# 8 Water Competition, Variability and River Basin Governance: a Critical Analysis of the Great Ruaha River, Tanzania

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## Introduction

This chapter analyses historical irrigation and river basin developments and narratives to demonstrate particular dimensions of water competition in the Great Ruaha River basin in southern Tanzania. Alongside this, we identify three interrelated scalar and emergent dynamic behaviours revealed as a part of basin development. These 'systems' behaviours relate to the growth and coalescing of areas of smallholder irrigated farms since the late 1950s. The three concepts are termed 'parageoplasia',[1] 'non-equilibrium behaviour' and 'share modification'. These insights provide additional layers to the ideas captured in Molle's (2003) conceptual framework for river basin development, specifically on the demand–supply equation, where we bring additional thinking to his allocation 'third way' and on the nature of basin development. While exploring the broad narrative of growth in water demand, we explore further dimensions arising from a highly variable inter-/intra-annual water availability, which affects the distribution of water and impacts of this growth curve, as informed by a sub-Saharan environment.

As well as explaining the concepts terms, we argue that the ideas revealed by this case study might have application to smallholder irrigation elsewhere in savannah agro-ecologies in Africa. The chapter explores how this analysis leads to new insights – particularly in relation to adaptation to climatic change expressed through increased variability of rainfall and river flow (Milly *et al.*, 2008).

## Context

The allocation and equity of division of water between sectors in certain kinds of basins is particularly difficult when rapid growth in one sector establishes a basin-wide potential towards disequilibrium. The term disequilibrium is used in the rangelands' ecological sense (Sulllivan and Rohde, 2002), pertaining to dramatic changes in inputs such that a medium-term, predictable resource offtake from a climax ecology is denied. Explored in more detail by Lankford and Beale (2007), basin disequilibrium occurs because of external and internal perturbations of water catchments and linked interconnections between upstream and downstream water-use systems. Externally derived perturbations arise via a variable water supply, expressed through climate and weather, bringing inter- and intra-seasonal fluxes of

*River Basin Trajectories: Societies, Environments and Development* (eds Molle and Wester) drought and wetness, potentially further exacerbated by climatic change. Internal perturbations occur due to feedback connections between linked sectors or systems where water abstraction and depletion occur – particularly in the irrigation sector, where depleted quantities are both large and highly variable inter- an intra-seasonally. Both types of perturbations pose problems for the management of river basins, particularly the 'equilibrium' expectation that the quality and quantity of water are either only mildly varying or predictable or both, and can be managed accordingly.

Unrealized or unfounded expectations about the slow and/or predictable behaviour and development of basins in turn generate challenges for dividing water between sectors such as rural and urban areas, industries that use water, agriculture and tourism. While many of these flux-related issues are relevant to water governance institutions globally, problems are particularly acute in semi-arid developing countries in Africa, where a particular type of water resource instability exists. This environment should be contrasted with the characteristics of temperate, humid flood-plain river basins of richer developed nations, shown on the left in Fig. 8.1. Typically, in northern Europe, greater stability and predictability are conferred by natural means (temperate/oceanic rainfall patterns, use of groundwater aquifers and low daily evaporation rates) and artificial means (river-training works, storage, piped reticulation, prediction and hydrological information via a network of monitoring stations). This supply-side predictability and stability allows society to monitor rising demands and therefore determines the 'sustainable' gross abstraction of water and hence environmental headroom (Carnell *et al.*, 1999). A regulatory approach to water, providing water rights to users, is achievable under such circumstances. Such a situation is further mollified by the fact that the underlying economy is not irrigation based (the UK uses 2% of fresh water for irrigation (Weatherhead, 2007)) and can invest in less water-intensive activities (e.g. light industry or service sectors), thereby reducing the demand for water.

However, the right side of Fig. 8.1 shows that instability in semi-arid Africa arises from the interplay of combined natural and institutional factors: high climate variability; minimal natural and artificial storage buffering; direct

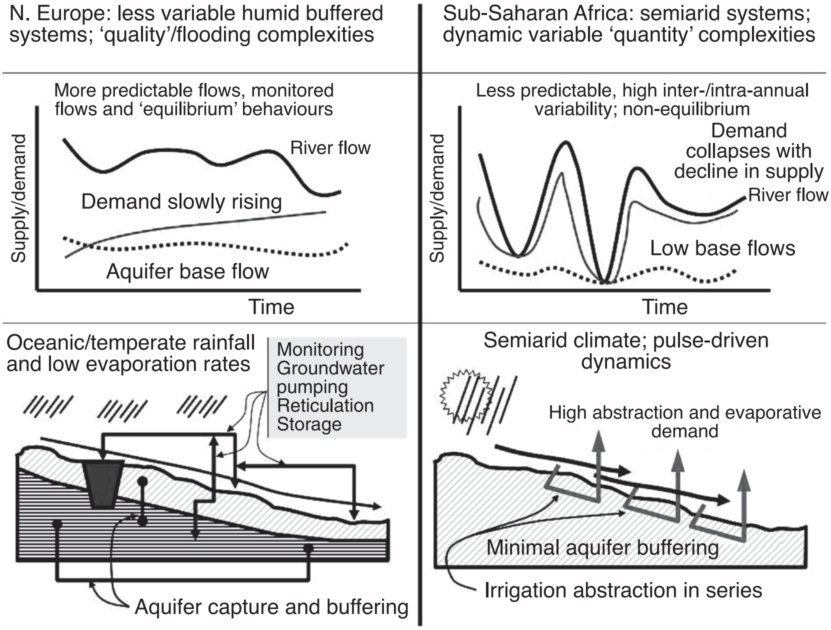

**Fig. 8.1.** The characterization of equilibrium and non-equilibrium river basin systems.

and immediate access to water for agriculture, often fed by gravity in a series of intakes; and significant abstraction and depletion rates, arising from high evaporative demands coupled with water spreading for irrigation. Here we observe a particular characteristic of such environments, where actual use follows supply closely, sometimes up to 100% of what is available. As water supply declines during the dry season or drought, so does usage, often over several orders of magnitude – in other words, daily demand for one area might vary from 5–10 $m^3/s$ in the main rainfall season to 0.50–0.1 $m^3/s$ in the dry season. In this environment, demand is a function of livelihoods that are immediately dependent on natural resources, with few options for switching to an economy that is less reliant on water. In addition to the large area of potentially irrigable land, this is one reason why potential demand is so high and why usage closely follows supply. Moreover, river flow and rainfall monitoring networks and mechanisms for mitigating or sharing varying and declining resources tend to be weak (Donkor, 2003), which undermines both transparency and predictive and risk-based responses. In these conditions, a normative regulatory approach to river basin management is much more problematic.

Added to this comparative analysis are the three key solutions to managing water sufficiency – supply, demand and allocation (share) management – each taking a part and role during river basin development. As rivers close, and when the fixes of supply-side infrastructural development become increasingly expensive, attention turns to issues of demand management, water conservation and water allocation (Molle, 2003; Molden *et al.*, 2005). Consequently, governments and NGOs, as well as the academic community, seek new and innovative understandings of the governance of demand management and of the means to share limited but varying amounts of water between users. This chapter explores the trajectory of the Ruaha River basin and stresses the challenging specificities of sub-Saharan African environments.

The growth of smallholder irrigated farms in the Usangu plains, in the Great Ruaha basin, from approximately 1000 ha in 1960 to an area of between 20,000 and 40,000 ha in the present day, with an associated rise in water competition, provides three insights on river basin systems and, as a consequence, new entry points for the refinement of irrigation and river basin management. These ideas illustrate related, but separable, issues that inform systems policy. Brief descriptions are given below, and illustrated in Table 8.1 and Figs 8.2 and 8.3. The chapter explores the ideas and their implications for river basin management in greater detail; captured in Fig. 8.3, they illuminate other possibilities related to, and building upon, the S-shaped model of basin development.

### *Parageoplasia*

This term applies to non-local externalities created by upstream water depletion in a river

**Table 8.1.** Three basin behaviours observed in southern Tanzania.

| Idea | Observation | Resulting from | Outcomes | Policy implication |
|---|---|---|---|---|
| Parageoplastic behaviour | Exported aridity downstream with specific timing, quantity and quality dimensions | Increased area of dry- and/or wet-season irrigation upstream | Altered behaviours and outcomes downstream | Discern parageoplastic links followed by basin or local solutions |
| Non-equilibrium systems and behaviour | Fluctuating area of wet-season irrigation between upper and lower limits | Climatic and weather variability leading to changes in rainfall and runoff amounts | Supply–demand equation non-linear, complicating allocation | Rethink irrigation planning methods to allow abstraction to mirror runoff flux |
| Share modification | Uneven proportional division of varying river flows between sectors | Poorly conceived irrigation design and installation of irrigation intakes | Changing inequity of supply between sectors | Remodel or refit irrigation intakes to improve proportional division of river flow |

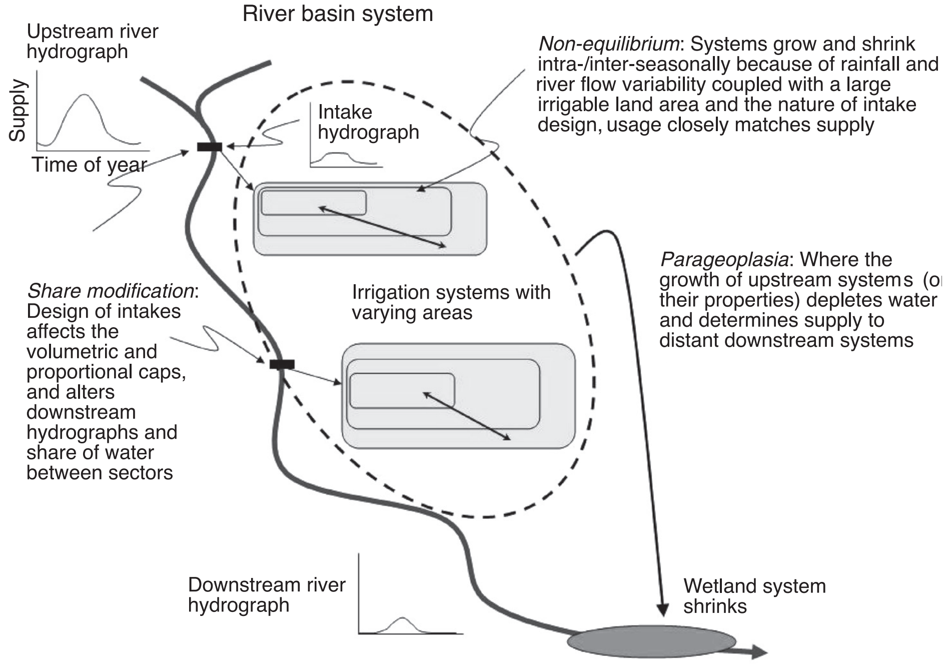

**Fig. 8.2.** Concepts of basin behaviours resulting from growth of irrigation.

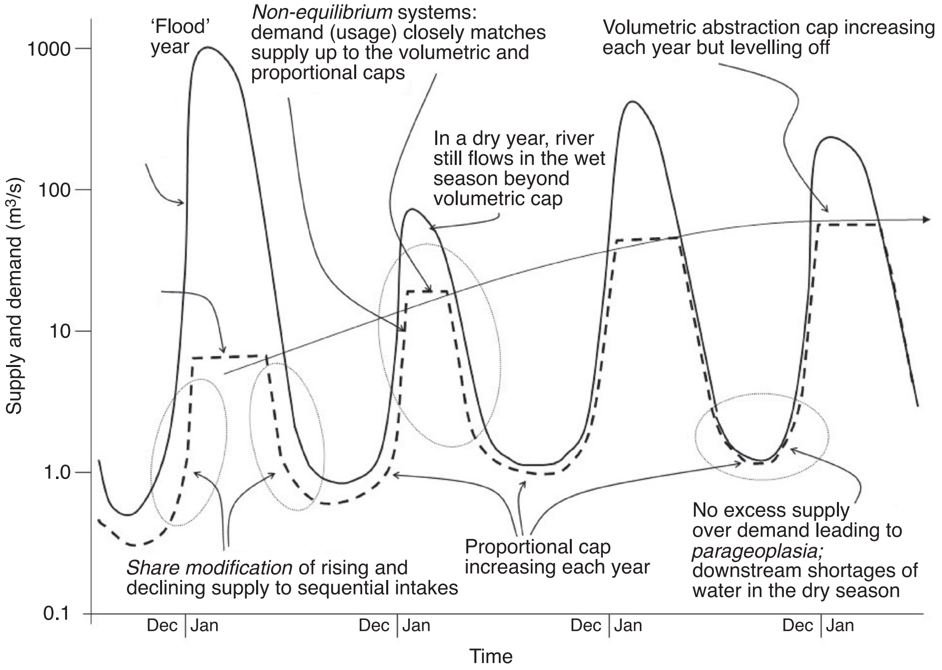

**Fig. 8.3.** Depiction of basin behaviours via a supply and demand hydrograph.

basin, prompting new behaviours as downstream users react to water shortages. Parageoplasia is captured in Fig. 8.2, where a downstream wetland experiences water shortage. The example in this chapter is of dry-season water shortages in the Ruaha National Park, caused by irrigation abstraction 100 km further upstream. Parageoplasia is defined as depletion or usage causing external symptoms of water shortages in a locality elsewhere in the basin.

#### *Non-equilibrium behaviour*

This is observed when demand closely follows and matches supply intra- and inter-seasonally. Figure 8.3 shows this as the demand (dotted) line rising and falling in line with the supply line. This occurs in southern Tanzania because the irrigated area rapidly increases to approximately 40,000 ha in a wet season (with normal rainfall) from about 5000 ha in the dry season (Lankford and Beale, 2007). By contrast, an 'equilibrium' situation might be characterized as one where demand is more restricted, so that an enlarged supply cascades a surplus to downstream users (or, in other words, where demand increases by a maximum of 50–100%, rather than 800% in the non-equilibrium case). Figure 8.3 demonstrates a rising trend of increased wet-season demand over time – notice the volumetric cap increases each year as more intakes are developed or modernized; the figure also shows that the area between the solid and dotted lines diminishes over time, indicating that the proportional abstraction cap increases with time, resulting in less water passing downstream (see Lankford and Mwaruvanda, 2007).

#### *Share modification*

This describes purposive or inadvertent changes in shares of water between sectors and/or users in the face of a declining or increasing flow rate resulting from existing or redesigned (new) river flow division infrastructures. Modification of shares is particularly prevalent with conventional designs of irrigation intake infrastructures combined with highly varying flows. On the other hand, proportional designs of river infrastructures help to reproduce the shape of the river flow curve proportionally between the offtaking canal and the downstream section of river.

In summary, these phenomena are realized through the evolving trajectory of the case study basin via three main facets: (i) the growth of irrigation area and demand over time; (ii) the presence of a variable sub-Saharan climate; and (iii) a combined effect of both the choice (intentional or otherwise) and density of infrastructure technology mediating the share of water between sectors.

## Study Area and Background

### Water resources and location

Tanzania faces perceived (and sometimes real) water scarcity problems at local levels despite the fact that, on average, it has abundant water resources to meet most of its present needs. However, while a third of these resources lie in highland areas, with precipitation in excess of 1000 mm, about one-third of Tanzania is arid or semi-arid, with rainfall below 800 mm. The major river systems constitute the principal surface water resources of the country, with mean annual runoff of about 83 billion $m^3$ and an estimated groundwater recharge of 3.7 billion $m^3$. Half of the surface runoff flows into the Indian Ocean from the Pangani, Wami, Ruvu, Rufiji, Ruvuma, Mbwemkuru and Matandu river systems. The remainder drains northward, into Lake Victoria, westward, into Lake Tanganyika, and southward, into Lake Nyasa. Some of the runoff also flows into internal drainage basins with no sea outlets. These include the Lake Rukwa and central Internal Drainage basins.

However, greater demand for water for irrigation and the long dry season (June to October) result in low river flows and seasonal scarcity (World Bank, 1996). As evidenced by the case study in this chapter, this has resulted in conflicts between hydropower and irrigation sectors, between irrigation and livestock sectors, and between upstream and downstream water users within the irrigation sector. Tanzania also lacks the economic resources to harness water and to overcome the extreme temporal and spatial variability in rainfall and surface flow.

The Great Ruaha River catchment (GRRC) is located in south-west Tanzania (Fig. 8.4). It has a catchment area of 83,979 km$^2$ and a population of 480,000, according to the 2002 national population census (TNW, 2003). Headwaters rise in mountains to the south, in the Poroto and Kipengere ranges, and drain onto the alluvial Usangu plains. The catchment can be divided into three major agro-ecological zones, which have different characteristics. The upper zone (1400–2500 masl) is semi-humid to humid, highly populated and has high rainfall, deep soils and intensive agricultural production. In this zone, both rainfed and irrigated agriculture is practised all year round. The intermediate middle zone (1160–1400 masl) is characterized by a high concentration of irrigation systems on alluvial fans, and here a limited presence of dry-season irrigated agriculture is an important means of livelihood. Therefore, this is an area of high competitive water demand and hence persistent water conflicts.

The lower zone (1000–1160 masl) is semi-arid with alluvial soils, with a low population density and a high concentration of livestock, particularly cattle. Here, the Great Ruaha River (GRR) and other tributaries pass through seasonally inundated grassland and permanent swamps, which are ecologically significant, supporting a considerable biodiversity, notably its extremely high bird-life diversity (SMUWC, 2001). The GRR discharges from the northern end of the plains at NG'iriama, an outlet of the permanent Ihefu swamp. The catchment area at this point is 21,500 km$^2$, and is commonly termed the Usangu basin, synonymous with the upper Great Ruaha River catchment (UGRRC). About 30 km further north, the river passes through the Ruaha National Park, and from there further north-east to Mtera and Kidatu reservoirs. During the dry season, from July to November, the river is the major source of water for much of the wildlife in this park.

As is the case in most of sub-Saharan Africa, the livelihoods of the majority of people in the Great Ruaha River catchment are largely dependent on agriculture. However, the area is characterized by high variability (with an average annual coefficient of variation of 24%), uncertainty, and poor and uneven distribution of rainfall during the crop-growing seasons (SMUWC, 2001; Rajabu *et al.*, 2005). Despite the fact that the rainfall regime is unimodal, with a single rainy season (with a mean annual

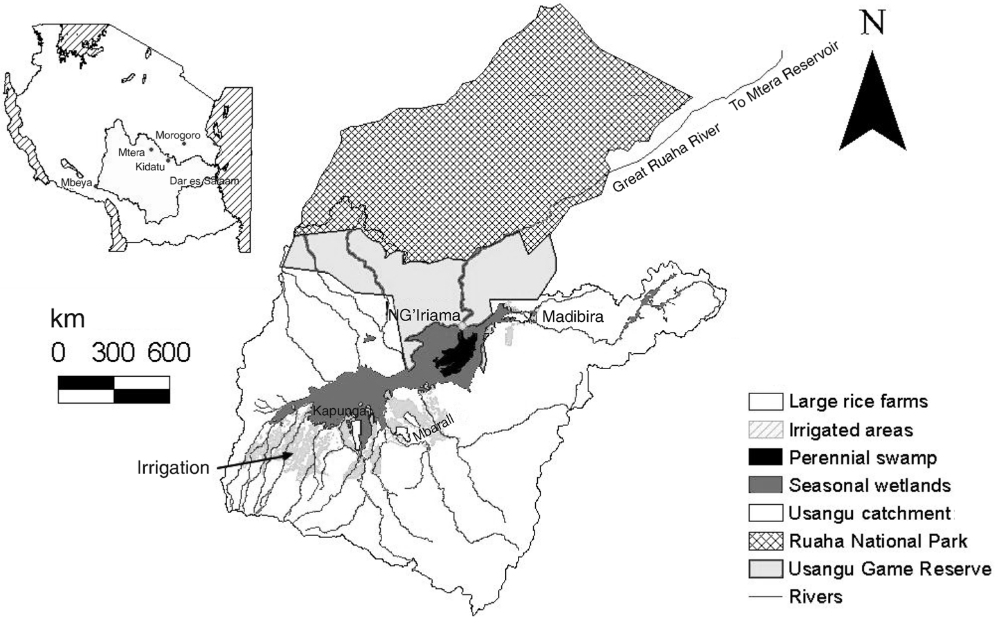

**Fig. 8.4.** Map of the Usangu basin within the Great Ruaha River basin.

areal rainfall over the UGRRC of 959 mm), the onset and duration of the rains vary from zone to zone and both are unpredictable in timing. Whereas the rainy season for the upper zone (highlands) runs from October to May, the rainy season for the middle and lower (the plains) zones runs between November and April. Of particular consequence for cropping on the plains is the fact that rainfall is between 500 and 700 mm on average, a marginal amount for rainfed maize, and necessitating supplementary irrigation for rice production.

Further analyses of the causes of hydrological changes and background to the area can be read in a number of additional articles (van Koppen *et al.*, 2004; Lankford *et al.*, 2007; McCartney *et al.*, 2008), while additional information on the prevailing political and institutional context can be found in Lankford *et al.* (2004).

### Farming systems and water users

As a strategy to cope with the uncertainty and poor distribution of rainfall during the crop-growing season, the local farming systems in the UGRRC have constructed diversions to abstract water from rivers for supplementary irrigation in order to minimize risks of crop failure. There are three types of irrigation systems, which are:

1. Traditional systems, which comprise village irrigation, based on the diversion of perennial or seasonal flows, used mainly for the production of rice, vegetables and other relatively high-value crops. These are self-sustaining systems, initiated, financed, developed and owned by the farmers themselves, without any external assistance.
2. Improved traditional systems are traditional systems that have received government- or donor-assisted interventions to improve the headworks and water control structures, and, on occasion, farmer training.
3. Modern large-scale schemes that comprise large-scale farms (such as Kapunga, Mbarali and Madibira rice farms) built with the aid of international finance.

In nearly all of these systems, basin irrigated rice (paddy) is grown, to the extent that the Usangu basin contributes about 15% of the rice production in Tanzania and supports the livelihoods of about 30,000 poor households in Usangu (Kadigi *et al.*, 2003).

Below the irrigation systems are the seasonal wetlands of the Usangu plains, containing the permanent wetland of the Ihefu, an area of about 80–120 km$^2$. The seasonal and permanent wetlands once contained significant numbers of fisherfolk and livestock keepers, but following their forcible removal by government authorities as a result of the formalization (gazetting) of the Usangu Game Reserve, these numbers have been greatly reduced. An examination of the contribution to the local economy is conducted and implications of this intervention are described below.

Further downstream, the total power-generating capacity of the Mtera and Kidatu plants is 284 MW, which is 51% of the total hydropower capacity of Tanzania (TANESCO, 2008). A fuller history of this hydropower development is given below, along with an analysis of the water management of the two dams.

After Mtera, the Kilombero Sugar Company abstracts water from the river for irrigation and cane processing. The company is located in the flat, fertile areas at the base of the Udzungwa mountains in the Msolwa and Lower Ruembe valleys in the Morogoro region of Tanzania. The mean annual rainfall in this humid region is 1347 mm, although moisture deficits are evident from June to December. Thus while crop moisture requirements are generally satisfied by rainfall between the months of January and April, irrigation is required to maximize growth during the remainder of the year and to allow planting operations to take place in the dry months. The sugar company has a year-round water right of 8.5 m$^3$/s from the Great Ruaha River.

Hence, six main river water users from upstream to downstream can be identified: domestic water users, in the high catchment and plains; irrigators, mainly on the plains; pastoralists and fisherfolk, in the seasonal wetlands and the Ihefu; wildlife and tourists, in the Ruaha National Park; electricity producers, at the Mtera and Kidatu power plants; and sugarcane producers.

For the analytical purposes of this chapter, these water users are divided into two main high user groupings: irrigated users and downstream users, split on the basis of level of abstraction of water into a first group of irrigation systems on the plains (mostly rice growers) ,and a second group comprising water users downstream of the main irrigation area on the plains (fisherfolk and wildlife in the wetlands, tourists and wildlife in the national park, and power generators). There are domestic and irrigation water users upstream of the plains and irrigators in the mountain watersheds, but these are minor in extent and quantity of water use, given higher rainfall and lower evaporation rates at these altitudes. These users are not shown in Fig. 8.4.

## Water accounting[2]

Utilizing the water-accounting methodology of the International Water Management Institute (IWMI) (Molden, 1997; Molden *et al*., 2001), we have generated a 'finger diagram' of water flows for a normal-to-wet hydrological year in the Usangu basin (Fig. 8.5). It should be recognized that the non-linear behaviour of the catchment, with variable surface areas of irrigation, wetlands and storage by the Mtera hydroelectric dam/reservoir, imply a highly variable model of water flows and partitioning. The finger diagram (Fig. 8.5) should not be interpreted as a static model of water apportionment. The key features are as follows:

**1.** The calculations represent surface flows only.[3] Catchment precipitation and green water evapotranspiration are not included. With regard to losses in groundwater, studies by the Sustainable Management of the Usangu Wetland and its Catchment (SMUWC) project and observations on the ground show that water losses of about 10% occur when rivers transit the geological fault-line of the East African Rift Valley from the high catchment to the plains. While this water supports perennial flows in the Mkoji subcatchment and some domestic use elsewhere, little of it creates a water table that can be used for substantial irrigation withdrawals or flow augmentation. The Usangu plains are typical African savannah plains rather than flood plains in the Asian sense. Thus groundwater losses are shown as losses from the gross inflow rate.

**2.** Two types of beneficial depletion occur: non-process (not intended), via evaporation of water from the wetland, and process, via net irrigation demand, and domestic and livestock

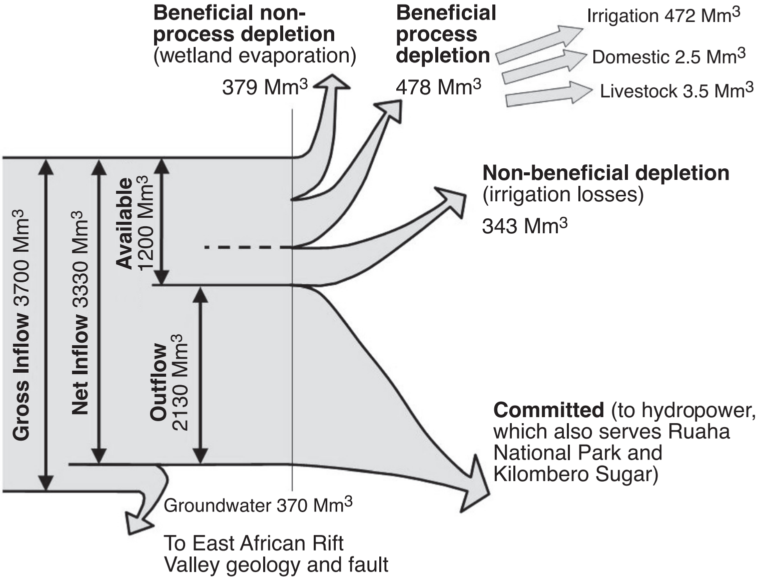

**Fig. 8.5.** Surface water accounting of the Great Ruaha River basin.

use. Irrigation losses represent the principal non-beneficial depletion (occurring mainly through non-recovered losses to groundwater and unproductive evapotranspiration). Livestock usage relates only to calculations of drinking water – note that green (soil) water is not calculated. These rates are shown in Fig. 8.5.

**3.** The fourth flow is a committed outflow to provide storage in the Mtera reservoir for evaporation and discharge through the Mtera turbines, which annually have a potential useful power-generating requirement of a flow of 96 $m^3$/s. This discharge flow and the dam evaporation combine to establish approximately 3800 $Mm^3$ annually. Hydrological analyses show that 56% of this is contributed by the upper Great Ruaha catchment, approximately 2130 $Mm^3$. This value very closely corresponds to the determination of the outflow of 2130 $Mm^3$ at the exit of the Usangu wetland (in other words the surplus water to that utilized in the UGRRC). This demonstrates the analysis by Yawson *et al.* (2003) that, during an average hydrological year, flows to hydropower storage are sufficient to meet generating needs, despite the common assertion that upstream irrigation is in direct competition with hydropower (Kikula *et al.*, 1996; Mtahiko *et al.*, 2006[4]).

## Introduction to policy stakeholders

In addition to the users mentioned in the previous section, throughout this chapter a number of key stakeholder groups are discussed, many of whom have converged and overlapped in influencing policy and providing supporting services to water management in the basin. They are briefly introduced here.

In 1996 (partly as a response to hydropower electricity power cuts during the mid-nineties), perceiving water resources management in Tanzania to be hampered by uncoordinated planning for water use, incomplete policies, inadequate water resources data and inefficient water use, the government of Tanzania, with the assistance of the World Bank (1996), initiated a sustained programme of reform. Tanzania adopted a river basin management approach for water resources management, in which the country was divided into nine river basins for water resources administration. These are Pangani River basin, Wami/Ruvu River basin, Rufiji River basin, Ruvuma River basin, Lake Nyasa basin, the Internal Drainage basin, Lake Rukwa basin, Lake Tanganyika basin and Lake Victoria basin. To manage each of these basins, a basin water office was created. The main activities of the basin water offices include: (i) regulating, monitoring and policing of water use in the basin; (ii) issuing formal water rights; (iii) facilitating and assisting in the formation of water user associations; (iv) billing and collection of water user fees; (v) awareness creation of water users regarding water resources management; and (vi) monitoring and control of water pollution (NORPLAN, 2000; Mutayoba, 2002).

A substantial programme of reform, centred on two pilot basins, the Pangani and the Rufiji, was implemented through the decade from the mid-1990s onwards, through the River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP), via a loan of US$21 million.[5] The smallholder component of RBMSIIP was deployed principally via the local district council (Mbarali), with significant assistance from the zonal irrigation office, located in Mbeya, and central support from the Ministry of Agriculture in Dar es Salaam.

In the late 1990s, the UK's Department for International Development (DfID) assisted RBMSIIP via a technical assistance project implemented by consultants. The project, SMUWC[2], determined the cause of the hydrological changes in the Great Ruaha and contributed to the development of water strategies that could be applied in other basins with wetlands in Tanzania. Despite its significant scientific findings, and also incorporating stakeholders, the project was discontinued in 2001, when DfID switched to development assistance via budget support. In recognition of this break, the Knowledge and Research division of DfID (KaR), with the assistance of the IWMI, funded a small project from 2001 to 2005, termed RIPARWIN (Raising Irrigation Productivity and Releasing Water for Intersectoral Needs)[2], and designed to complete some of the studies started by SMUWC.

From 2000 onwards, an increasingly important role has been taken by the World Wildlife Fund (WWF), which has culminated in its ongoing project, the Ruaha Water Programme. In addition, the environmental group 'Friends of Ruaha'[6] has played a number of political advocacy roles in drawing attention to the consequences of water management.

The Mbarali District Council also was a key player. Despite a counter-productive effect on meat revenues, Mbarali district (almost synonymous with the Usangu plains, see Fig. 8.4) was a key advocate of gazetting the Usangu Game Reserve. Furthermore, because of the council's developmental concerns, manifested by support for irrigation, it sought to diminish the conflicts between rice growers and cattle keepers by removing the latter and by siding with the mainstream governmental view that the river should be restored to year-round flow through the construction of improved intakes (also a counter-productive move for reasons explained elsewhere in the chapter).

## Historical Trends and Changes in the Basin

As Table 8.2 testifies, the upper Great Ruaha basin has seen many changes over the last 50 years or so, mostly related to population increases associated with greater utilization of natural resources. Associated with this have been major land-use changes. The natural vegetation of the alluvial fans has been largely cleared and replaced with rainfed and irrigated cultivation and grazing areas. Other events listed in Table 8.2 are discussed below and elsewhere in the chapter.

### Growth in population, livestock and irrigated area

Between 1950 and 2003, the population in the UGRRC increased from less than 50,000 to approximately 480,000 (TNW, 2003), largely through in-migration from other regions of Tanzania. This growth has also been mirrored in the expansion of the largest urban conurbation, Mbeya, just outside of the catchment in the south-west.

In the plains, most people are farmers, cultivating rainfed and irrigated plots, but a smaller number are pastoralists, who have brought more cattle into the plains. Livestock numbers also increased, although these probably peaked

**Table 8.2.** Summary of historical events occurring in the upper Great Ruaha catchment.

| Period | Events and notes |
|---|---|
| 1935–1967 | Pristine condition, pre-El Niño flood event in 1968. Estimated total area of rice reported in 1958 was 3000 ha, at end of 1967 = approx 10,000 ha |
| 1962 | Kilombero Sugar Company first factory commissioned |
| 1969–1973 | Estimated total area of rice at end of 1973 was approximately 14,000 ha |
| 1970 | Kidatu dam constructed (100 MW), with another 100 MW added in 1976 |
| 1972 | Mbarali rice farm constructed |
| 1974–1985 | Post-Mbarali, pre-expansion in rice. Estimated total area of rice at end of 1985 = approximately 25,000 ha |
| 1978 | Hazelwood and Livingstone report filed |
| 1980 | Mtera dam completed and started to fill |
| 1986–1991 | Expansion in rice, pre-construction of Kapunga scheme |
| 1992 | Kapunga is constructed; weirs across Chimala river |
| 1992–2000 | Post-Kapunga and Chimala river changes, continued expansion of rice, construction of upgraded intakes, introduction of widespread dry-season irrigation, Madibira constructed in 1998. Estimated total area of rice at end of 1999 = approximately 40,000 ha |
| 1996– | RBMSIIP project, which was the forerunner to the wider Water Sector Support Project with funding from 2007 to 2012 (both World Bank funding) |
| 1999–2001 | SMUWC project (DfID funding) |
| 2001–2005 | RIPARWIN project (DfID funding) |

in the early 1980s, at around 550,000. In 2000, the number of cattle was estimated at around 300,000 head, with about 85,000 other livestock (SMUWC, 2001). The pastoralists moved into the Usangu catchment in search of pastures, following long periods of drought or competition over resources in their home villages. The areas include central and northern areas of the country, namely Dodoma, Singida, Shinyanga and Arusha regions, although commonly they are known collectively as the Sukuma. The numbers of cattle, goats, donkeys and sheep in the catchment has been a source of scientific debate for the last 10 years. While regional authorities proffered a figure of one million cattle (largely to support arguments that the plains were being degraded by overstocking), various study reports give different levels of the stock in the catchment. The livestock census conducted in 1984 showed for Mbarali district a herd of about 513,600 animals, of which 438,000 were cattle (SMUWC, 2001).

During this 50-year period, the area irrigated in the wet season has increased from approximately 3000 ha to 40,000–44,000 ha (Fig. 8.6), although the area varies significantly from year to year, depending on rainfall. In dry and wet years, the total area can swing from 20,000 ha to 40,000 ha, respectively. It is this growth in area that has led to increased competition and conflict over water, particularly in the dry season, and has led to the emergence of the three behaviours seen and characterized in this chapter.

The bar line in Fig. 8.6 indicates the extent of variability in the area under cultivation from wet to dry years (SMUWC, 2001, adapted).

### Environmental changes downstream

Many of the environmental changes in the area were associated with this growth of irrigation; however, most publicly noted has been rapid hydrological change. This is testified by visible changes in the flow of the major river draining the plains. The Great Ruaha River used to be perennial – river flow lasted throughout the dry season. However, since the early 1990s, the discharge through the Ruaha National Park has altered, becoming seasonal, with flows ceasing during part of the dry season. This cessation is explained by water levels in the eastern wetland dropping below the crest of the rock outcrop at NG'iriama (see Fig. 8.4), resulting in the wetland being unable to feed the river downstream. An analysis of flows measured at Msembe Ferry, a gauging station located approximately 80 km downstream of NG'iriama, indicated an increasing frequency and extension of zero flow periods between 1990 and 2004 (Kashaigili *et al.*, 2006) of between 15 and 100 days, depending on rainfall and upstream abstraction, with no discernible upward or downward trend during that time. Coinciding with low flows in the mid-1990s were a series of electricity power cuts from Mtera and Kidatu, fuelling speculation that upstream irrigation was depleting water destined for downstream ecological and economic purposes.

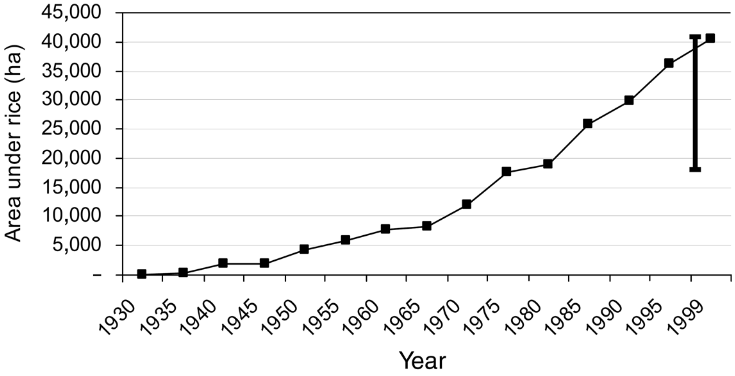

**Fig. 8.6.** Growth in irrigated area surrounding the Usangu catchment.

Other environmental changes include an encroachment of cultivation into the wetland and a marked decline in wildlife species – most striking of all is the replacement of wildlife herds by cattle. The combination of cultivation and grazing has resulted in a reduction of grass species and a concomitant rise in woody shrub species, which otherwise would have been kept at bay by natural flooding and grassland fires; both suggest a progressive degradation of the alluvial fans and plains. In the highlands, changes have perhaps been less dramatic. However, ever-increasing areas have been, and are still being, converted to cultivation and settlement; erosion on steep slopes is advanced in places; and even where the woodland is relatively intact, it has been exploited for the important timber species.

An analysis of declining dry-season flows and wetland area shows that between 1958 and 2004 the dry-season minimum area decreased significantly, but there was no clear trend in the wet-season maximum area. Overall, the dry-season minimum area was found to have decreased from an average of about 160 km$^2$ (1958–1973) to approximately 93 km$^2$ (1986–2004), i.e. a proportional decrease of approximately 40% (Kashaigili *et al.*, 2006). Average dry-season inflow to the Usangu wetland (the Ihefu) between 1986 and 2004 was estimated to be 76 Mm$^3$, compared with 200 Mm$^3$ between 1958 and 1973. Although rainfall over these two periods was not exactly the same, this nevertheless indicates a reduction of dry-season flows of approximately 60%, and in some months (e.g. September and October) the reduction was closer to 70% (Kashaigili *et al.*, 2006). However, these data cover the period when the gate closure programme was coming into effect and so slightly underestimate historic water withdrawals. Flow measurements made by the SMUWC project at the end of the dry season in 1999 found that 91% of upland flow was being abstracted and, overall, it was estimated that, on average, 85% was being withdrawn in low-flow months (SMUWC, 2001). More recent studies conducted in 2003 and 2004 in the Mkoji subcatchment, the most heavily utilized for irrigation, continue to show dry-season abstraction levels in excess of 90% on some rivers (Rajabu *et al.*, 2005).

## Mtera–Kidatu hydropower

The presence of nearly 50% of Tanzania's electricity generation downstream of the upper Great Ruaha catchment has imposed a particular character to the debates and narratives about water development and management in the basin, and thus we provide here a historical background to the development of hydroelectricity.

In response to growing electricity demand, the decision to construct the Kidatu hydropower station was taken by the government of Tanzania in 1969. The 204 MW Kidatu dam and hydropower plant was the first phase of the Great Ruaha Power Project, funded via loan agreements between the Tanzanian government, the Tanzania Electric Supply Company, the Swedish government and the World Bank. As the demand for electricity further increased, phase two of the Great Ruaha Power Project was considered by constructing a dam at Mtera. The government agreed to the proposal, as the purpose of this reservoir was essentially as an upstream reservoir to ensure there would be sufficient water reserved throughout the year, and especially during the dry season, to supply Kidatu. By December 1980, Mtera dam was completed. Following further consultations, it was proposed that another smaller power station of 80 MW should be built at Mtera, an addition not originally foreseen in the planning of the 1960s. The water stored in the reservoir would generate power before flowing downstream to Kidatu to generate 204 MW of power again. The 80 MW Mtera power station became Phase III of the Great Ruaha Power Project and started operating in 1989.

Mtera has a total storage of about 3600 Mm$^3$ and a live storage of 3200 Mm$^3$, when, at the maximum (full) supply, the water level is 698.50 masl. The minimum water supply level allowed for normal power generation is 690.00 masl. Below this level, down to the bottom at 686.00 masl, is a 'dead storage' volume of about 500 Mm$^3$ of water, which may be used only when there is an emergency such as a national power crisis. Although SWECO's report indicated that the water in 'dead storage' could be used during emergencies, it added that emptying the reservoir below 690.00 masl would have adverse effects on the ecosystems that had developed in and around the dam. The reservoir-operation simulation conducted by SWECO in 1964 illustrates that about 25% of the inflow into the reservoir was lost by evaporation because of the ratio of the very large surface area to the volume.

## Irrigation governance narratives

Associated with changes in the basin are narratives regarding irrigation development and governance. There is not enough space here to deal with a wider treatment of the Tanzanian political economy in a post-colonial era, particularly the agrarian impacts of the socialist government of Julius Nyerere arising from villagization and farming collectivization. Instead we concern ourselves with two narratives that pertain to irrigation and basin development: first, agricultural growth and modernization from 1960 to 1990 and then, linked to it, a narrative of efficiency, environmentalism and water reallocation during the period 1995–2005. The former spans the period in which water and land were seen to be abundant, while the latter drew from perceptions regarding a finite supply of water and concerns over power cuts, described in the previous section.

### *1960s to 1990 – expansion and modernization of irrigated agriculture*

The contemporary tension between the two agendas of developmental modernization and environmental protection can be traced to government intentions from 1960 to the 1980s to utilize the water resources of the upper Great Ruaha for irrigation. The key development projects of the formal, state-run irrigation schemes of Mbarali (1972) and Kapunga (1992), plus the concerted efforts to 'improve' traditional intakes, can be traced to the 1978 Hazelwood and Livingstone study of the economic options available to the government of Tanzania in developing the Usangu plains (Hazelwood and Livingstone, 1978a), commissioned by the Commonwealth Fund for Technical Cooperation (CFTC). The request came as a 'pre-feasibility study with the aim of elucidating the nature of development problems of the plains, determining the appropriate pattern of development, assessing the potential for development and identifying projects for detailed feasibility study' (Hazelwood and Livingstone, 1978a: vol. 3). The objective is stated as 'to assess the potential of Usangu for development and for contributing to national economic goals', while it also says 'that its total programme should be seen as a long term plan for the eventual full exploitation of the resources of Usangu' (Hazelwood and Livingstone, 1978a). The ongoing concerns in the 1960s and 1970s with generating economic growth in the region, typified by the study by Hazelwood and Livingstone, were heralded in 1961 by the FAO Rufiji basin study (FAO, 1961) and a US Bureau of Reclamation (USBR, 1967) study offering similar visions of large-scale irrigation development, limited only by water availability and labour, and unencumbered by economic, social or environmental constraints (Palmer-Jones and Lankford, 2005).

Although the formal schemes for Mbarali and Kapunga amount to a total of 6800 ha, there can be no doubt that the Hazelwood and Livingstone work stimulated further developments in the region. Some are directly attributable to this work: for example, prior to 1978, 16 intakes of informal schemes were concrete but since then an estimated 40 intakes have been upgraded by a variety of donors, including the government of China, JICA, the World Bank and FAO. This probably allowed an additional 10,000 ha of rice to be cultivated, and is certainly one major reason for the growth of irrigation from 17,500 ha, recorded in 1978, to nearly 40,000 ha, recorded by SMUWC in 2000. This hectarage makes Usangu one of the single most significant rice-producing areas in Tanzania, contributing 15% of the national total (Kadigi *et al.*, 2003). Other major projects were followed through: the Madibira scheme (3000 ha) was directly supported by Hazelwood and Livingstone and saw its first irrigated planting in 1999/2000. Overall, the development of natural resources has sustained very high population growth in the Mbarali district, with 4–5% annual growth rates.

### *1990s onwards – irrigation efficiency, environmentalism and allocation*

Irrigation efficiency is of significant importance in the discourse on irrigation and river basin management in Tanzania, and since the mid-1990s it has been at the heart of attempts to reallocate water downstream to meet hydropower and wetland water requirements. Raising water-use efficiency was the key rationale for the River Basin Management and Smallholder Irrigation Improvement Project, initiated in the RBMSIIP project funded by the World Bank (World Bank, 1996).

Setting aside the incorrect claims for upstream water originating from powerful interests allied to power generation (as serious though that may be), the economic return on the US$22 million loan to the government of Tanzania was predicated upon the argument that water saved in irrigation through raising efficiency would pass through the turbines at Mtera/Kidatu, generating considerable financial and economic benefits. The single tenet underlying gains in efficiency was that if traditional intakes were improved by the use of a sluice gate, set in concrete headworks, this would give control over abstraction and thus reduce the volume taken into irrigation systems during wet periods. The project also matched intake improvements with ‘demand management’ through the selling of water rights, as this would regulate upstream demand and send more water downstream.

Interestingly, this discourse was initiated in the 1970s when Hazelwood and Livingstone explored differences between the Mbarali system (perceived to be modern and to have adjustable headworks control) and traditional farmers who employed traditional intakes made of local materials (Lankford, 2004a). Hazelwood and Livingstone (1978b:207) demonstrate prevailing views regarding the waste of water by smallholders:

> The possibility exists of controlling agricultural practices of peasants particularly at the time at which they plant, because an efficient irrigation system requires a considerable degree of water management. It is true that in the area with which we are dealing the limited peasant irrigated cultivation that at present takes place uses irrigation constructions which are largely unplanned and not professionally designed, and for which there is effectively no control or administration of the distribution of water. But this system is very wasteful in its use of water, it is also wasteful of land because cultivable areas are lost through flooding, and it is inequitable in its allocation of water between individual farmers.

The contribution of Hazelwood and Livingstone to this debate should not be underestimated. By publishing figures early on, they affected, perhaps even underwrote, the present-day view that smallholders are less efficient than larger-scale farmers (JICA, 2001; Kalinga *et al.*, 2001). The case study in Usangu provides an example of the errors in scientific understanding of irrigation efficiency. The RBMSIIP was based on the premise that the project could raise efficiency from 15 to 30%, allowing substantial reallocation of water, as the quote below from the appraisal report explains, and that this would be achieved by improving intakes, selling volumetric water rights and training farmers.

> In order to illustrate this effect, the ‘savings’ in water which result from the improvement of some 7000 ha of traditional irrigated area under the project (this includes both basins) are valued using their capacity to generate electricity in the downstream turbines. An average ‘in the field’ requirement of 8000 $m^3$ of water, for one ha of rice production, implies withdrawal of 53,300 $m^3$ from the river, with an irrigation efficiency of 15 percent. Following improvements in irrigation infrastructure and an increase in irrigation efficiency to 30 percent, the withdrawal requirement from the river drops to 26,700 $m^3$ per hectare. This releases some 26,700 $m^3$ for every hectare of improved irrigation, to be used for hydropower generation downstream. For this exercise, the water is valued at US 5 cents per $m^3$, the valuation for residential electricity use (34 percent of all electricity use, and intermediate point between the two alternate values)
>
> (World Bank, 1996:42).

Yet closer measurement indicates that effective efficiency was probably in the region of 45–65%, precisely because of reuse of drain water by tail-enders (Machibya, 2003). The erroneous assumptions contained in this quote are that: (i) the efficiency was very low; (ii) the losses were depleted from the basin; (iii) improving intakes would reduce losses; and (iv) savings would automatically move downstream to the hydropower reservoirs. The failure to ground-truth some of these assumptions is evident in that the project went ahead as planned.

The fact that the RBMSIIP programme sought to increase efficiency by upgrading intakes rather than by tackling in-field water management is indicative of the viewpoint of Hazelwood and Livingstone that it is the lack of control at the headworks river intake that reduces efficiency. This understanding fails to recognize that farmers use high flows to cascade water through their system, expanding the cultivation area at tail-end reaches, which in turn places an efficiency emphasis on cascade management rather than what is happening at a single point on the river intake.

## Environmental governance stakeholders and impacts

Arguably, the upper Ruaha has become a cause célèbre for a number of individuals and organizations. Foremost has been the interest shown by WWF, an international NGO in the restoration of year-round flows via the establishment of its Ruaha Water Programme. This programme has been working closely with local stakeholders to improve water management, with the aim of returning the river to year-round flow by 2010. It is also thought that WWF successfully obtained high-level support for environmental interventions by the government of Tanzania, manifested by the promise by former President Sumaye (speaking at the Rio +10 preparatory meeting, 6 March 2001, London) to re-establish 'year-round flow' by 2010.

The government of Tanzania, via the Ministry of Tourism and Natural Resources (which also manages the Ruaha National Park), agitated for the gazetting of the Usangu wetland and surrounding plains into a Game Reserve, thereby legitimizing the removal of human inhabitants from the area (Moirana and Nahonyo, 1996). Thus, in March 2006, the government, through the office of the vice president, issued a statement declaring to evict pastoralists and agro-pastoral and smallholder communities from the Usangu catchment and Kilombero valley in Mbarali and Kilombero districts, respectively (PINGOs, 2006). The reasons put forward mainly included, *inter alia*, environmental degradation as a result of overstocking beyond the carrying capacity, land-use conflict between different user groups, and poor agricultural and irrigation techniques. The statement further pinpointed issues of scarcity of water flows in the Ruaha River and subsequent low water levels at the Mtera dam (low hydropower productivity). Omitted from these reasons were the perceived territorial advantages of drawing the wetland and plains into the larger Ruaha National Park and the financial gains to the government via the licensing of game hunting.

In the period from May 2006 to May 2007, large numbers of Sukuma agro-pastoralists and Taturu and Barabaig pastoralists and their livestock were evicted from the Usangu plains in the Mbarali district, Mbeya region (IWGIA, 2008). It is reported that most have now moved to Kilwa and Lindi districts. It is estimated that more than 400 families and 300,000 livestock were involved in this move, and that a large number of livestock died or were lost in the process. The same action was taken against the fisherfolk of the Usangu wetland, including the impounding of bicycles and other belongings. Although some surreptitiously remain, most have returned to their villages and fields, dispersed throughout the Usangu basin.

This action has potentially reversed two opportunities for the management and sharing of environmental services and benefits. The first is that taxes on livestock and meat sales through the Mbarali town livestock market generated an estimated 52% of district council income in 1998 (livestock taxes generated US$0.2 million; SMUWC, 2001). Then, as now, there appears to be no contingency plan in place to suggest how such an income foregone might be compensated for.

Second, the removal of wetland livestock keepers and fisherfolk precludes the establishment of a co-management plan for the Usangu wetland. Such a plan could have allowed local people to stay in the area in return for channelling and directing water flows through the wetland in order to ensure a small dry-season flow at the exit of the wetland. Calculations show that an exit flow of 0.5 $m^3/s$ could be generated by a reduction in the dry-season wetland area of approximately 10% (McCartney *et al.*, 2007). A co-management plan would then generate environmental benefits for the district council, the Ruaha National Park and local people. Although this idea has been proposed to local stakeholders since the year 2000, sadly there has been little sign of its uptake.

### Summary

Thus, in summary, the upper Great Ruaha has experienced new and changed 'drivers' of water abstraction: increasing area of irrigation in both wet and dry seasons, a rising number of irrigation intakes, and a shift in the design of irrigation intakes from traditional to an 'improved' (but conventionally designed) intake. This has led to a variety of symptoms of problematic water sharing, declining downstream flows and a rise in competition over water. Associated with these trends have been a number of governmental and non-governmental interests in the region, which, among other discourses of natural resource governance, focused on interventions that first helped to drive up water abstraction from rivers for irrigation and, second, attempted to redress the balance of supply between agriculture and downstream needs.

## Interactions and Competition

### Introduction

In this section, we explain some of the other interactions and conflicts found in the upper Great Ruaha, taking the opportunity also to explore the political construction of upstream scarcity to explain electricity shortages, and to briefly outline the three concepts that appear to be central to understanding how the basin might be managed.

### Hydropower claims for upstream water

Here, we explore the 'water scarcity' claims by the representatives and allies of Mtera–Kidatu of overuse of upstream water. A series of analyses demonstrates that despite claims by power-generation authorities, the power cuts experienced from 1992 onwards were largely due to improper dam operation and not to upstream depletion of water – put simply, low water levels at Mtera have recurred almost every year, regardless of the year being dry or wet.

In 1992 and 1994, the Mtera reservoir experienced water shortages for the first time since commissioning and, consequently, TANESCO was forced to impose electricity rationing, with serious consequences for the country's production and economy. Reflecting its unexpected suddenness, there have been controversies over the causes of the low water level. The scantiness of existing data often meant that their interpretation became informed by the partisan interests. It was argued, often via the national press, that the power cuts and water shortages were caused by droughts or by upstream water use and other impacting activities. The activities accused were rice irrigation, deforestation and soil erosion in catchment areas, and valley-bottom agriculture along streams. However, other analyses pointed to the operation of the reservoir, as explained below.

In 2004, the situation became so critical that the Mtera reservoir was operated by utilizing the dead storage. The move was sanctioned by the government, despite advice to the contrary from the Rufiji Basin Water Office (RBWO) and the ministry responsible for water. In fact, the then Minister for Water and Livestock Development, on learning that there were low inflows and very little water in the Mtera reservoir, issued a decree that the power company should not use any more water from Mtera beyond the dead storage level. This announcement by the minister was not heeded. We do not have information regarding why this was the case, but one might assume that the government deemed power generation to be the more expedient decision.

Faraji and Masenza (1992) carried out a hydrological study for the Usangu plains. They compared monthly and annual flow volumes entering during the years 1989–1992 and found that the amounts that went into the reservoir were within the magnitude of the range of the long-term mean. They concluded that, although irrigation had increased over the years, its effects did not show up in the volumes that went into the Mtera reservoir. They suggested the combined management of the two reservoirs was an important dimension, given that, although irrigation was not invoked as a problem during the period 1980–1988, critically, there was no power generation facility at Mtera.

A DANIDA/World Bank study (1995) analysed 30-year annual flows of the Great Ruaha. The results also gave no evidence either of a trend towards decreased runoff from the basin or of any aggravating impact on the droughts in 1965/67, 1975/77, 1981/82 and 1991/92. They were unable to link upstream activities directly with decreasing water levels in Mtera.

Investigations and analyses conducted by SMUWC (2001) revealed that, although there was widespread and significant abstraction of water for irrigation in the Usangu catchment, the critical impact period was in the dry season. However, volumetrically, most of the reservoir recharge occurs during a period of 3–4 months in the rainy season, and thus dry-season flows had always been very small and added little to the total flow. SMUWC argued that the Mtera reservoir receives most of its flow during the peak rainfall months, and power generation is dependent on the storage and management of that flow during the remaining, dry, part of the year. The study also refuted strongly held beliefs (Kikula *et al.*, 1996) that changes in rainfall and, in particular, deforestation were causes of reduced base flows of rivers flowing off the escarpment.

Since the commissioning of the Mtera reservoir, there have been enormous changes in both the demand and supply of electricity in the country, not adequately adapted to by the dam operators. The mismanagement of water in the Mtera–Kidatu system was confirmed by a further study on the system. Yawson *et al.* (2003; see also Machibya *et al.*, 2003) investigated possible causes for the failure of the Mtera–Kidatu reservoir system within the Rufiji River basin in Tanzania in the early 1990s. Application of the TALSIM model (Froehlich, 2001) to the Mtera–Kidatu system revealed the presence of unaccounted for or unnecessary spillage from the reservoirs. They proposed that the core issue regarding the error-prone management of the Mtera–Kidatu system was that flows generated within the intervening catchment (i.e. the catchment between Mtera and Kidatu) were neglected, while simultaneously pursuing a policy to generate maximum power most of the time. Mtera should only generate power during the dry season, utilizing water being released to Kidatu. They concluded that if these rules (also recommended by the consultants, SWECO (1994)) were followed, then Mtera would not have gone dry in the 1991–1994 period. The validity of this assertion was tested with the TALSIM 2.0 model and an efficiency of 95% was achieved, indicating a very good correlation with the investigative techniques employed in the study.

### Parageoplastic behaviour

The salient feature of Usangu's parageoplastic behaviour is that the growth in rice area did not generate symptoms of downstream water shortages during the wet season but it did during the dry season. The total mean annual flow into the Ihefu under natural conditions is estimated to be approximately 3330 Mm$^3$. Currently, average annual water withdrawals are estimated to be approximately 820–830 Mm$^3$, just slightly more than the mean annual volume of evapotranspiration from the wetland (790 Mm$^3$) but less than the net loss (of approximately 390 Mm$^3$) once rainfall received by the wetland is taken into account. However, both the annual and dry-season volumes abstracted vary considerably from year to year, both in absolute terms and as a proportion of the flow. Hydrological analyses using linear regression confirm a statistically significant decreasing trend in dry-season flows (Fig. 8.7), based on the Student's t-test). While there is a downward trend in total annual flows over the same period, this is not statistically significant. Thus, while the basin witnessed the most visible changes in dry-season flows, the flow volumes during this period represent just a small proportion of the total annual flow (of approximately 6–10%).

The declining wetland area is also associated with the drying of the Great Ruaha River.

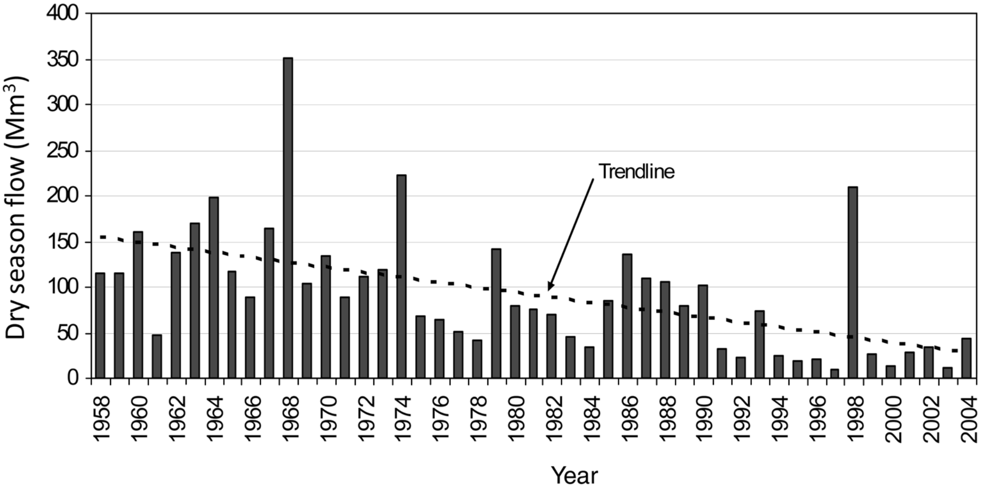

**Fig. 8.7.** Trend-line in dry-season flows in the Great Ruaha River at Msembe Ferry, plus rainfall (1987–2005).

Although systematic surveys have not been recorded, there is widespread agreement that the hydrological change has considerably altered the ecology of the park near the river. Lack of water directly caused the death of hippopotami, fish and freshwater invertebrates, and disrupted the lives of many others that depend on the river for drinking water. The WWF reports that freshwater oyster populations have disappeared from the river, along with the clawless otters that lived on them. It is estimated that for animals that must remain within 1 km of water to survive (e.g. buffalo, waterbuck and many waterbirds), the lack of water has reduced the dry-season habitat by nearly 60% (Coppolillo *et al.*, 2004). The movement of animals outside the park in search of water has led to increasing conflict with local human populations and the death of some animals. Overcrowding of hippopotami in shrinking water pools has led to eutrophication and anoxic water, as a result of which many animals have succumbed to infectious diseases (Mtahiko *et al.*, 2006).

To summarize, the parageoplastic connection between upstream irrigation and downstream shortages in the Ruaha National Park arose from excessive abstraction of water through an increasing number of modernized intakes in the dry season. Although the area of dry-season irrigation was measured by SMUWC at approximately 5000 ha, large amounts of water were abstracted inadvertently through concrete intakes and ‘spilled’ on to fields that had been cultivated but harvested by that time, leading to unproductive evaporation. The presence of wet-season rice combined with modernized intakes appeared to increase the total length of the season of abstraction. Thus the rice-irrigating season has increased from approximately 150–200 days, observed by Hazel and Livingstone, to 250–350 days, seen in the last decade.

## Non-equilibrium behaviour and basin governance

The second basin behaviour revealed by the case study is the inter-annual swing in the rice cultivated area, from approximately 20,000 to 40,000 ha, also mirrored in individual farmed areas, which change from a fraction of a hectare in a dry year to many hectares in a wet year. A second intra-annual fluctuation takes place when the wet-season area cultivated shrinks to approximately 3000–5000 ha during the dry season, seen as a core area made possible by the perennial rivers found on the plains.

Figures 8.2, 8.3 and 8.6 show this dynamic in various ways. The considerable change in cultivated area is forced by three factors: (i) a highly varying river flow; (ii) a large amount of irrigable land on the plains; and (iii) the ability of a large number of intakes to abstract more water when the rivers increase in supply, up to a cap set by the limitations of the intake dimensions. The dynamic is termed 'non-equilibrium' because it establishes an environment that does not lend itself to predictable regulatory water management, thus providing a remarkably different context in which to frame and formulate irrigation planning. This contrast between equilibrium and non-equilibrium thinking is captured in Table 8.3.

Table 8.3 proposes that marked contextual differences exist between equilibrium and non-equilibrium irrigation and water management. The key issue is how the management of the plateau part of the river-basin development curve is theorized (assuming that in the earlier stages of development, supply outstrips demand in both equilibrium and non-equilibrium contexts). For example, in equilibrium basins (or basins deemed to behave within predictable parameters) supply can be raised by adding storage, and demand management is fostered through regulatory and price-based reforms. In non-equilibrium basins, while these measures might apply in theory and be adopted in practice, their intended outcomes of creating further headroom are either limited or unpredictable. Thus, in a basin where the upward potential for unmet demand is so large (e.g. say because of irrigable land), additional storage may not bring intended equitable benefits for all users if the distribution of that additional water is not governed adequately or hard-wired into the infrastructure. The use of normative irrigation planning procedures in widespread use (FAO, 1998) can lead to designs of abstraction headworks that significantly desiccate catchments during the dry season when river flows are negligible (Lankford, 2004b). Furthermore, demand management in a basin where demand already 'crashes' due to a natural supply deficit must also be carefully considered.

Particular dimensions of the River Basin Management Project (the RBM component of RBMSIIP) applied to the non-equilibrium Usangu basin throw light on the ill-considered design of the project. The Rufiji Basin Water Office (RBWO), supported by RBMSIIP, designed a water rights system (see also MWLD, 2002) in order to effect regulatory demand management, which was wholly unsuitable for the basin for a variety of reasons (van Koppen

**Table 8.3.** Comparing equilibrium and non-equilibrium irrigation and river basin governance.

| | Equilibrium | Non-equilibrium |
|---|---|---|
| Observation | Irrigation area and demand for water are fixed within limitations | Irrigation area and demand for water vary widely with supply |
| Inter-annual area of irrigation | Fluctuates <100% | Fluctuates <1000% |
| Irrigable land | Constrained by planning, soil type, gradients or zoning restrictions | Large area of high potential land available |
| Climate | Tends to be temperate, tropical oceanic, which reduces water availability | Tends to be semi-arid with a high coefficient of variation of rainfall |
| Irrigation planning | FAO-type methodology for determining fixed/adjustable peak irrigation demand | Requires a river-centred approach allowing for proportional intakes |
| Water rights and permits | Defined by quanta (e.g. l/s) | Defined by proportions of river flow (%) |
| Basin development curve | S-shaped, rising to a stable plateau | S-shaped to high variable supply/ demand curve |
| Supply, demand, share management | Adding storage, applying demand management | Storage and demand management, share modification |
| River basin governance | Suggests normative forms of regulatory management | Suggests modular and localized models to meet local apportionment |

et al., 2004, 2007; Lankford and Mwaruvanda, 2007). The key reason the adopted system was faulty was its choice of a fixed quanta for a water right (e.g. 250 l/s). This specified flow rate implied that the water abstracted into an irrigation system in the Usangu would be measured. Yet, with the exception of the Mbarali intake and occasional record keeping at the Kapunga intake, no intake is monitored in this fashion, principally because there is no evidence for the existence of flow measurement structures.[7] The consequences of this are that farmers do not regulate (throttle back) their abstraction when they exceed their water right, in terms of either discharge or annual volume. For abstraction during the wet season, it should be noted that many intake dimensions do not correspond with the formal entitlement, either in the initial design stage or by further flow calibration (Rajabu and Mahoo, 2008). It should also be stated that the water rights are not calculated systematically using any meaningful algorithm – not least because command areas fluctuate and an excessively high rice water duty of 2.0 l/s/ha is widely employed. Studies by SMUWC (2001) found that the water duty was closer to 1.0 l/s/ha because irrigation is mostly supplemental to the 600 mm or so of annual rainfall. Thus, having paid their water right, there is no mechanism for farmers not to exceed their right. This situation becomes untenable in the dry season, when river flows are a tenth or less of their wet-season flows, leading to officially sanctioned water rights and concrete intake designs that far exceed the actual water available. Indeed, the hydrological conditions in which water rights might apply accurately in combination with other water rights on a stretch of river to cumulatively add up to an irrigation sector cap (therefore giving rise to a surplus for downstream needs) are statistically quite rare because the river fluctuates markedly above or below the level at which demands were calculated. At most, the system can be employed administratively as a record of intakes, names and owners.

Managing the allocation of water in different contexts also suggests a rethink, given that normative regulation is questionable in a non-equilibrium context. To explain this, a new dimension to water allocation – share modification – is explored in the next section.

### Share modification

Modification describes implicit and unintended contemporaneous changes in the share of water between users or sectors as a result of a changing supply being modulated by existing institutional and infrastructural architecture (Lankford, forthcoming). Thus, while ‘allocation’ applies to longer-term applications of intersectoral sharing, or where an equilibrium climate (e.g. oceanic, temperate) exists, modification of shares of water has greater relevance to non-equilibrium, pulse-driven semi-arid climates. The upper Great Ruaha case study shows that when supply variability is marked, leading to greater amplitude of hydrological events, and abstraction infrastructure is ‘fixed’, share modification and its management become more important. Here, a variable water supply (where supply increases or decreases over orders of magnitude within relatively short periods of time) ‘forces’ disproportionate shifts in usage in different sectors, depending on how users differentially abstract an increasing or decreasing rate of supply. This can be seen as a modification of the supply variability upon the proportions of shares to users and intakes.

Share modification is best explained via the case study typical of the Mkoji subcatchment in the Usangu, where an intake of say 250 l/s continues to abstract that fixed amount in the face of a declining river flow supply. Thus, if the flow rate declines from a peak of about 3000 l/s during the wet season down to about 50 l/s during the dry season, the 250 l/s abstraction leads to a concomitant reduction in downstream supply, and eventually to a zero flow. This behaviour contrasts with a proportional abstraction, where the intake takes might be redesigned to abstract a percentage of whatever flow is present, so that the surplus percentage flows downstream. It is the application of many intakes in the Usangu with fixed abstraction design parameters that leads to an uneven allocation of water between upstream irrigation and the downstream wetland during the end of the wet season, which runs into the dry season.

Another interesting example of share modification that influences water distribution between the wetland and the downstream riverine stretch through the Ruaha National

Park arises via the natural rock outcrop that holds back the wetland water, leading to zero flows in the river when the water level drops below the sill level. The SMUWC and the WWF Ruaha projects both considered that installing a weir or a pipe with an adjustable sluice gate would enable more water to be held back in the wetland and also provide some controllability of distribution of environmental flows. This type of infrastructure provides additional levels of proportionality to an otherwise on/off system.

## Conclusions

In the last 60 years in the Great Ruaha basin, modernist and progressive narratives regarding water development and conservation have reified into local and external donor initiatives and projects. The period 1950 to the mid-1980s was marked by an expansionist, developmental narrative, resulting in the construction of formal irrigation systems with large engineered headworks to abstract river water. While we might not judge harshly those decisions taken, given the era in which they were formulated, we can be much more critical about a continuing and related set of ideas around regulatory, efficiency and technological improvement approaches to river basin management that have contemporary significance. From the last quarter-century to the current day, we see that ideas of irrigation headworks' construction are still promulgated as a part of an 'efficiency' and volumetric water rights narrative, resulting in an era of contested solutions in attempting to balance allocation between multiple calls on limited water.

An unforeseen complex set of interlinked dynamics has emerged as a result of evolving abstraction and depletion of water in this highly variable river basin. Upstream access to water was further captured by irrigated agriculture, partly led by state interventions such as publicly owned schemes and donor-funded improvement programmes using justifications based on intake upgrading and irrigation efficiency, resulting in inequitable and inefficient allocation across the river basin, and the prompting of new behaviours downstream as downstream users react to non-local, internal and external hydrologic perturbations.

Using three ideas, we have critiqued the efficiency and water management found in the Great Ruaha catchment. In studying the responses of users along these interlinked river sub-basins the authors coined the term 'para-geoplasia' to explore how distant symptoms and behaviours arise from non-local depletion. Simply put, headwork designs that aimed to regulate upstream water abstraction during the wet season led to unforeseen dry-season para-geoplastic impacts some 50–300 km further north in the wetland and the Ruaha National Park.

Using ideas of non-equilibrium water theory, we see that attempts to use fixed volumetric water rights to regulate flows in an environment where flows vary weekly, monthly and seasonally through several orders of magnitude were also misplaced. Instead, proportional water rights and headwork structures should be regarded as a starting point for upstream–downstream water allocation and distribution.

Related to this, water-share modification contrasts further the differences between equilibrium and non-equilibrium environments. Share modification describes the differential uneven apportionment of water to intakes sequenced on a river as a result of the interaction between a declining or increasing flow rate over time and the design parameters of the headworks. A series of proportional intakes would result in a more even distribution of water shares than a series of fixed or regulated orifice intakes, with a percentage of flow designed to pass downstream to the wetland.

How do these ideas relate to river basin development? They underline the high level of interconnectedness between differing subsystems behaving in unforeseen ways in different periods of the hydrological calendar. In particular, theories that underpin water resources development during a growth phase of a river basin (in this case headworks designed using unrealistic water duties supported by standard irrigation design methodologies) might store up problems for governing water during the plateau phase of a river basin's development. Additional signals of wet and dry periods bring a variable supply of water to a basin, which imposes further challenges in the management of demand and allocation. If the plateau phase is not stable or varying within predictable peaks and troughs, but is highly dynamic, then demand management has to be rethought, because the basin is more driven by a non-equilibrium collapse of demand with supply. This, in turn, means that the basin, in the absence of large-scale storage or groundwater, has to welcome expansion of demand during wet years but facilitate a contraction of demand across all users during dry periods. In a maturely developed basin such as the upper Great Ruaha, these effects and behaviours point significantly to proportional water rights and infrastructure as the key departure point for managing surface water flows, combined with domestic provisioning for dry periods.

A key problem is nevertheless the vexed issue of how to cap an upper limit of irrigation abstraction during wet seasons so that water passes downstream for other sectors. While an individual proportional intake can be designed with an upper flow limit, the problem of growth of the number of intakes, seen in the recent past, remains a risk in the future, regardless of the approach to individual intake design. The RBWO is considering an approach which provides a single volumetric water right to a subcatchment (acting as the volumetric cap) so that the user association decides how to share this out among users. With this in place, it will then be necessary to revisit a catchment's intakes to ensure that intra-intake shares are coordinated and that the catchment as a whole provides a downstream proportion during times other than the wet season. A fuller explanation of an approach to volumetric and proportional caps is given in Lankford and Mwaruvanda, 2007. It is not yet clear how this will be fully adopted by Usangu farmers and supported by local government services.

Thinking wider afield and more generically, our ability to select governance theories for future phases of the basin trajectory in different types of basins will be paramount, not least because basin interconnectedness will grow, uncoordinated experimentations with storage and river infrastructure will continue, and hydrometeorological extremes – and transitions between those extremes – may become more commonplace in sub-Saharan Africa.

## Notes

1 This word is coined from Greek: 'para' meaning beyond, 'geo' meaning earth or land, and 'plasia' meaning something made or formed. The term is inspired by the concept of 'paraneoplasticity', derived from medical research into cancer, which describes how, in the body, other cancer-related tumours start to occur remotely from the first and main tumour.

2 There is not enough room to describe in detail the productivity analyses of water conducted by the RIPARWIN (Raising Irrigation Productivity and Releasing Water for Insectoral Needs) project, which was funded by DfID (UK Department for International Development) and succeeded another DfID-funded project, SMUWC (Sustainable Management of the Usangu Wetland and its Catchment). But it is worth mentioning that productivity is highest for localized livelihoods supported by livestock, brick-making and domestic uses, averaging at around US\$1.00/m$^3$ of depleted water (Kadigi et al., 2008). In addition, the productivity of irrigated rice (US\$0.02/m$^3$ of water abstracted) can be compared with the value of water when it is used to generate and sell electricity – generating about ten times the amount, or US\$0.2/m$^3$.

3 The runoff coefficient for the basin was calculated by SMUWC (see Note 2). It studied three time windows in its hydrological analysis; pre-1974, 1974–1985 and 1986–1998. The runoff coefficient for the first window is 14%, while it is 9% for the second window and 13% for the third window. If the heavy flooding years of 1998 and 1968 are excluded from calculations, then the resulting runoff coefficients are 12, 9 and 10%, respectively, for the three windows.

4 The paper by Mtahiko has a number of errors in it, including citing the SMUWC study for asserting that upstream irrigation resulted in less water for hydropower.

5 Recently, the World Bank (2007) has upgraded its assistance to Tanzania with a US\$200 million Water Sector Support Project.

6 See www.friendsofruaha.org

7 Flow can be measured from the properties of the intake flume combined with knowledge of the head difference of water levels, taking the long-crested weir sill height as a datum. In reality, flow-gauging plates are not installed or monitored.

## References

Carnell, J., Lawson, J.D., von Lany, H. and Scarrott, R.M.J. (1999) Water supply and demand balances: converting uncertainty to headroom. *Journal of the Chartered Institution of Water and Environmental Management* 13(6), 413–419.

Coppolillo, P.B., Kashaija, L., Moyer, D.C. and Knap, E. (2004) *Technical Report on Water Availability in the Ruaha River and State of Usangu Game Reserve, November 2003*. Wildlife Conservation Society and WWF-Tanzania Program, Tanzania.

DANIDA (Danish International Development Agency)/World Bank (1995) Water resources management in the Great Ruaha basin: a study of demand driven management of land and water resources with local level participation. A report prepared for the Rufiji Basin Water Office, Ministry of Water, Energy and Minerals. DANIDA, Ministry of Foreign Affairs of Denmark, Copenhagen/World Bank, Washington, DC.

Donkor, S.M.K (2003) Development challenges of water resource management in Africa. *African Water Journal* 1–9. UN Water/Africa. Pilot Edition.

FAO (Food and Agriculture Organization of the United Nations) (1961) *The Rufiji Basin, Tanganyika*. FAO report to the government of Tanganyika on preliminary reconnaissance survey of the Rufiji basin. FAO, Rome.

FAO (1998) *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56. FAO, Rome.

Faraji, S.A.S. and Masenza, I.A. (1992) *Hydrological Study for the Usangu Plains with Particular Reference to Flow Entering the Mtera Reservoir and Water Abstractions for Irrigation*. Ministry of Agriculture and Livestock Development, Irrigation Division, Dar es Salaam, Tanzania.

Froehlich, F. (2001) Application of the TALSIM 2.0 model on the Mtera–Kidatu reservoir system in the Rufiji River basin in southern Tanzania. Research undertaken at the University of Dar es Salaam, Tanzania and submitted to the Technical University of Darmstadt, Germany. (www.ihwb.tu-darmstadt.de/ihwb/c-vertiefer/Froehlich/vertiefer-Froehlich.html)

Hazelwood, A. and Livingstone, I. (1978a) *The Development Potential of the Usangu Plains of Tanzania*. Commonwealth Fund for Technical Cooperation, The Commonwealth Secretariat, London.

Hazelwood, A. and Livingstone, I. (1978b) Complementarity and competitiveness of large- and small-scale irrigated farming: a Tanzanian example. *Oxford Bulletin of Economics and Statistics* 40(3), 195–208.

IWGIA (International Work Group for Indigenous Affairs) (2008) Eviction of pastoralists from Usangu plains, Tanzania. www.iwgia.org/graphics/Synkron-Library/Documents/Noticeboard/News/Africa/2008/Memo%20Usangu%20Plains.all.pdf. Accessed 5th July 2008.

JICA (Japan International Cooperation Agency) (2001) *The Study on the National Irrigation Master Plan in the United Republic of Tanzania*. Japan International Cooperation Agency, Ministry of Agriculture and Food Security, Government of Tanzania, Dar es Salaam, Tanzania.

Kadigi, R.M.J., Kashaigili, J.J. and Mdoe, N.S. (2003) The economics of irrigated paddy in Usangu basin in Tanzania: water utilization, productivity, income and livelihood implications. 4th WARFSA/Waternet Symposium. Gaborone Botswana, 15–17 October 2003.

Kalinga, G., Simba, A.H. and Temu, R.J.M. (2001) National Irrigation Development Plan – Update. In: *Proceedings of the 1st National Irrigation Conference, Morogoro, Tanzania, 20th to 22nd March 2001. Theme: 'Irrigated Agriculture for Food Security and Poverty Reduction', Vols I and II*. Ministry of Agriculture and Food Security, Dar es Salaam, Tanzania.

Kashaigili, J.J., McCartney, M.P., Mahoo, H.F., Lankford, B.A., Mbilinyi, B.P., Yawson, D.K. and Tumbo, S.D. (2006) *Use of a Hydrological Model for Environmental Management of the Usangu Wetlands, Tanzania*. IWMI Research Report 104. International Water Management Institute, Colombo, Sri Lanka.

Kikula, I.S., Charnley, S. and Yanda, P. (1996) *Ecological Changes in the Usangu Plains and their Implications on the Down Stream Flow of the Great Ruaha River in Tanzania*. Research Report No. 99. Institute of Resource Assessment, University of Dar es Salaam, Tanzania.

Lankford, B.A. (2004a) Irrigation improvement projects in Tanzania; scale impacts and policy implications. *Water Policy* 6(2), 89–102.

Lankford, B.A. (2004b) Resource-centred thinking in river basins: should we revoke the crop water approach to irrigation planning? *Agricultural Water Management* 68(1), 33–46.

Lankford, B.A. (forthcoming) Responding to water scarcity – beyond the volumetric. In: Mehta, L. (ed.) *The Limits to Scarcity: Contesting the Politics of Allocation*. Earthscan, London.

Lankford, B.A. and Beale, T. (2007) Equilibrium and non-equilibrium theories of sustainable water resources management: dynamic river basin and irrigation behaviour in Tanzania. *Global Environmental Change* 17(2), 168–180.

Lankford, B.A and Mwaruvanda, W. (2007) A legal–infrastructural framework for catchment apportionment. In: van Koppen, B., Giordano, M. and Butterworth, J. (eds), *Community-based Water Law and Water Resource Management Reform in Developing Countries*. Comprehensive Assessment of Water Management in Agriculture Series, CAB International, Wallingford, UK, pp. 228–247.

Lankford, B.A., van Koppen, B., Franks, T. and Mahoo, H. (2004) Entrenched views or insufficient science? Contested causes and solutions of water allocation; insights from the Great Ruaha River basin, Tanzania. *Agricultural Water Management* 69(2), 135–153.

Lankford, B.A., Merrey, D., Cour, J. and Hepworth, N. (2007) *From Integrated to Expedient: an Adaptive Framework for River Basin Management in Developing Countries*. Research Report 110. International Water Management Institute. Colombo, Sri Lanka.

Machibya, M. (2003) Challenging established concepts of irrigation efficiency in a water scarce river basin: a case study of the Usangu basin, Tanzania. PhD thesis, University of East Anglia, Norwich.

Machibya, M., Lankford, B. and Mahoo, H. (2003) Real or imagined water competition? The case of rice irrigation in the Usangu basin and Mtera/Kidatu hydropower. In: *Proceedings of the Tanzania Hydro-Africa Conference, 17–19 November 2003, at Arusha International Conference Centre, Arusha, Tanzania*. International Centre for Hydropower, Norway.

McCartney, M.P., Lankford, B.A. and Mahoo, H.F. (2007) *Agricultural Water Management in a Water Stressed Catchment: Lessons from the RIPARWIN Project*. Research Report 116. International Water Management Institute. Colombo, Sri Lanka.

McCartney, M., Kashaigili, J.J., Lankford, B.A. and Mahoo, H.F. (2008) Hydrological modelling to assist water management in the Usangu wetlands, Tanzania. *International Journal of River Basin Management* 6(1), 51–61.

Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P. and Stouffer, R.J. (2008) Stationarity is dead: whither water management? Policy Forum. *Science* 319(5863), 573–574.

Moirana, L. and Nahonyo, C.L. (1996) Why the Usangu plains should be an environmentally protected area (Usangu Game Reserve). Internal Report. Ruaha National Park, Tanzania National Parks, August 1996.

Molden, D. (1997) *Accounting for Water Use and Productivity*. SWIM Paper 1. International Irrigation Management Institute (now International Water Management Institute), Colombo, Sri Lanka.

Molden, D., Sakthivadivel, R. and Habib, Z. (2001) *Basin-level Use and Productivity of Water: Examples from South Asia*. Research Report 49. International Water Management Institute, Colombo, Sri Lanka.

Molden, D., Sakthivadivel, E., Samad, M. and Burton, M. (2005) Phases of river basin development: the need for adaptive institutions. In: Svendsen, M. (ed.) *Irrigation and River Basin Management: Options for Governance and Institutions*. CAB International, Wallingford, UK, pp. 19–29.

Molle, F. (2003) *Development Trajectories of River Basins: a Conceptual Framework*. Research Report 72. International Water Management Institute, Colombo, Sri Lanka.

Mtahiko, M., Gereta, E., Kajuni, A., Chiombola, E., Ng'umbi, G., Coppolillo, P. and Wolanski, E. (2006) Towards an ecohydrology-based restoration of the Usangu wetlands and the Great Ruaha River, Tanzania. *Wetlands Ecology and Management* 14(6), 489–503.

Mutayoba, W. (2002) Management of water resources in Tanzania through basin management. In: *Proceedings of 3rd WATERNET/WARFSA Symposium: Water Demand Management for Sustainable Development 30–31 October 2002*. WaterNet, Dar es Salaam, Tanzania.

MWLD (Ministry of Water and Livestock Development) (2002) *National Water Policy (NAWAPO)*. Ministry of Water and Livestock Development, P.O. Box 456, Dodoma, Tanzania.

NORPLAN (Norwegian Consulting Engineers and Planners) (2000) *Review of Water Resources Management Policy, Legislation and Institutional Framework. River Basin Modelling*. Norwegian Consulting Engineers and Planners. Ministry of Water, Tanzania.

Palmer-Jones, R. and Lankford, B.A. (2005) Agricultural development: reflections on the study of the irrigation potential of the Usangu plains of Tanzania. In: Tribe, M., Thoburn, J. and Palmer-Jones, R. (eds) *Development Economics and Social Justice. Essays in Honour of Ian Livingstone*. Ashgate. Aldershot, UK, pp. 141–158.

PINGOs (Pastoralists Indigenous Non-Governmental Organisation's Forum) (2006) Resource mis-management and the misery of pastoralists in Usangu basin. A draft baseline report of the fact finding mission on proposed eviction of livestock keepers submitted to members of Pastoral Civil Society Organisations, Arusha, Tanzania, April, 2006. http://pingosforum.org/Docs/usangu_research_report.pdf (accessed 5th July 2008).

Rajabu, K.R.M. and Mahoo, H.F. (2008) Challenges of optimal implementation of formal water rights systems for irrigation in the Great Ruaha River catchment in Tanzania, *Agricultural Water Management* 95(9), 1067–1078.

Rajabu, K.R.M., Mahoo, H.F., Sally H. and Mashauri, D.A. (2005) Water abstraction and use patterns and their implications on downstream river flows: a case study of Mkoji sub-catchment in Tanzania. In: Lankford, B. and Mahoo, H.F. (eds) *Proceedings of the East Africa Integrated River Basin Management Conference*, 7–9 March 2005, ICE Conference Hall, Sokoine University of Agriculture, Morogoro, Tanzania, pp. 233–245.

SMUWC (Sustainable Management of the Usangu Wetland and its Catchment) (2001) *Final Project Reports*. Directorate of Water Resources, Ministry of Water, Government of Tanzania, Dar es Salaam, Tanzania.

Sullivan, S. and Rohde, R. (2002) On non-equilibrium in arid and semi-arid grazing systems. *Journal of Biogeography* 29(12), 1595–1618.

SWECO (1994) *Follow up Study of the Environment at Mtera Reservoir and Region – Hydrology Draft Report*. SWECO AB, Stockholm, Sweden.

TANESCO (Tanzania Electric Supply Company Limited) (2008) Tanzania Electric Supply Company Limited (TANESCO) web site ‘Generation’. http://www.tanesco.com/ (accessed 6 April 2008).

TNW (Tanzania National Website) (2003) The 2002 population and housing census. Tanzania National Website. http://www.tanzania.go.tz/census/districts (accessed 24th July 2005).

USBR (United States Bureau of Reclamation) (1967) *Rufiji River Basin*. United States Bureau of Reclamation, Washington, DC.

van Koppen, B., Sokile, C., Hatibu, N., Lankford, B.A., Mahoo, H. and Yanda, P. (2004) *Formal Water Rights in Tanzania: Deepening the Dichotomy?* Working Paper 71. International Water Management Institute, Colombo, Sri Lanka.

van Koppen, B., Sokile, C., Lankford, B.A., Mahoo, H., Hatibu, N. and Yanda P. (2007) Water rights and water fees in Tanzania. In: Molle, F. and Berkoff, J (eds) *Irrigation Water Pricing: the Gap between Theory and Practice*. International Water Management Institute/CAB, UK, Wallingford, pp. 143–164.

Weatherhead, E.K. (2007) *The 2005 Irrigation Survey for England and Wales*. Report for Department for Environment, Food and Rural Affairs (DEFRA). Cranfield University, Cranfield, UK.

World Bank (1996) *River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP)*. Staff Appraisal Report, Washington, DC.

World Bank (2007) *Water Sector Support Project*. Project Appraisal Document, Washington, DC.

Yawson, D.K., Kashaigili, J.J., Mtalo, F.W. and Kachroo, R.K. (2003) Modelling the Mtera–Kidatu reservoir system to improve integrated water resources management. In: *Hydro Africa 2003*, CD Proceedings, 17–19 November, Arusha, Tanzania.