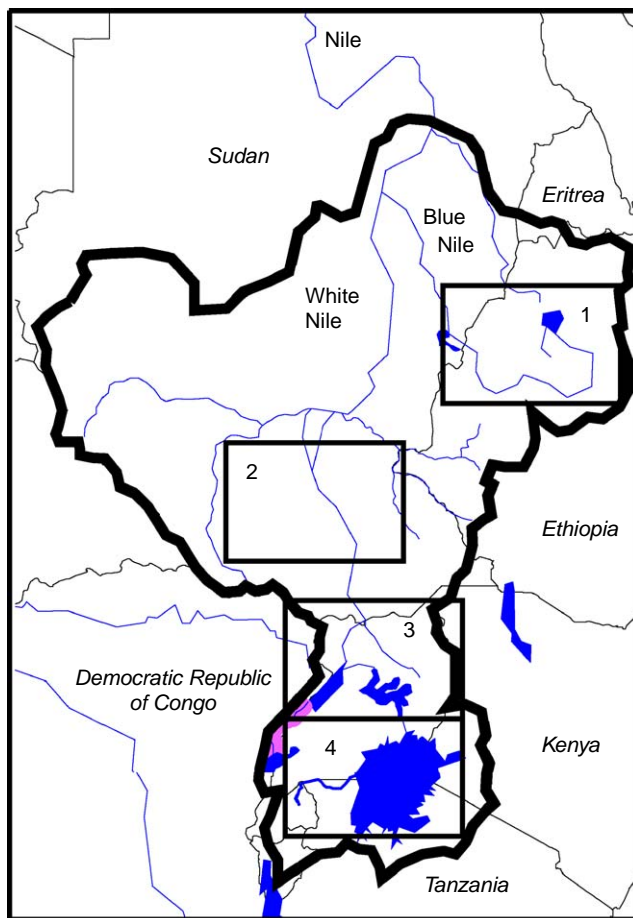


Fig. 1. The Nile basin upstream of Egypt and the Aswan High Dam reservoir. Boxes show approximate regions used to calculate area averages of temperature and rainfall projections from climate models (see Fig. 4). Nile Delta not shown. (1) Blue Nile region; (2) Sudd wetlands in Southern Sudan; (3) Lake Kyoga central Uganda; (4) Lake Victoria, Kenya, Tanzania and Uganda.

(Fig. 1). Egypt is almost entirely dependent upon water that originates from the upstream Nile basin countries; Uganda, Ethiopia, Tanzania, Kenya, Rwanda, Burundi, Democratic Republic of Congo, Eritrea and Sudan.

The Nile displays large multi-year rainfall and hydrological fluctuations and I use these to explore examples of adaptation across various spatial and temporal scales. Three case studies of such variability, two from the headwaters and one from Egypt, are used to provide context to investigations of adaptation to climate change and its interaction with wider processes of social change. Future climate change scenarios for the basin are presented and discussed in relation to climate variability and uncertainty about other non-climate trends.

Two interesting aspects of the Nile basin are explored in terms of adaptation to climate variability and change. The first aspect is related to Egypt's position as a downstream riparian. Egypt is water scarce, and facing fundamental

water supply and allocation challenges as its population continues to grow rapidly and the likelihood increases that upstream riparians will demand more water. I discuss these existing water resource management challenges in relation to adaptation to climate variability and change, given broader political and socioeconomic considerations. The second aspect is the international context of water management and allocation in the Nile basin: because of its size, climate variability or change that is manifest locally or regionally may have regional and even international consequences through its effects on Nile river flows. I examine this international dimension in relation to the role that climate change may play in affecting water availability and how this may influence current progress towards achieving cooperation over water in the basin.

Adaptations are often place- and context-specific, they may encompass a broad range of actions and they may be anticipatory, reactive or a combination thereof (Smit et al., 2000; Adger et al., 2005). Adaptive actions can be implemented across all levels of society at local, national and international scales; but in all cases actions related to climate variability or climatic change occur within a decision-making framework that encompasses wider socio-economic and political considerations. This paper examines observed responses to climate variability to explain how adaptation occurs, who is involved and at what scale it takes place as a basis for contextualising future climate change.

2. The Nile: a source for the study of variability

Variability in Nile flows and their management implications have prompted study of this phenomenon for millennia; from the ancient Egyptians' recording of Nile floods to the noted hydrologist H.E. Hurst's work on long term storage in the Nile (e.g. Hurst et al., 1965). In terms of future climate change, the Nzoia River, a tributary of Lake Victoria, was the subject of one of the earliest attempts to evaluate the impacts of climate change on runoff (Kite and Waititu, 1981). They used the Sacramento catchment model to investigate the sensitivity of river flow and lake level to varying precipitation and evaporation scenarios. More recently research has concentrated on the implications of fluctuations in Nile flows for water resources in Egypt, particularly since a prolonged period of low flows occurred during the 1970s and 1980s. Concern about this phenomenon actually goes back much further; it was heavily researched in relation to the planning and management of the Aswan High Dam (AHD) and the drawing up of the Nile Waters Agreement during the 1950s. At the time attention was centred around the possible effects on the operation of the AHD of a re-occurrence of a prolonged period of high Nile flows that occurred towards the end of the 19th century (Hurst

et al., 1966). Abu-Zeid and Biswas (1991) and Conway and Hulme (1993) considered the implications of climate fluctuations for water management with emphasis on the Nile. They stressed the uncertainties involved in predicting future climate change and that existing planning processes and hydrologic methodologies need

to be improved to deal with such challenges. They also emphasised the significance of fluctuations in river flow over the historical period for managing water resources. Since Kite and Waititu's (1981) work various studies have considered climate change and Nile flows and these are listed in Table 1 with details of their methods and

Table 1
A summary of climate change studies on the Nile, type of study and main findings

Authors	Type of study	Main results
Hulme (1994)	Review of future changes in temperature and rainfall based on GCM results for the Nile basin.	Qualitative discussion of their implications for Nile flows.
Gleick (1991)	Applied an annual water balance model to three subbasins of the Nile basin, the Upper White Nile, Sobat and Blue Nile/Atbara.	The model produced a 50% reduction in runoff in the Blue Nile catchment due to a 20% decrease in rainfall.
El-Shaer et al. (1997)	Impacts of climate change on maize and wheat in Egypt. Stresses the difficulty of predicting trends in Egyptian agriculture even assuming no change in climate due to interactions between factors that determine <i>inter alia</i> , land use, crops types and systems, population growth, and loss of agricultural land.	Yields and water-use efficiency were lower than with current climate conditions. On-farm adjustments did not improve crop water use efficiency or offset yield losses but broader ranging economic measures including improving water use in the agricultural system, soil drainage, land management and crop alternatives were very important.
Onyeji and Fischer (1994)	Economic analysis of potential impacts of climate change in Egypt. Their analysis did not incorporate climatically induced changes in Nile supply.	Projections indicated a decline in agricultural and non-agricultural self-sufficiency and highlighted a number of potentially negative effects of climate change.
Conway and Hulme (1996)	Used hydrologic models of the Blue Nile and Lake Victoria to assess impacts of future climate change on Nile flows. Sensitivity analysis of hypothetical changes in rainfall and evaporation, and a set of seven equilibrium GCM scenarios for 2025.	They obtained a range (due to differences between GCM scenarios) of –9% to +12% change in mean annual Nile flows for 2025. Results were used to estimate changes in the availability of Nile water in Egypt based on the Nile Waters Agreement.
Strzepek and Yates (1996)	Spatially aggregated monthly water balance model used to explore the sensitivity of Nile flows to climate change.	Divergence between climate model results for the Nile basin; from a sample of four models two produced increases and two produced decreases in flows.
Yates and Strzepek (1998)	Follow-up study to Strzepek and Yates (1996)	Five out of six climate models produced an increase in Nile flows at Aswan, with only one showing a small decrease.
Sene (2000)	Investigated the influence of Lake Victoria on flows in the Upper White Nile using a model that represented the main river channel by a series of interconnected lakes and swamps.	The results indicated extreme sensitivity of White Nile flows to changes in Lake Victoria levels and outflows, in particular to variations in direct rainfall on the lake surface.
Strzepek et al. (2001)	Impacts – they used a sample population of climate change scenarios for the basin that incorporate uncertainties due to differences between climate models, climate sensitivity estimates, and emission pathways. They selected nine representative scenarios from the full range to produce Nile flow scenarios using a suite of water balance models.	A propensity for lower Nile flows (in 8 out of 8 scenarios). The wet scenario only produced moderate increases from the 2040s onwards, whilst 3 (4) of the flow scenarios produce large and rapid changes in flows of the order of 40–50% (20–40%) reductions in flow by 2025 (2020) and over 60% (roughly 30–60%) by 2050.
Yohe et al. (2003)	Develop the approach in Strzepek et al. (2001). Vulnerability to climate variability and change is considered as a function of exposure, sensitivity and adaptive capacity. They select two critical assumptions in their economic scenarios; that Egyptian policy will maintain food sufficiency and macroeconomic vitality as prime objectives. They define a set of socioeconomic scenarios used to drive an economic model for Egypt.	The results focus on 2067, a point when all the climate scenarios are fairly divergent, and use food self-sufficiency and the sum of food and consumable consumption to reflect critical components of domestic welfare. Results are presented with and without Nile flow scenarios and with and without adaptations based around micro solutions to adopt drip irrigation and recycle municipal water, and macro-level solutions represented by large groundwater drilling projects in the Sahara.

main findings. Some important points emerge from these studies as follows.

- Lake levels and river flows across the basin show substantial fluctuations during the 20th century due primarily to rainfall fluctuations.
- The White Nile system, particularly Lake Victoria, exhibits marked interannual and interdecadal variability and its interconnected system of large lakes and wetlands gives it a complex smoothed response to climate perturbations.
- Some characteristics of the hydrological components of the basin produce quite high sensitivity to rainfall variability, for example, Lake Victoria levels and runoff in the Ethiopian highlands.
- Whilst temperatures are expected to increase there is uncertainty about the direction and magnitude of future changes in rainfall, particularly due to differences between global climate model (GCM) results for the basin.
- Egypt's almost complete reliance on the Nile for freshwater makes it an interesting case study for examining societies' sensitivity to climate driven changes in water resources.
- Integrated analyses of climate change in Egypt (including population growth, land cover change, socioeconomic and domestic growth strategies) suggest the impacts of increasing or decreasing Nile flows may be relatively minor in relation to other non-climate changes (Conway et al., 1996; Strzepek and Yates, 1996).

3. Variability in the headwaters of the Nile: driver of fluctuations in Nile flows

3.1. Rainfall variability in the headwaters of the Nile

The source areas for the Nile are the humid highlands of East Africa and Ethiopia. Neither region experiences particularly high interannual rainfall variability, however, marked fluctuations in rainfall have occurred over decadal timescales with significant consequences for Nile flows. As it is possible to explain most of the variability in Nile flows by considering the Blue Nile (Ethiopian highlands) and Lake Victoria (East Africa, the main component of the White Nile system) this section presents a hydroclimatic analysis of both regions and their integrated effects on the overall flows of the Nile. Rainfall over the Blue Nile is typically monsoonal with most rain occurring between July and September whereas over Lake Victoria rainfall is equatorial with two wet seasons, one from March to May (long rains) and one from October to December (short rains). During the 20th century there has been no obvious

correlation between rainfall over the source areas of the White and Blue Niles even though rainfall over both regions shows some association with the El Niño–Southern Oscillation. During El Niño events July to September rainfall over the Blue Nile tends to be below normal and October to December rainfall over Lake Victoria tends to be above normal, but these associations are not always consistent. Other influences on rainfall, from its short term predictability to decadal variability, are not fully understood and although considerable progress has been made towards development of statistical models of seasonal rainfall in both regions (Sileshi and Demarée, 1995; Mutai et al., 1998; Eldaw et al., 2003) these capture only a proportion of the variability.

Fig. 2 shows annual rainfall anomalies over the source areas of the Blue and White Niles from 1900–2003 and 1900–1999, respectively. The Blue Nile record prior to 1955 should be interpreted with caution because it is based on only a few gauges. In the Blue Nile basin a slight increasing trend occurred between 1905 and 1965 followed by a prolonged decline which bottomed out in 1984 and recovered substantially during the 1990s. In contrast rainfall over Lake Victoria shows a moderate increasing trend up to 1960 followed by a prolonged increase in annual rainfall due to a combination of extremely wet years, e.g. 1961, 1963 and 1977 and smaller increases in some other years. In fact, annual rainfall over much of Lake Victoria's catchment increased by roughly 8% between 1931–1960 and 1961–1990. This increase, along with storage effects in Lake Victoria, is sufficient to explain a rapid and sustained rise in its level described below (Conway, 2002).

3.2. Variability in White and Blue Nile flows: effects on Nile river flows

Fig. 3 shows annual Blue Nile flows, Lake Victoria levels and Nile flows at Aswan. Mean annual Blue Nile flows are 45.9 km^3 (1961–1990) and have ranged from 20.6 km^3 (1913) to 79.0 km^3 (1909) and the lowest decade-mean flow was 37.9 km^3 from 1978 to 1987. Annual river flow, like rainfall, shows a strong association with El Niño. Lake Victoria levels had two short-lived high periods during 1903–1907 and 1916–1918 but the annual series is dominated by the change from 1962 onwards. A significant and sustained increase in Lake Victoria levels and outflows occurred in late 1961 and has been fully documented in Kite (1981), Piper et al. (1986) and Conway (2002). The level increased by 2.3 m from 1961 to its peak in 1964, equivalent to an increase in storage volume of 151 km^3 . Levels have decreased steadily, except for short-lived rises in 1978–1979, 1990–1991 and 1997–1998, although they remain above

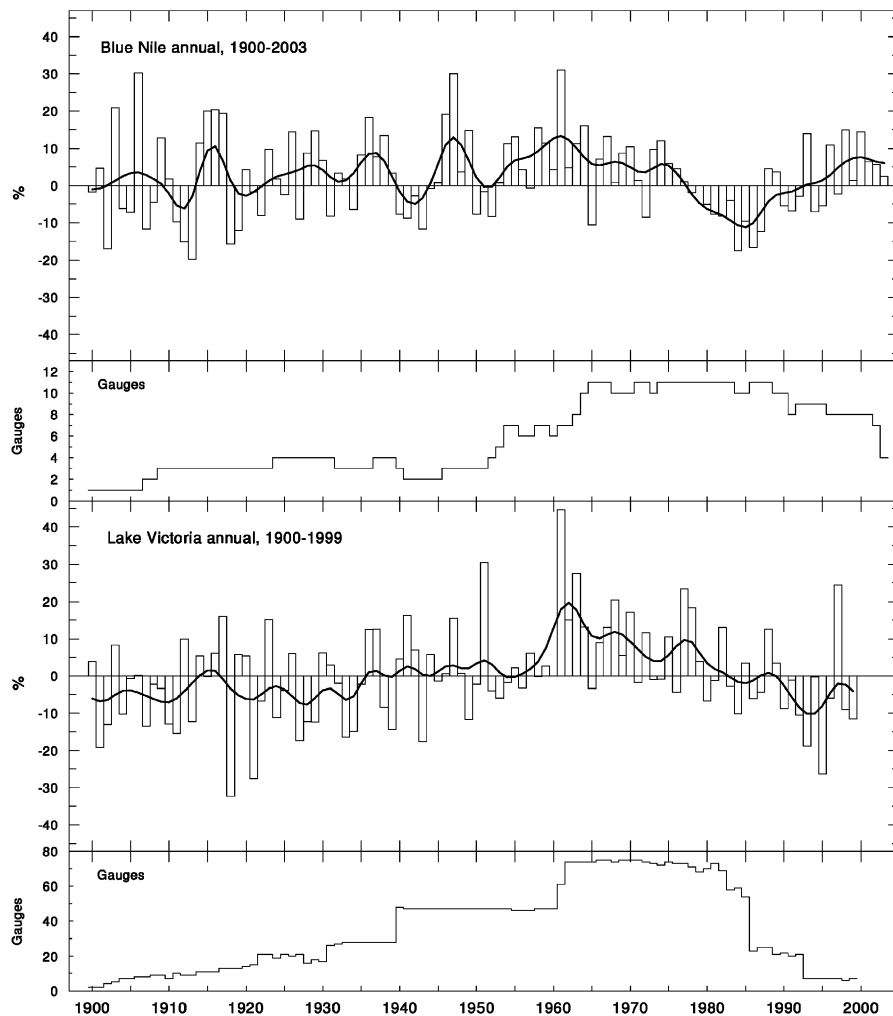


Fig. 2. Annual rainfall anomalies Upper panel; Blue Nile area-average (updated from Conway, 2000). Lower panel; Lake Victoria region average. Bold line represents 10-year Gaussian filter. Small panels show the number of rain gauges used to generate the rainfall series.

their pre-1961 levels. Lake Victoria outflows roughly doubled between 1931–1960 and 1961–1990.

Downstream the long record of Nile flows into Egypt integrates the effects of the Blue Nile and Lake Victoria along with other lakes and wetlands on the White Nile system and varying contributions from other tributaries in the basin. Nevertheless, because of the large proportional contributions to the Nile from the Blue Nile and Lake Victoria their variability is strongly reflected in the Nile flow record. The period of high flows prior to 1899 has been the subject of a number of studies especially concerning the accuracy of the early gauge data. After careful scrutiny and some adjustment, accepted flows were published in Hurst et al. (1946) and have been used quite widely, see for example Sutcliffe and Parks (1999). The reduction in flows after 1899 is discussed further in (Section 4.2). The low Blue Nile flows during the 1980s were partially offset by higher White Nile flows since the 1960s but their effects were still apparent in the Nile flows which reached their second lowest point in 1984.

The recovery of rainfall in the Blue Nile region during the 1990s is also reflected in the increased Nile flows during this period.

4. Contextualising climate change: analogues from recent climate variability and projections of future climate

4.1. Recent climate variability—analogue for the future?

Regional temperature trends presented in IPCC (2001) show trends for grid boxes located in Sudan and Ethiopia in the order of $+0.2$ – 0.3 °C/decade ($+0.2$) from 1946 to 1975 (1976–2000). Hulme et al. (2001) found an African mean trend of about 0.5 °C/century. In contrast to the observed warming in parts of the basin during the 20th century there is no evidence of annual or seasonal rainfall behaviour that might be attributed to global warming. Given the high levels of rainfall variability since the 1860s and the inter-model

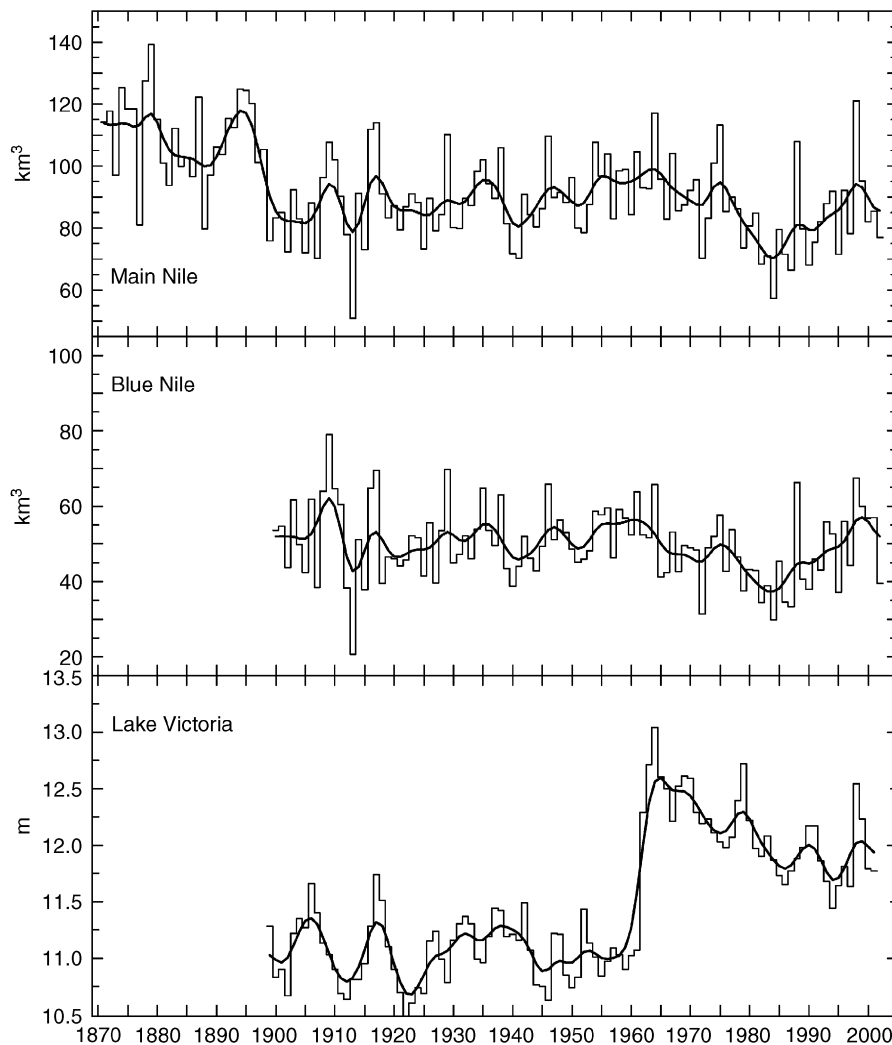


Fig. 3. Annual river flows and lake levels for various periods. Note different vertical scales. Upper panel; Nile flows 1870–2002 (from a combination of records at Aswan, Wadi Halfa, Kajartay and Dongola). Middle panel; Blue Nile flows 1900–2002 (from a combination of Khartoum, Roseires and el Deim). Lower panel; Lake Victoria levels 1899–2001. Bold line represents 10-year Gaussian filter.

divergence in future rainfall it is likely to be some time before an anthropogenic climate change signal emerges clearly in the rainfall and hydrological records for the Nile.

Uncertainty about the detail of climate change remains a major consideration in studies of regional climate change and adaptation, especially with regard to rainfall which is fundamental to any analysis of future climate and its implications. This is coupled with massive uncertainty about future socio-economic and political change and rapidly growing populations in many of the Nile basin countries. Partly in view of this uncertainty Glantz (1992, p. 203) has written in the context of climate change in Africa that ‘This... ..should prompt investigations about how societies today cope with interannual and interdecadal variability in the existing regime. Improved understanding of these interactions can only serve to benefit present and future generations

in their ability to cope with as yet unknown environmental changes.’ Improved understanding of existing climate-society linkages is essential to contextualise climate change that may occur in the future and to begin to evaluate the need for planning and actions for adaptation in the near future. This is sometimes known as an analogue method (e.g. Glantz, 1992), particularly where the impacts of dry/wet or warm/cool periods are used as a proxy for the impacts of climate change of a similar magnitude as the analogues (spatial analogues are also used). There is great potential to undertake this type of analysis for the Nile across a range of temporal and spatial scales, for example:

- subsistence rain-fed cultivation by farmers in the Ethiopian highlands exposed to variability in daily rainfall and soil moisture;

- lakeshore communities on the White Nile lakes exposed to seasonal and annual fluctuations in lake extent (Goulden, 2004) and pastoralists in Southern Sudan exposed to varying flood dynamics in the Sudd (Johnson, 1988);
- national water supply in Egypt exposed to interdecadal variability in Nile flows.

The diversity of situations and experience is enormous, as is the degree of exposure and complexity of response to climate perturbations. Although it is true that future climate change will generally be different to the magnitude and duration of climate anomalies in the recent past; this is more so the case for temperature but less for rainfall where observed interannual and

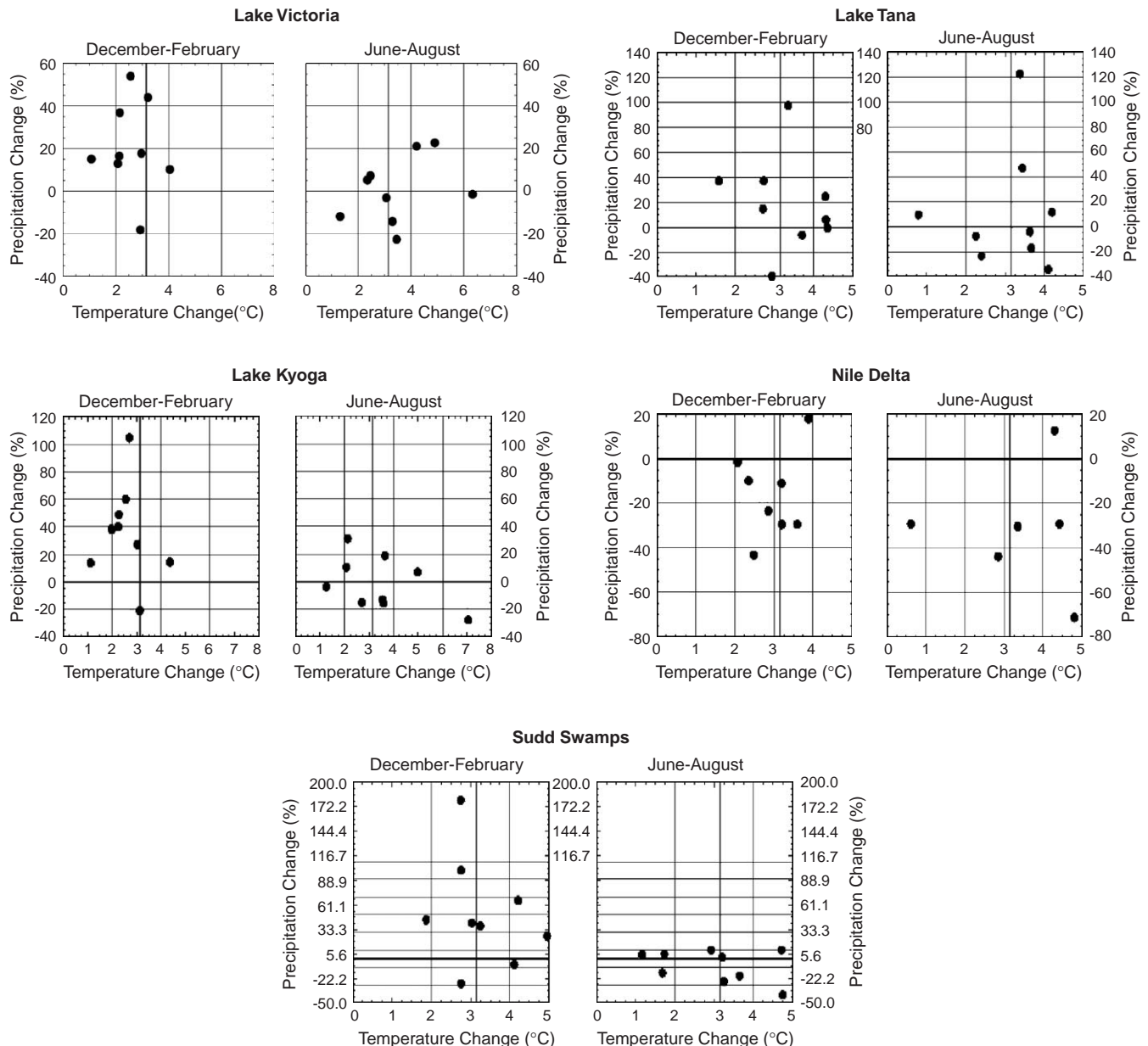


Fig. 4. Change in average seasonal climate for the period around the 2080s, relative to 1961–1990 climate. Each dot represents the result from one GCM. Data are averaged over the relevant area. These changes assume the IPCC SRES A2 scenario—a mid-to-high range emissions scenario. The vertical line marks the annual-mean global warming for the 2080s, and for the SRES A2 scenario, as calculated by the IPCC, a value of about 3.2 °C. Results to the right of this line are more extreme than the global average; results to the left of the line are less extreme. The horizontal line at zero distinguishes between results in which climate gets wetter or drier. IPCC (2001) definitions of consistency: seven out of nine GCMs must show a consistent change for results to be classified in agreement. Large increase (decrease)—agreement on increase with average change greater than + (–)20%. Small increase (decrease)—agreement on increase with average change between + (–)5 and + (–)20%. No change—agreement with average change between –5 and +5%. Locations of areas are shown in Fig. 1.

interdecadal variability is larger and the climate model signal for the future much less consistent. To a certain extent the similarity of the analogue conditions to future changes (which are highly uncertain) is not crucial for the approach; what it can provide is the insight and context necessary to generate a richer understanding of the sensitivity and the response of environmental and societal systems to climate anomalies and their interaction with other non-climate factors.

4.2. Integrating climate variability and climate change: water availability in Egypt

With respect to the future climate in the Nile basin there is high confidence that temperatures will rise, leading to greater losses to evaporation. However, there is much less certainty about future rainfall because of the low convergence in climate model rainfall projections in the key headwater regions of the Nile. For example, [Hulme et al. \(2001\)](#) found large inter-model differences in the detail of rainfall changes over Ethiopia using results from seven recent climate model experiments. Inter-model disparities in future rainfall change over much of the basin are also presented in [IPCC \(2001\)](#). [Fig. 4](#) shows rainfall changes for five key regions in the Nile basin for summer (June to August, JJA) and winter (December to February, DJF) from nine recent climate model experiments using IPCC SRES emissions scenarios (outlined in [Hulme et al., 2003](#)). The Blue Nile region shows large divergence in rainfall changes in summer which is the crucial monsoon rainfall season. In the White Nile system (Lakes Victoria and Kyoga and the Sudd), winter shows inter-model convergence towards a small to large increase in rainfall but there is divergence in summer. The models are consistent for small decreases in winter rainfall in the Nile Delta and large decreases in summer but these are unlikely to be significant as rainfall is negligible in these months. Climate model projections for warmer temperatures are more consistent throughout the whole basin.

The Nile flows are currently divided between Sudan and Egypt according to the 1959 Nile Waters agreement with 55.5 km³ for Egypt, 18.5 km³ for Sudan and 10 km³ for evaporation from the AHD as shown in [Table 2](#) (first column). These figures were based on a fixed mean annual flow of 84 km³ from 1900 to 1959 and the proportions they represent (column two) are used to derive estimates of Egypt's allocation under different mean Nile flow regimes; the recent low decade-mean (1981–1990) and a high decade-mean (1881–1890, [Fig. 3](#)). The last two columns show modelled estimates of future Nile flows and allocations based on the above criteria using a 'wet', and a 'dry' case to cover the range of results from seven climate models for the year 2025 (based on [Conway and Hulme, 1996](#)). It should be noted that the Nile Waters Agreement is only between Egypt and Sudan and it is based on absolute volumes, not proportions. The proportions that these volumes represent are used to illustrate the implications of changes in the mean flows for water allocation, however, this basis for allocation may not apply in the future. The results highlight the significance of natural variability, primarily due to rainfall fluctuations over the Ethiopian highlands, for Egypt's water supply. Whilst the flow results for the 2020s with climate change lie within the interdecadal variability they represent changes, not just periodic fluctuations as have occurred in the past, and so they would have potentially greater implications for water supply. To reflect such a possibility the figures in brackets show the much wider range of flows possible after superimposing the observed decadal variability on the future 30-year 'mean' flows for the 2020s. But note that the use of the full 110 year record to define decadal variability for a 30-year period inflates the range somewhat. Although these wet and dry scenarios originate from an early generation of equilibrium climate model experiments they are not wildly dissimilar to results from recent climate models; for example those presented in [Section 4.1](#). A recent study by [Strzepek et al. \(2001\)](#), however, did present much drier scenarios of Nile flows; with nine recent climate scenarios impacts

Table 2

Allocation of water according to the Nile Waters agreement 1959, based on the original mean annual flow used for the agreement (84.0 km³ 1900–1959) and its proportional allocation in %, the high decade-mean (1891–1900) and the recent low decade-mean (1981–1990)

	Current climate		Historical variability		Future climate	
	Volume 1900–1959	%	Volume 1881–1890	Volume 1981–1990	'Dry' 2020s	'Wet' 2020s
Egypt	55.5	75	75.0	49.9	50.1 (44.5–69.6)	64.7 (59.1–84.2)
Sudan	18.5	25	25.0	16.6	16.7 (14.8–23.2)	21.7 (19.8–28.2)
AHD reservoir evaporation	10.0	—	10.0	10.0	10.0*	10.0*
Mean flow (km ³)	84.0	—	110.0	76.5	76.8	96.4

Flows and allocations are also shown with two climate change scenarios for the year 2025. The flows in brackets represent the possible range of observed decadal variability (from the full 110 year record) superimposed on the future 30-year 'mean' flows for the 2020s. * Assumes no increase in evaporation losses. All volumes in km³.

ranged from no change to a roughly 40% reduction in flows by 2025.

5. Adaptation across scales: from headwater tributaries to international river basin

5.1. Headwater tributaries: adaptation in the Ethiopian highlands and Lake Victoria

This section highlights just two examples where climate variability exerts strong influence; at the local to national scale—drought and food security in the Ethiopian highlands and at the national to international scale—water resources management in Lake Victoria. It is not possible to consider in detail the full diversity of the Nile headwater regions and the role of climate variability. For Ethiopia alone there is a huge literature on the historical and contemporary dynamics of food security much of it with an explicit or implicit consideration of climate variability. Complete dependence on natural rainfall, low-input and low-output characterise Ethiopian agriculture. Drought and famine have been a feature of life in Ethiopia throughout history and in more recent times 1972/3 and 1984/5 stand out as years with major droughts and famine conditions. Rainfall variability, droughts and their consequences for food security have to be put into context with the historical and contemporary dynamics of socio-economic, political and environmental factors that also influence the opportunities and food security of Ethiopians. The role of drought alongside other confounding factors in recent devastating famines (Rahmato, 1991; De Waal, 1997) underscores the need for improved understanding of these interactions to contribute to this contentious policy area. For much of rural Ethiopia (roughly 80% of the population) adaptation is about coping; short term expedience in the face of limited options outweighs most other considerations in the struggle to escape from chronic poverty and episodic shocks. The problem of poor food security is pervasive throughout much of the country and it is a major priority for government policies at the national level.

The shift in Lake Victoria's level and outflows (Fig. 3) is an excellent example of the challenge that climate change represents for water resources management; how to deal with non-stationary behaviour. The short-term hydrological impacts of the rapid increase in lake level in the early 1960s included disruption and damage due to inundation of lakeshore and wetland areas and river flooding, as far downstream as the Sudd wetlands in Southern Sudan (Johnson, 1988). The rise in Lake Victoria level prompted an international programme to explain the phenomenon with the establishment of the *Hydrometeorological Survey of the Catchments of Lake*

Victoria, Kyoga and Mobutu Sese Seko through the WMO with participation from Kenya, Tanzania, Uganda, Sudan and Egypt (Hydromet, 1982). Extreme rainfall events during the October–December rainy season in East Africa are responsible for much of the variability. These are closely associated with periodic circulation dipole events in the Indian Ocean. These tend to be associated with above average and sometimes very extreme rainfall (see for example Webster et al., 1999). Lake behaviour in the future will be highly dependent upon whether and how these events are affected by global climate change, however, at present they are not simulated realistically by climate models.

The shift in hydrological regime has generated controversy surrounding the feasibility of expanding existing and developing new hydro-power installations on the White Nile in Uganda (Waterbury, 2002). Choice of a suitable baseline for Lake Victoria for management and planning purposes is difficult because assumptions made about the reliability of outflows determine the economic feasibility of hydropower development. Given that there is no strong evidence to suggest that rainfall conditions will either continue as they are, return to pre-1960 conditions, or even increase again, then it would seem reasonable to base decision making and planning on the long term (i.e. including pre and post-1961) behaviour of the lake system (Tate et al., 2004). Management practice and future adaptation strategies have an international dimension because the lake is shared by three countries and its outflows affect Sudan and Egypt. Decisions will have to consider the trade-off between hydro-power generation, maintaining acceptable lake levels and the effects of downstream flooding.

5.2. Downstream riparians: observing adaptation to climate variability in Egypt

As research began to appear on the implications of climate variability and change for the Nile in the early 1990s the focus was very much on drought and its implications for Nile water management (Hulme, 1994; Abu-Zeid and Abdel-Dayem, 1992; Abu-Zeid and Hefny, 1992; Conway and Hulme, 1993). This was because Egypt had just come out of a prolonged period of low flows lasting from around 1978–1987, unprecedented in the historical record back to 1870. While Egypt is fairly well insulated against the effects of interannual variability by over year storage in the AHD the 1980s showed it is vulnerable to interdecadal variability. The effects of the dry period can be seen in the record of AHD reservoir levels in Fig. 5. The realisation that by summer of 1988 Egypt was very close to a major water shortage initiated a set of responses and anticipatory planning to cope with future such situations. Although the storage was sufficient to meet established releases (55.5 km³/year) the government

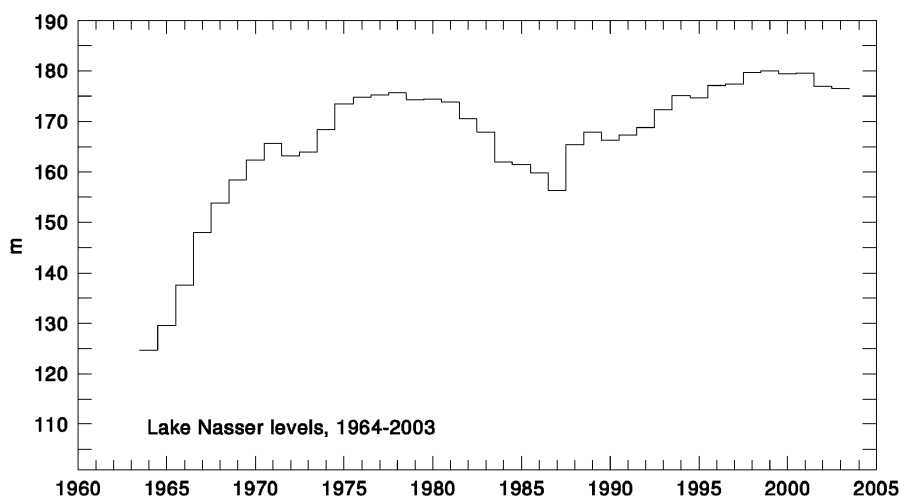


Fig. 5. Annual mean Aswan High Dam reservoir levels, 1964–2003.

made emergency plans to counter further drought conditions, including reduction in the annual releases from the AHD through more efficient regulation, extension of the irrigation system's winter closure period, reduction of the area under rice and improvement of the Nile's navigable channel to maintain levels to supply irrigation outtakes (Abu-Zeid and Abdel-Dayem, 1992). The Ministry of Water Resources and Irrigation (MWRI) also issued at the time a study in May 1988 based on a Lake Nasser (the AHD reservoir) simulation model to review several options for reservoir operation under a set of possible Nile flows and downstream releases. However, the timely high flow in 1988 removed the immediate threat of severe shortage and since then Nile flows have been sufficient to maintain releases at 55.5 km^3 and increase storage. In 1991, Abu-Zeid and Abdel-Dayem noted that the high flow year in 1988 was thought at the time to indicate an end to the drought period and the beginning of a cycle of high flows—as it turned out this was indeed the case.

This dry period is now cited as one of three important factors that influence current management of water resources in Egypt, alongside acceptance that the Jonglei canal scheme to reduce evapotranspiration losses in the Sudd will not be finished in the near future and the need to supply an ambitious land reclamation programme (El-Kady, 2003). The dry period initiated the establishment of a 'planning studies and models' department responsible for monitoring and forecasting which at the time was based on upstream flows and levels with roughly one month's lead time, and simulation of the Nile (Abu-Zeid and Abdel-Dayem, 1992). This department has evolved into the MWRI's Nile Forecast Center (NFC) which uses a modelling system developed through a three phase USAID funded project (through NOAA and the FAO) aimed at predicting inflows to

Lake Nasser with as much lead time as possible. Originally the project involved development of a forecasting system for the Blue Nile which was later extended to the White Nile and uses satellite estimates of rainfall over the upper basin (Schaake et al., 1993). The MWRI has also undertaken some research into seasonal forecasting (Elwan et al., 2002). Finally, there is also a Nile Basin Management—Decision Support System (also partially funded by USAID through the FAO) which has been developed at the Georgia Institute of Technology Development originally to implement a computerized control scheme for the operations planning of the Equatorial Lakes in the Upper Nile. This now includes models of all the sub-components of the basin, lakes, reservoirs and other environmental components and has been used to explore climate and management scenarios in parts of the basin (Georgakakos, 2004).

The capriciousness of climate, however, meant that by the mid-1990s Nile flows had returned to higher levels and Lake Nasser levels were recovering and by 1999 reached their highest point since the dam was completed (Fig. 5). Therefore within 10 years the short-term management challenge was completely reversed and Egypt was forced to use the Toshka overspill canal to avoid overtopping of the AHD as there is limited capacity to handle increased releases downstream of the dam. A Dutch funded 'Lake Nasser Flood and Drought Control Project', based in the MWRI was established 2002 in response to this new problem with the aim of analysing the impacts of flooding and also climate change on operation of the AHD reservoir. The consequences of the high flows during the 1990s are discussed in the next section. In summary, the decadal variability described in this section has prompted a series of adaptive responses by the MWRI designed to

improve early warning of Nile flows and build capacity to handle the impacts of multi-year episodes of high and low flows more effectively.

5.3. *Downstream riparians: climate change, water resources management and adaptation in Egypt*

Egypt has commissioned a series of strategic water assessments since the 1970s which contain extensive quantitative measurements and estimates of current and projected water supply and demand in the basin and within Egypt (see for example, [Abu-Zeid and Hefny, 1992](#); [MWRI, 1999](#)). These studies demonstrate that although classified as water scarce Egypt still has some surplus water in the system. [Wichelns \(2002\)](#) quotes estimates of 63.7 km³ total annual supply and 61.7 km³ total annual water use so that nationally water is not yet a limiting resource, although some areas experience water shortages due to inadequate local supplies or capacity constraints in delivery systems. This headroom could easily be wiped out by climate variability or change. [Waterbury \(2002\)](#) identifies potential slack within the system which is or may be achieved through four main opportunities; reliance on virtual water (see [Allan, 2003](#) for discussion of the concept), economic measures to improve water use efficiency, rainwater harvesting and drainage schemes in southern Sudan. Egypt's net virtual water import is estimated to be 15.3 km³ by [Hoekstra and Hung \(2002\)](#). With Egypt's population growing by roughly one million every nine months the current surplus is dwindling fast and the main opportunities to ease the pressure are not without cost. Given continued political stability in Ethiopia and Eritrea and a regional population in 2000 of 162 million that is expected to double by 2030 ([Wichelns et al., 2003](#)) there is the strong possibility that upstream abstractions may increase.

The AHD buffers against interannual variability but recent decades highlight Egypt's vulnerability to inter-decadal variability. Prolonged dry periods require additional response primarily in terms of effective contingency planning to limit reservoir releases in the face of reduced storage and inflows and reduce the downstream effects of such actions. Equally measures to deal with prolonged high flows and excess storage must be considered. As outlined above responses to both types of variability have been implemented. Regular reviewing and updating of drought responses and research into improved long-term forecasting (plus improved understanding of decadal variability) will enhance Egypt's ability to cope with prolonged drought. The response to higher flows is less obvious and is discussed below. Climate change may also bring more prolonged and even permanent changes in Nile flows which would go beyond the capacity of measures to deal with variability and require significant changes in

current management strategies and possibly infrastructure. Prolonged decreases in flow will require national level coordination of water management and allocation. Timescales are relevant in this respect, and given the magnitude of decadal variability it may be decades before a clear change in flow regime becomes apparent, whilst it may be beneficial to take certain planning and management steps now. Changes in supply due to climate should be considered alongside the certainty of demographic trends, potential abstractions by upstream riparians and unknowable events such as the economic effects (particularly through their impacts on tourism) of the wars with Iraq, terrorism events in Egypt and elsewhere.

The possibility that climate may exacerbate existing challenges should reinforce the need for Egypt to develop its options for coping with water shortage. Reliance on virtual water has economic and political implications and it has already been noted that national food security remains an important political aim. Supply-side options in Egypt are limited by the size and accessibility of reserves. In Sudan water saving schemes which comprise wetland drainage, are contentious on social, political and environmental grounds and not realistic in the current political situation. Water demand management has potential in terms of improved use and sectoral allocation. Literature on this topic for Egypt clearly demonstrates widespread awareness and recognition of looming water scarcity and the need to act ([Mohamed and Savenije, 2000](#); [Strzepek et al., 2001](#); [Kandil, 2003](#)). For example a [MWRI \(1999\)](#) positional paper on Egypt's water vision for the 21st century includes a focus on policies to shift from supply approaches to integrated approaches which include both supply and demand management.

Paradoxically Egypt is also engaged in a massive expansion policy for irrigated agriculture in the Western Desert and Sinai. Whilst it is beyond this analysis to consider the socioeconomic and political rationale behind these policies (see for example [Wichelns, 2002](#)), in the context of climate variability and change they will reduce flexibility and therefore increase Egypt's exposure to the risk of future water shortage and inability to meet demand for water (i.e. in climate terms they are maladaptive). [Wichelns \(2002\)](#) quotes estimated water requirements of 1.7 km³ for 90,000 ha to be reclaimed in the Sinai and 5 km³ for the first stage of 210 000 ha in the Southern Valley Development Project (Toshka or New Valley project). Egypt has initiated work on potentially the world's largest pumping station as a first step in the irrigation scheme for the Western Desert by transporting water along a giant canal. This project is expected to cost over US \$2 Billion and to link the El Kharga and Farafra Oases. These substantial additional commitments of water may be met whilst storage in the AHD reservoir is high and high flows are maintained,

however, if flows are reduced over a prolonged period and demand outstrips supply Egypt will face difficult decisions about water allocation. Much of this expansion policy is predicated on the assumption that large savings can be made from the existing use of water in Egypt.

Whilst Egypt's move towards water demand management is primarily driven by increasing scarcity due to population growth—in the future adaptation to climate change will become more of a consideration. In terms of capacity the MWRI has strong technical expertise and capacity in water management (good for supply side options) but less capacity in terms of socio-economic and institutional management more appropriate for implementation of water demand management options. The huge size and influence of the MWRI may cause inertia and reluctance to consider fundamental changes in policy to address growing problems such as water scarcity and its possible exacerbation by climate change. These issues have strong resonance with the work of Ohlsson and Lundquist (2000) and Turton (1999) in relation to adapting to water scarcity and for adapting to scarcity in general with Homer-Dixon (1995). Detailed studies of water use in Egypt highlight the complexities of matching local supply to demand patterns and the role of technical and administrative systems governing operation of water supply; while the government exercises control over the macro-level system it does not at the village level (Radwan, 1997). Prudent planning requires investment in development of expertise and policy design in this area. There are, however, important socio-economic and political considerations associated with introducing demand management policies in Egypt; at the national level political and institutional support will be important to promote capacity and action in this area. For individuals legitimacy of policy will be important along with issues of fairness related to distributional effects of changes in access, taxes, subsidies for land and water as part of water demand management. Proposals for institutional reform towards a greater role for the private sector will also raise these issues (Kandil, 2003).

6. Crossing scales: the international river basin context

Egypt and Sudan have generally been close partners in the basin and a Permanent Joint Technical Commission (PJTC) on the Nile has existed since the 1959 Agreement. The PJTC has three functions one of which is to negotiate reductions in the basic allocation due to regional drought (Waterbury, 2002) something that, as far I am aware, has never occurred but is an interesting facility and would have applications in managing climate change. Beyond the agreement between Egypt and Sudan there is no recognised treaty or agreement on

the Nile between all the riparians. The ten countries that share the Nile basin do not naturally or historically all share association in many other areas—there is no community or set of shared norms within the basin (Waterbury, 2002). The existing legal treaties and agreements reflect colonial, cold war and national/regional interests and many are unrecognised by one or more of the riparians. Generic reviews of climate change and water resources have recognised the need for research on its implications for management of international rivers (Frederick and Gleick, 1999). Nandalal and Simonovic (2003 citing White, 1986) list stresses due to climate variability and change as one of three sources of environmental conflicts, along with actual or prospective action which provokes changes that other stakeholder groups see as disturbing their functions, and disagreement over management of water supply at one location as it affects its use elsewhere.

There is a long and chequered history of attempts to foster improved cooperation within the Nile basin with a view to developing a basin organisation and agreement. Recently the World Bank has taken an active role in promoting cooperation in the Nile basin by helping to establish the Nile Basin Initiative (NBI) in 1999. Wichelns et al. (2003) have suggested a broad perspective that presents a cooperative framework that encompasses water *and* other resources and products to enhance regional cooperation. Such a framework includes making use of comparative advantage such as developing hydropower in Ethiopia and cotton processing in Egypt. Waterbury (2002) notes there are few examples of comparative studies of negotiating processes that have brought about successful establishment of water agreements. Waterbury assumes that cooperation in the use of transboundary resources is desirable and will tend to enhance net benefits but notes that without many small steps the search for comprehensive agreements is problematic: *'there are too many players and their interests in the resource and the benefits they are likely to draw from basin-wide cooperation too asymmetrical'* (Waterbury, 2002, p. 174).

To overcome the inertia of the existing situation clear benefits need to be on offer to the countries that are indifferent to the status quo. Change may also be facilitated by visionary political leadership in the basin that can see beyond the obstacles and the zero sum game to seize the undoubted benefits of enhanced cooperation over water and in other areas. Waterbury (2002) identifies four main concerned actors in the Nile basin (Egypt, Sudan, Ethiopia and Uganda) and a fifth unrecognised by any of the others (Southern Sudan) with a view to establishing their interests in cooperation. The importance of the Nile to Egypt is declining (less dependence on hydro-power from the AHD, development of non-water intensive sectors), although the Toshka development reverses this trend, whereas

Ethiopia and Uganda will at some point begin to develop Nile waters, as will Sudan to potentially a much greater extent in the longer term.

The role that climate change may play in the process of developing cooperation in the basin needs to be considered in the context of the other main influences that currently exist; growing scarcity and third party involvement (for example, the World Bank and the NBI). Scarcity at the moment is not compelling as there is still some slack in the system but it is rapidly approaching and potentially a huge threat to the status quo. The NBI is offering substantial carrots to the riparians to achieve cooperation but whether this is enough to attract and sustain interest and commitment in cooperation remains to be seen. Climate change is most likely to influence the process by its effects on scarcity, but at the moment it is unclear how this will be manifest because of uncertainty in future rainfall patterns. On a practical level climate change should certainly be considered in any future negotiations to share Nile water, which could include proportional shares rather than fixed volumes and an update of the volume used for the 1959 Nile Waters Agreement. In terms of adaptation the Nile raises interesting questions related to the role of growing scarcity in catalysing or inhibiting collective action over water and for the need to consider flexibility (or robustness to uncertainty, Adger et al. this issue) in the design of institutions and accords for international water management.

7. Discussion and conclusions

The effects of climate variability, principally rainfall variability in the Ethiopian highlands and Lake Victoria, are shown to have caused significant inter-annual and interdecadal variability in Nile flows with major implications for water resources in Egypt. Recent climate variability provides a rich source of empirical detail to contextualise the implications of very uncertain climate change in the future. This type of analysis provides insights into the sensitivity of environmental and societal systems to climate perturbations. The examples presented here highlight the varying nature of climate perturbations (here, rainfall variability), their effects on water resources and the degree of exposure and sensitivity across a range of scales. The observed responses make it possible to examine how adaptation occurs, who is involved and at what scale it takes place. This is an area ripe for more detailed analysis; however I offer some tentative conclusions as follows.

In the headwater tributaries it is subsistence farmers in the Ethiopian highlands that are most exposed and vulnerable to climate variability. At the level of the individual adaptation for many is primarily a matter of survival strategies to deal with the effects of rainfall

variability. Nationally the Ethiopian government is implementing a basket of policies aimed at improving food security which include greater utilisation of Nile waters. How climate change will affect the situation is unclear; if rainfall increases then there may be benefits for crop yields, although these may be offset by increased variability and soil erosion due to higher rainfall intensities, if rainfall decreases food security is likely to deteriorate. The critical outcome of government policies must be to help enable Ethiopian farmers move from subsistence coping to more productive, less climatically sensitive, agricultural methods and to enhance their opportunities to diversify their income generating activities.

In the White Nile system the combination of extreme rainfall anomalies and hydrological characteristics has produced short- and longer-term flooding and fluctuations in lake and wetland extent. These impacts have required adaptive responses in riparian communities and water management institutions. For individuals this has meant dealing with the disruption brought by periodic and prolonged flooding set within other environmental, social and economic events including drought, health problems, insecurity and increases in taxes (Goulden, 2004). National and international concerns around Lake Victoria relate to trade-offs in management goals, including maximising hydropower generation, maintaining acceptable lake levels and reducing downstream disruption due to high outflows. The observed non-stationary lake level behaviour underscores the need to base management on long term observations although such concerns may be overridden by short term priorities such as expanding hydropower capacity.

Downstream during the last two decades conditions have moved from a prolonged period of low flows with the very real threat of water shortage in Egypt, only alleviated by a timely high flood in 1988, to a series of relatively high flows which have brought the AHD reservoir to record levels and enabled the Egyptian Government to pursue a major expansion programme of irrigated agriculture into the Western Desert and Sinai Peninsula. The resultant increase in demand for water will reduce Egypt's flexibility to manage changes in future water supply due to climate change and to non-climate factors such as abstractions by upstream riparians. The observed responses in Egypt primarily highlight institutional reactive adaptations generally at the national level.

In both the headwater and downstream situations, many actions, from the individual level to the national level, will have some to exposure to climate change and consequences for vulnerability. Determining the efficiency of such actions from a climate adaptation perspective or other perspective is far from trivial. An interesting example is Egypt's policy for increasing

irrigated agriculture in the face of looming water scarcity: whilst this outwardly appears maladaptive from a climate perspective (and also on other grounds), in terms of Egypt's international situation vis-à-vis negotiations over Nile water it may be in its advantage to always maximise utilisation of available water to ensure that it can claim as much water as possible based on the assumption of acquired rights through prior utilisation.

Studies since the early 1990s highlight the low convergence of climate model scenarios of rainfall over the Nile basin. Climate scenarios of rising temperatures are more consistent and could lead to large increases in evaporation because of the large expanses of open water and irrigated agriculture in the basin. From a practical viewpoint what, if any, adaptation actions should be implemented now, by whom and where? Should construction of a new hydropower scheme just under-way on the Main Nile in northern Sudan consider adaptive actions in view of future climate change? This question is already relevant to the management of existing dams and planning of new ones downstream of Lake Victoria. The current situation points to the need to consider flexibility in design and within institutions and policies. This paper has highlighted some clear examples but many of the details remain to be explored: How can individuals and government policy in Ethiopia most effectively build resilience to drought? What are the underlying factors in policy decisions about water in Egypt? What role will scarcity (partially induced by climate change) play in influencing cooperation in the basin? Practical considerations relating to adaptation are being faced in many developed countries. In the UK for example, progressive policies on adaptation to climate change (Hulme and Turnpenny, 2004) have produced many examples of stakeholder-led initiatives to consider adaptation to climate change. However, this is relatively new territory, no clear pathways or blueprints exist and the approaches may become quite complex and require substantial resources and expertise. Subak (2000) for example, found a diversity of experiences in the UK water industry associated with its requirement to consider changes in water supply and demand due to climatic trends.

The Nile basin has provided the framework for this analysis—in terms of climate and hydrology it provides a helpful unit of study and allows the exploration of linkages across scales as the Nile integrates rainfall variability and hydrological processes over a huge region of Africa. It is less easy to integrate across scales in terms of social and economic context for adaptation to climate change because of the diversity of conditions at the local level and because there is no community of shared norms at the international basin level. Nevertheless it is clear that people throughout the Nile basin in their capacities as individuals, employees in organisa-

tions, decision-makers and so on have been and continue to adapt with varying levels of success to episodic shocks and multi-year climate fluctuations. This process will continue although it may be that in the short term concerns about climate change and adaptation will be over-ridden by other social and economic considerations and potentially lead to maladaptive outcomes. In many instances throughout the basin present day climate variability may therefore serve as the most appropriate entry point for adaptation to climate change. This reinforces the need for flexibility or robustness of design and the need to strengthen generic capacity and reduce exposure and sensitivity to climate variability and change.

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