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RESEARCH REPORT

116

Agricultural Water Management in a Water Stressed Catchment: Lessons from the RIPARWIN Project

Matthew P. McCartney, Bruce A. Lankford and Henry Mahoo

International Water Management Institute

RIPARWIN
Raising Irrigation Productivity And Releasing Water for Intersectoral Needs
river basin management research in Tanzania

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Research Report 116

Agricultural Water Management in a Water Stressed Catchment: Lessons from the RIPARWIN Project

Matthew P. McCartney, Bruce A. Lankford and Henry Mahoo

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Cover photograph by Bruce Lankford shows inspection of the dried riverbed of the Great Ruaha River, at NG'iriama, Usangu Plains.

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Acronyms

AWUA	Apex Water Users Association
DFID	Department for International Development (UK Government)
DSS	Decision Support System
IMF	International Monetary Fund
MAF	Mean annual flow
MWLD	Ministry of Water and Livestock Development
NAFCO	National Agriculture and Food Corporation
NEPAD	New Partnership for Africa's Development
RBG	River Basin Game
RBMSIIP	River Basin Management and Smallholder Irrigation Improvement Project
RBWO	Rufiji Basin Water Office
RIPARWIN	Raising Irrigation Productivity and Releasing Water for Intersectoral Needs
RUBDA	Ruaha Basin Decision Aid
SMUWC	Sustainable Management of the Usangu Wetland and its Catchment
SWMRG	Soil Water Management Research Group
TANAPA	Tanzania National Parks
TANESCO	Tanzania Electricity Supply Company
WUA	Water User Association
WWF	World Wide Fund for Nature

Summary

This report presents the key findings of the research conducted in the RIPARWIN project: a multi-disciplinary investigation of water allocation and management in a water stressed catchment in Tanzania. The research, conducted over five years, demonstrated that: i) under certain circumstances, improving local irrigation efficiency is important because, by reducing non-beneficial losses, water can be liberated for other uses; ii) care is needed in the development of irrigation infrastructure intended to increase catchment level water productivity since, if inappropriately designed and managed, it can have the opposite effect; iii) economic efficiency is a necessary, but not sufficient, criteria for determining water allocation; iv) in situations where withdrawals are vital for livelihoods and poverty alleviation, it is not reasonable to plan to fully implement environmental flows and it may be necessary to manage trade-offs between different ecosystems; v) although care is necessary not to perpetuate past inequities, the effectiveness of contemporary approaches to water management may be improved if built on traditional arrangements which tend to be better suited to the livelihood strategies and social norms of local people; and vi) different types of decision support systems that improve understanding of system dynamics and facilitate social learning and dialogue can contribute to better water resource management. At a time when irrigation is being strongly promoted as a significant contributor to attaining the Millennium Development Goals, the findings are relevant to catchments in developing countries where there is competition for water and irrigation is one of the main uses.

Agricultural Water Management in a Water Stressed Catchment: Lessons from the RIPARWIN Project

Matthew P. McCartney, Bruce A. Lankford and Henry Mahoo

Introduction

Irrigation has an important role to play in contributing to food security and poverty alleviation. Consequently, many countries in sub-Saharan Africa are planning to increase irrigated agriculture as a contribution to attaining the Millennium Development Goals. The New Partnership for Africa's Development (NEPAD) has called for US$37 billion of additional investment in the agricultural sector by 2015 (NEPAD 2003). Similarly, the Commission for Africa proposed a doubling of the area of arable land under irrigation by 2015 (Commission for Africa 2005) and the World Water Development Report calls for "substantial increases in investment in rural areas, where water management plays a central role in raising the productivity of agriculture" (UNESCO-WWAP 2006). However, in situations of growing water stress[1] and with increasing awareness of the importance of environmental protection to ensure sustainability, the need for improved water resources management to secure and maximize the benefits from water, is widely recognized (e.g., Cosgrove and Rijsberman 2000; Hashimoto 2003).

Against this background, RIPARWIN (*Raising Irrigation Productivity and Releasing Water for Intersectoral Needs)* was a five-year action-research project, conducted to investigate water management in a water stressed catchment. The main purpose of the study was to test the premise that, in a catchment where agriculture is the principal anthropogenic use of freshwater, sufficient improvements in irrigation efficiency and productivity could be found to provide adequate water for other sectors and downstream needs.

The project comprised a multi-disciplinary study, investigating technical, economic, institutional and social aspects of water use and management in the Great Ruaha River, which is a tributary of the Rufiji River and, in terms of the national economy, is one of Tanzania's most important waterways. The primary focus of the project was the Usangu Plains, located in the headwaters of the basin. Since the mid-1990s the Great Ruaha River has ceased flowing in the dry season every year. This has occurred because water levels in a large wetland, located on the Usangu Plains, have dropped below a critical level and outflows from the wetland have ceased. The key questions that the research aimed to answer were:

- What flow is required downstream of the wetland and how much water needs to flow into the wetland to maintain this flow?
- What management interventions (both technical and non-technical) could be used to improve downstream flows?

[1] In this report, water stress refers to periodic water scarcity leading to competition between different users, shortfalls in some sectors and, in some places, environmental degradation.

- Is local irrigation efficiency an important factor and could it be improved to liberate sufficient water for downstream uses?
- What role should economic valuation of different water uses play in determining water allocation in the catchment?
- Is the recently introduced system of formal water rights and fees an effective mechanism for water management?
- How are different types of decision support system best used to improve water management and the decision-making process?

The Study Area

The Great Ruaha River has a catchment area of 83,979 square kilometers (km^2). The headwaters rise in the Poroto and Kipengere mountains, in southwest Tanzania, and drain through the broad alluvial plains of Usangu (Figure 1). The Usangu Plains, which cover approximately 4,480 km^2, are characterized by seasonally inundated grassland and permanent swamps, which are ecologically very important and support many livelihoods. The Great Ruaha River discharges from the Plains at a place called NG'iriama. The catchment area to this point is 21,500 km^2. At this location, a rock outcrop acts as a natural dam forming a permanent swamp upstream, known as the Eastern Wetland or *Ihefu*. About 30 kilometers (km) downstream of NG'iriama the river enters the Ruaha National Park. During the dry season (i.e., July to November) the river, which constitutes the southern boundary of the Park, is the major source of water for much of the wildlife. Further downstream the Great Ruaha River flows into the hydropower reservoirs of Mtera and Kidatu. The installed power generating capacity of these plants is 284 megawatts (MW), approximately half the total capacity of Tanzania (SMUWC 2001). Downstream of the Kidatu Reservoir, the Kilombero Sugar Company abstracts water from the river for irrigation and sugarcane processing (Hamerlynck 2001). Ultimately, the Great Ruaha River discharges into the Rufiji River. Hence, seven main users of water from the river, from upstream to downstream, can be differentiated:

- Farmers and domestic water users in the high catchment (i.e., uplands surrounding the Usangu Plains)
- Irrigators in the Plains
- Domestic users in 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
- Irrigators and sugarcane processors at the Kilombero Sugar plantation

Over the past 50 years, the population of the Usangu headwater catchment has risen steeply. Between 1950 and 2000, the population on the Plains increased from less than 50,000 to more than 210,000, largely through the in-migration of people from all over Tanzania. Most of these people are farmers, cultivating rainfed and irrigated plots, but a smaller number are pastoralists who have brought more cattle into the Plains. Over the same period the total irrigated area increased from approximately 5,000 to 45,000 hectares (ha) (Figure 2), although the exact area varies significantly from year to year (see section, *Irrigation on the Usangu Plains*). Between 1973 and 2000, the total area of bare soil and cultivation on the Plains and in the immediate vicinity, increased from 121,200 to 874,300 ha (Kashaigili et al. 2006a). The large influx of people and the increase in demand has led to increased competition and conflict over water, particularly in the dry season.

Historically, the Great Ruaha River was perennial; flow lasted throughout the dry season in all but the exceptionally dry years. However, since the early 1990s, water levels in the

FIGURE 1.
Map of the Great Ruaha River.

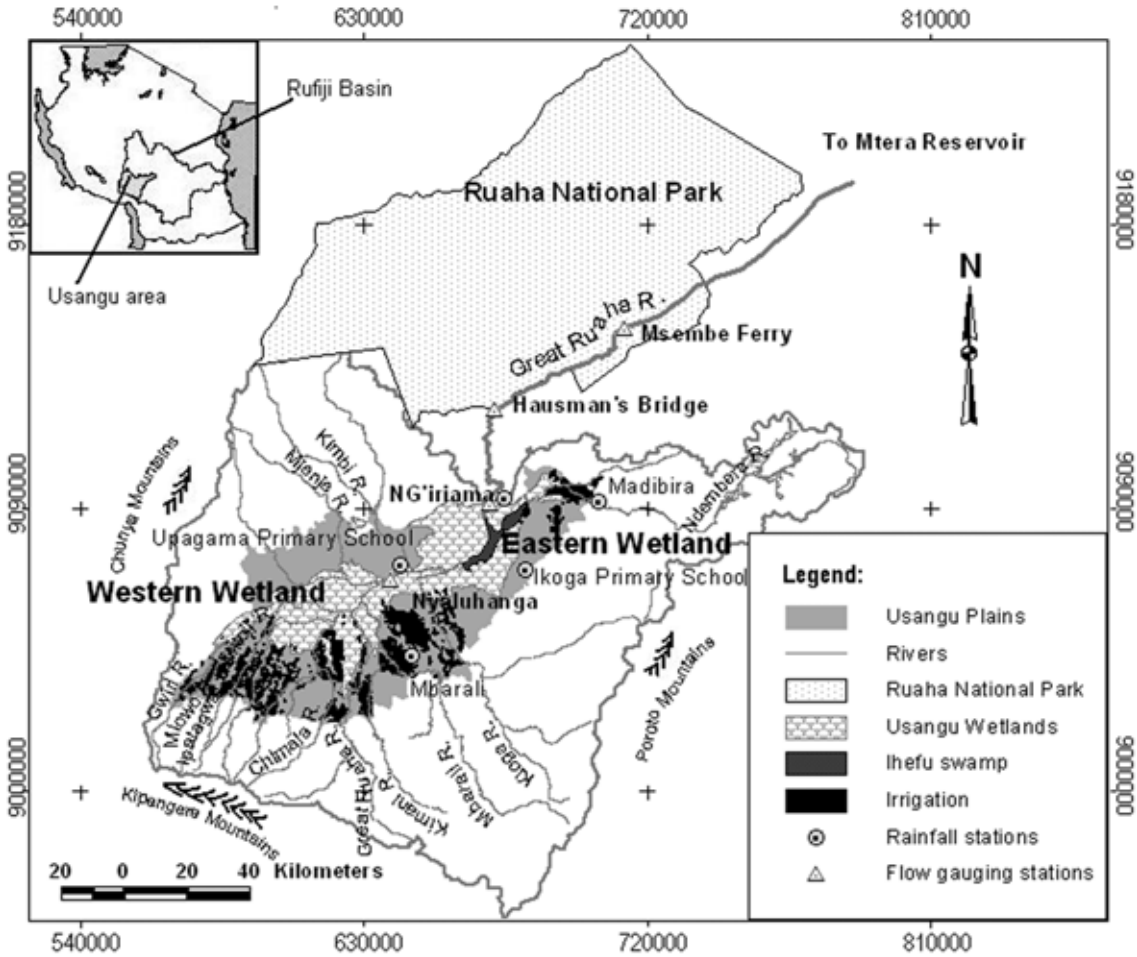
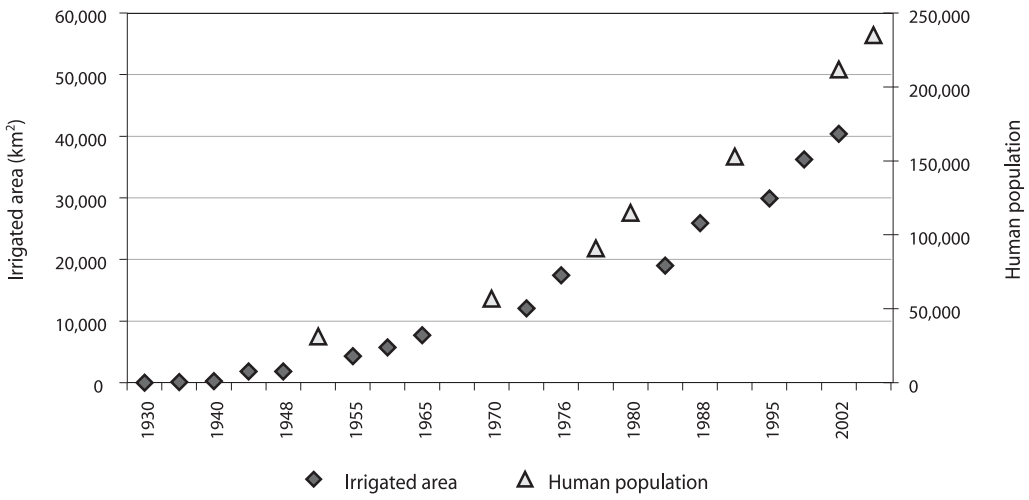


FIGURE 2.
Changes in population and the area under irrigation in and immediately surrounding the Usangu Plains (1930-2005).

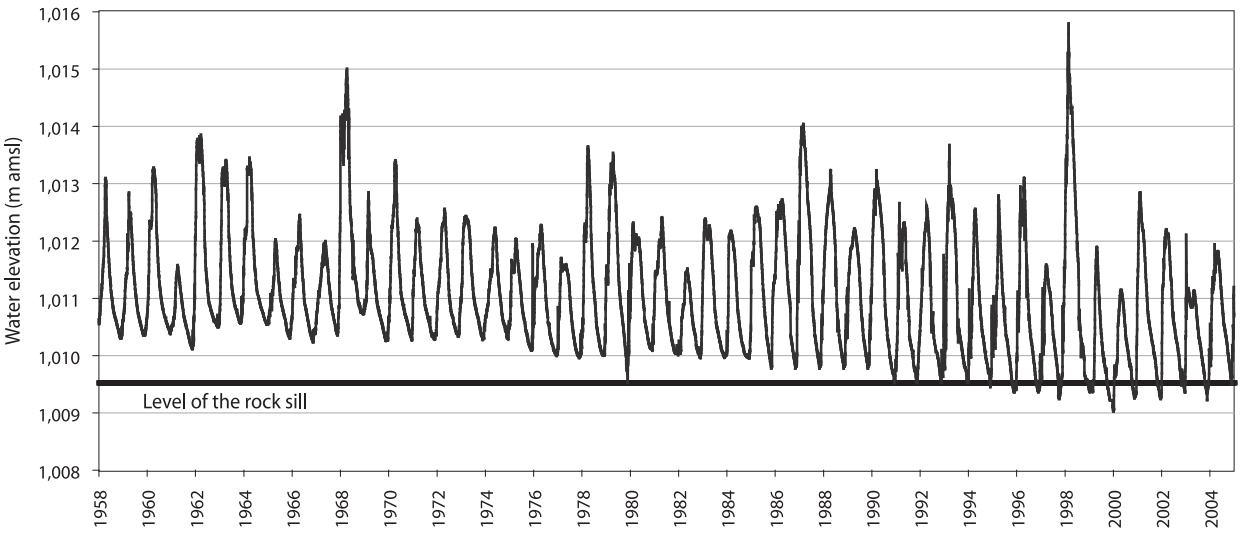


Source: SMUWC 2001; Hazelwood and Livingstone 1978; Franks et al. 2004; Tanzania National Bureau of statistics – population census.

Eastern Wetland have dropped below the crest of the rock outcrop (Figure 3) and consequently flows downstream of NG'iriama have ceased in the dry season every year. Analysis of flows measured at Msembe Ferry, a gauging station located approximately 80 km downstream of NG'iriama, indicate an increasing frequency and extension of low flow periods between 1958 and 2004 (Kashaigili et al. 2006b). Linear regression analyses confirm a statistically significant (based on student t-test (Helsel and Hirsch 1993)) decreasing trend in dry season flows (Figure 4a). There is also a downward trend in total annual flows over the same period but this is not statistically significant (Figure 4b). The fact that the trend in annual flows is not statistically significant can be attributed to the fact that the greatest changes are in dry season flows, but these represent just a small proportion of the total annual flow. Despite the fact that absolute volumes withdrawn in the wet season are much greater than in the dry season (see section, *Impact of Irrigation on River Flow*), wet season flows (which dominate the annual time series) do not show a statistically significant decline.

The drying up of the river coincided with power shortages in Tanzania, which the national power company, TANESCO, attributed to reduced dry season inflow to the Mtera and Kidatu reservoirs (Lankford et al. 2004a). Although this assertion was subsequently discredited[2], it was largely concerns over the need to safeguard power production, in conjunction with environmental concerns, that prompted the Government of Tanzania to promise to re-establish a "year-round flow" by 2010 (former Prime Minister, Mr. Frederick Sumaye, speaking at the Rio +10 preparatory meeting, 6th March 2001, London).

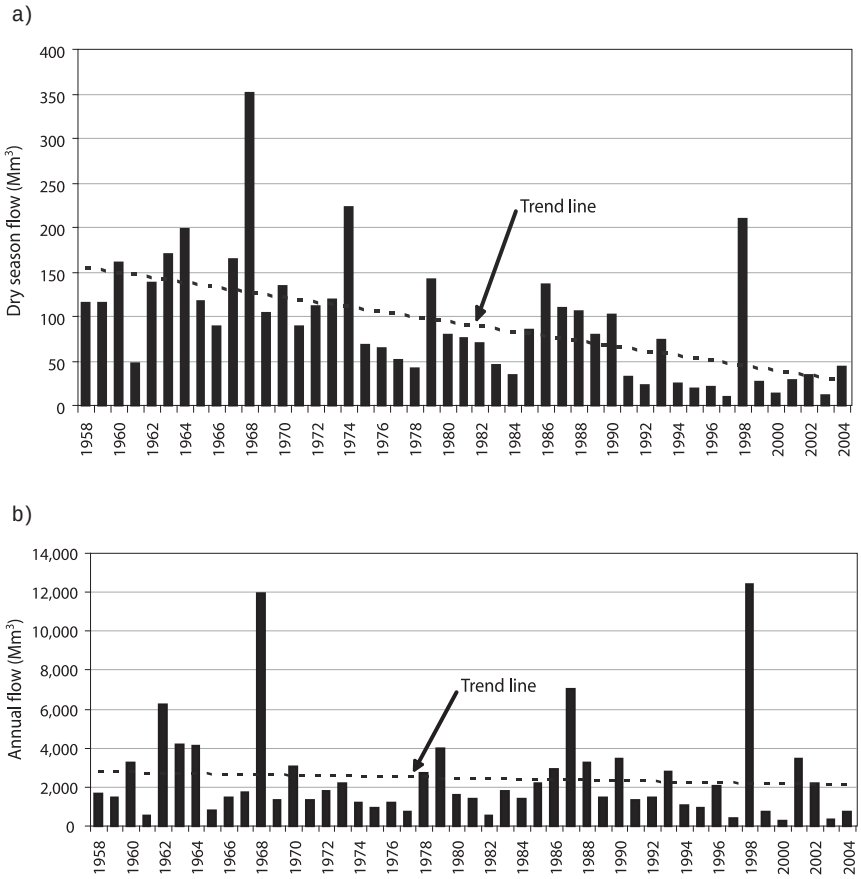
FIGURE 3.
Water levels at NG'iriama for the period 1958 to 2004.



Source: NG'iriama exit flow analyses (Kashaigili et al. 2006b).

[2] It is wet season flows, rather than dry season flows, which are critical for the hydropower production. The need to curtail hydropower production in the mid-1990s was attributed to mis-management of water stored for short-term economic gain (i.e., profit was placed before performance) (Yawson et al. 2003; Machibya et al. 2003) and perhaps for political reasons.

FIGURE 4.
Trends in a) dry season flows and b) annual flows, in the Great Ruaha River at Msembe Ferry, plus the rainfall and number of zero flow days in each year (1987-2005).



	Annual Rainfall (mm)	No. of zero flow days
1987/1988	858	0
1988/1989	598	0
1989/1990	631	0
1990/1991	577	15
1991/1992	599	21
1992/1993	663	12
1993/1994	868	27
1994/1995	565	43
1995/1996	792	71
1996/1997	444	98
1997/1998	756	22
1998/1999	477	0
1999/2000	187	33
2000/2001	365	21
2001/2002	643	37
2002/2003	353	53
2003/2004	477	45
2004/2005	580	20

Background to the Research

Faced with problems of water stress in the Rufiji and elsewhere, the Government of Tanzania embarked on a process of fundamental reforms in the water sector. This included the development of a new National Water Policy (MWLD 2002), which is largely founded on the Dublin Principles agreed at the International Conference on Water and the Environment (WMO 1992). It provides a framework for integrated management of water resources, adopting the river basin as the principal unit for management and regulation (Mutayoba 2002). The policy, underpinned by principles of sustainability and equity, embraces concepts such as full cost recovery, water rights and fees and stakeholder participation in water resources management (van Koppen et al. 2004).

Because of its importance to the national economy, the Rufiji Basin was selected as one of three in which the new policy and basic concepts would be pilot tested[3]. As part of this endeavor, the Ministry of Water and Livestock Development (MWLD) established the Rufiji Basin Water Office (RBWO) in 1993, with the mandate to oversee all matters concerning the development, management and regulation of

[3] The other two were the Pangani River and Lake Victoria Basin.

water resources in the basin. The mandate of the RBWO is to:

- Monitor the available water resources in the basin, using existing hydrometric stations and installing new ones where necessary.
- Enforce and follow-up on existing legislation and regulations governing water use and control of pollution.
- Issue, administer and collect water abstraction fees associated with issued water rights.
- Facilitate the establishment of lower level (catchment, sub-catchment and village level) water management organizations, which will bring together stakeholders of the same source.
- Assist in conflict resolution in water use, allocation and pollution control.
- Conduct research into basin water resources in collaboration with research partners.
- Institutionalize into statute relevant customary laws and practices.

In 1996, the River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP) was instigated with support from the World Bank. Based, to a large extent, on the premise that irrigation, and particularly smallholder irrigation, is extremely inefficient in its use of water, the aims of this program were to: i) at the national level, strengthen the government's capacity to manage water resources and address water-related environmental concerns; and ii) in the Rufiji and Pangani basins, to help fund the activities of the basin offices and improve the irrigation efficiency of selected smallholder irrigation schemes principally by the construction of concrete weirs and intake structures with control gates (World Bank 2004). On the Usangu Plains, the RBMSIIP constructed six concrete intake structures on streams shared by a number of traditional irrigation schemes.

A DFID-funded project, the Sustainable Management of the Usangu Wetland and its Catchment (SMUWC), was conducted between 1998 and 2001. The SMUWC project investigated the nature and causes of hydrological change in the Great Ruaha River, with the intention of assisting the Government of Tanzania and key stakeholders (both local and national) in the development of a sustainable natural resources management strategy. The project conducted a number of specialist studies, including: groundwater assessment, catchment degradation and conservation studies, water use and water rights surveys, participatory basin management and water quality and environmental monitoring (SMUWC 2001[4]). The study concluded that water abstraction, rather than deforestation or climate change, was the principal cause of cessation of flows downstream of the Ihefu.

Since 2003, the World Wide Fund for Nature (WWF) has been assisting the RBWO and other river basin management institutions through its Great Ruaha River Catchment Programme. The principal objective of the program is to develop an environmentally acceptable integrated water management plan for the catchment and to reduce inefficient and/or unsustainable catchment, and water use, management practices by suggesting suitable alternatives.

Following the SMUWC project, the RIPARWIN project, which ran from November 2001 to March 2006, continued the study of water resources management in the catchment, with the specific aim of gaining an understanding of water competition, management and productivity in the catchment and determining how the Government of Tanzania could keep its promise to restore the Great Ruaha River to a year-round flow by 2010. The research was conducted in five interlinked studies comprising: i) assessment of irrigation efficiency and productivity, ii) hydrological and environmental analysis, iii) economics and livelihood analysis, iv) assessment of the

[4] One author–Lankford–was the irrigation specialist on SMUWC.

effectiveness of water rights and fees, and v) development of decision support systems (DSS) to support water managers and increase stakeholder participation. Throughout the project, researchers collaborated closely with key institutions in the area, most notably the RBWO, the District Councils and WWF-Tanzania. This report comprises a summary of the research conducted and the project findings, supported by evidence from other studies, where appropriate. A number of generic lessons, distilled from the research, are presented.

Irrigation Management: Efficiency and Productivity

Worldwide, agriculture is the principal user of water in many places, so improving irrigation efficiency and productivity are widely perceived as key strategies towards mitigating local and regional water stress (UNESCO-WWAP 2006). However, in recent years there has been considerable debate about how increasing water productivity can be best achieved through the management of water resources. Issues of scale have been highlighted. In particular, the need to distinguish between crop water productivity (i.e., the crop produced per unit of water consumed) and basin water productivity (i.e., all forms of production relative to total depletion of water at the basin scale) has been emphasized.[5] In the latter case, the dilemma lies in allocating water among multiple uses and users. This requires value judgments on priorities. In the Great Ruaha River Basin, the focus has been on increasing local irrigation efficiency, and hence crop water productivity, by reducing 'non-beneficial' losses of water in irrigation, in order to 'free' water for downstream uses and users. As noted above, this was one of the key objectives, of the RBMSIIP, to be brought about through targeted investments in infrastructure and institutional reforms. It continues to be a principal aim of the RBWO.

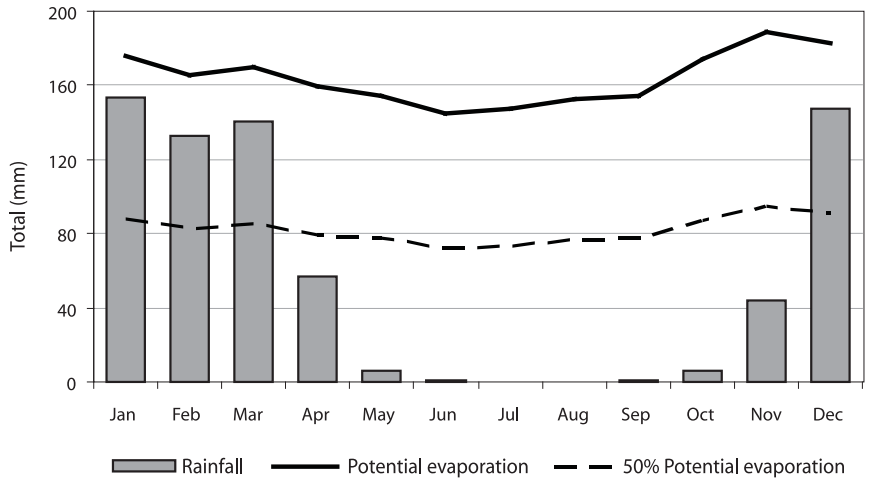
Irrigation on the Usangu Plains

The bulk of irrigation in the Great Ruaha River Basin is concentrated on the Usangu Plains. The rainfall regime is unimodal with a single rainy season from November to April. However, rainfall is irregular, highly localized and spatially varied. It is strongly correlated with altitude, with a mean annual rainfall of approximately 1,600 millimeters (mm) in the mountains and between 500 and 700 mm on the Plains. Mean annual Penman-Monteith potential evapotranspiration on the Plains is 1,970 mm and rainfall, typically, only exceeds 50 percent of potential evapotranspiration for the months of December to March (Figure 5). Consequently, rainfall conditions are not ideal for the growth of crops and irrigation is necessary to reduce the risk of water shortages. Mean annual temperature varies from about 18°C at higher altitudes to about 28°C in the lower and drier parts of the Plains.

Most irrigation is located on the southern side of the Plains (Figure 1). The maximum irrigated area in normal to wet years is approximately 44,500 ha, comprising 42,000 ha of rice and 2,500 ha of mixed crops, including maize, beans, vegetables and fruits. Irrigation water is abstracted from the five perennial rivers

[5] Classical irrigation efficiency is defined as the crop water requirement (actual evapotranspiration minus effective rainfall) divided by the water withdrawn or diverted from a specific water source. Losses in this case include evapotranspiration, but also seepage, percolation and runoff, processes in which the water is not consumed. The need to consider basin water productivity arises because the latter "losses" may be captured or recycled for beneficial uses (including the environment) elsewhere in the catchment (Kijne et al. 2003).

FIGURE 5.
Mean monthly rainfall and mean monthly potential evaporation over the Usangu Plains.



Source: Climate data provided by the Rufiji Basin Water Office (RBWO).

(i.e., Mkoji, Mbarali, Kimani, Chimala and Ndembera) as well as the large number of seasonal streams draining from the high catchment onto the Plains. Surface water is used in preference to groundwater because groundwater is less abundant in the area and its location, which is closely associated with permeable deposits and paleo-river channels, is difficult to predict (SMUWC 2001). There are approximately 150 river intakes in the Usangu area of which 121 are traditional diversion structures comprising brush weirs, stone and brick intakes, and sand and earth bags (Figure 6a). Most of these structures do not have gates and have little scope for adjusting the amount of water being abstracted. Many are washed away every year in the wet season. Twenty-six are modern concrete weirs, similar to those constructed in the RBMSIIP, with adjustable inlet gates (Figure 6b).

Between 1960 and 1990, ten large and medium scale irrigation schemes were developed with the assistance of donor agency grants. For many years these schemes were managed by a parastatal, the National Agriculture and Food Corporation (NAFCO). They have been privatized very recently, but throughout this report are known as NAFCO farms. The schemes, which are characterized by designed field layouts and modern intakes, range in size up to 3,200 ha. Many of the canals also provide domestic water to villages that have grown up within the schemes. On the Plains, in addition to these farms, there are smallholder farms which are located downstream. Initially developed without outside assistance, they comprise smallholdings in which rice is irrigated in small basins (locally called *vijaruba*). Thus, there are three types of smallholder farming systems:

- traditional smallholder: use traditional diversion structures.
- improved smallholder: either from new, as in the NAFCO farms, or by improving existing systems. Both use modern diversion structures, built by donor agencies and the RBWO.
- smallholder located downstream of the NAFCO farms.

Traditionally, rice irrigation occurred in the wet season (i.e., January to May) with rice being transplanted in a staggered pattern as water became available incrementally in downstream areas. However, the total irrigated area varied considerably depending on water availability. Smallholder farmers continue to be very flexible in their response

FIGURE 6.
Irrigation intakes a) “traditional” diversion structure, and b) modern diversion structure.

a)

b)

Source: Photographs
a. photo credit: Abraham Mehari.
b. photo credit: Bruce Lankford.

to changing conditions and each year utilize or abandon plots based on their perceptions of rainfall and flow (Machibya and Mdemu 2005). Consequently, the total area irrigated and also the total rice yield still varies considerably from year to year.

Figure 7 presents times series of the annual area of paddy, total rice production and rice productivity, in comparison to variations in rainfall between 1989/1990 and 2003/2004. The graphs illustrate:

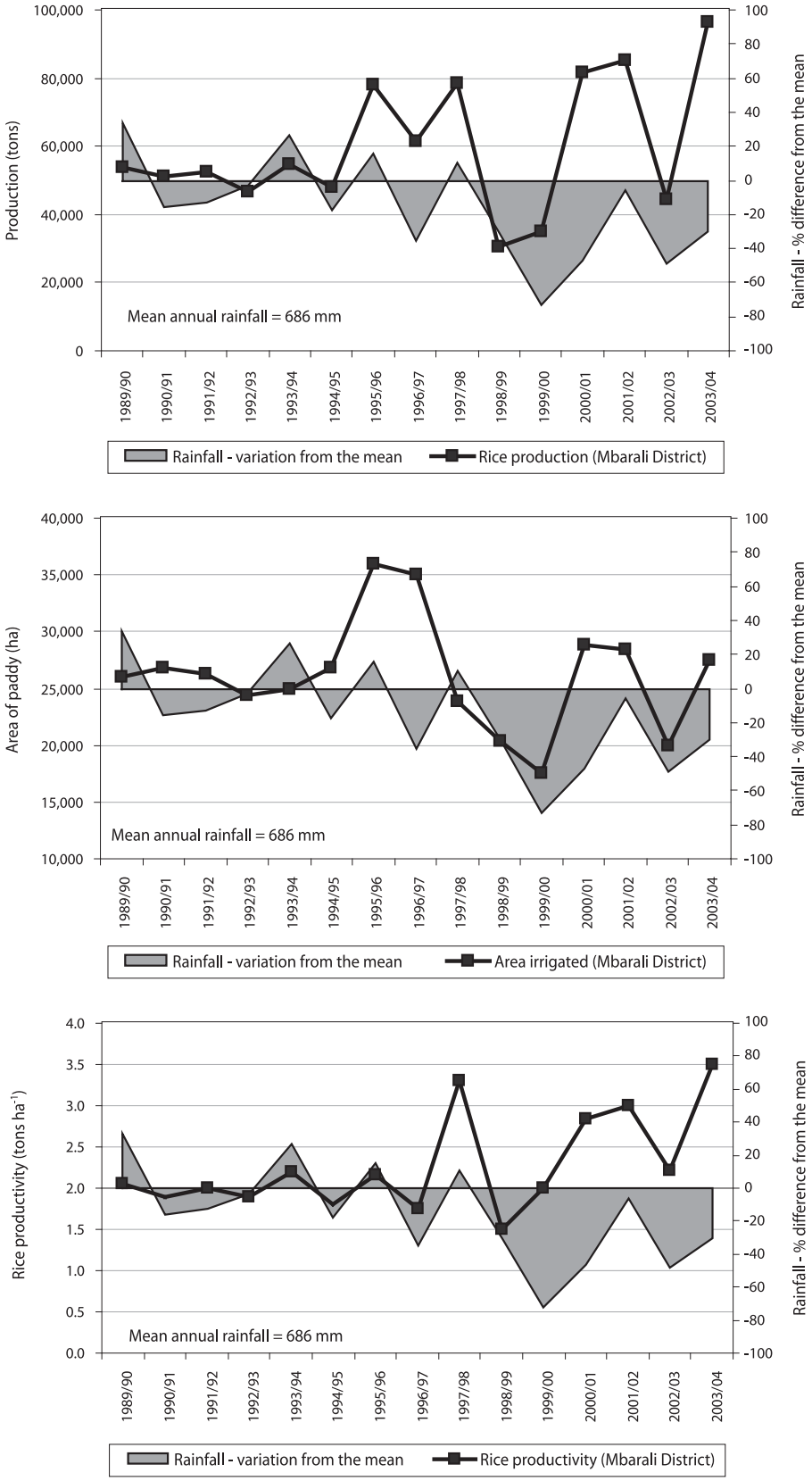
- the area cultivated and the production of rice are, in reality, only weakly correlated with rainfall on the Plains;
- particularly since 1996/1997 there has been very poor correlation between the area of paddy and the total production of rice;
- despite a prolonged period of below average rainfall since 1998/1999, productivity has increased slightly (i.e., from an average of 2 tons/ha^{-1} between 1989/1990 and 1996/1997 to an average of 2.6 tons/ha^{-1} between 1996/1997 and 2003/2004)[6];
- since 1996/97 the inter-annual variability in the area cultivated, total production and hence productivity, has increased significantly.

An identifiable reason for these observations is not discernable. Rather, a number of factors appear to be influencing rice yields and the area irrigated. The growth of irrigation beyond the core area normally irrigated (i.e., between about 20,000 and 40,000 ha) is predominantly ‘tail end’ rice, generated partly by extending flows of surface water, but mostly sustained by rainfall. Water supply in these areas tends to be intermittent and, accordingly, yields are lower and fluctuate significantly from year to year.

Another possible explanatory factor is both spatial and temporal variability in rainfall. While rain in the mountains can be substantial, leading to much larger river flows, this is not associated with rains on the Plain. Thus, the area of rice extends despite it being dry locally (SMUWC 2001). Furthermore, since 1998/1999 rainfall has generally been significantly less than average

[6] The World Bank attributes improvements in productivity to increases in the schemes on which the RBMSIIP focused and specifically as a result of the training of farmers in crop production and agro-business techniques and the introduction of high-yielding varieties of rice. However, the Bank makes no comparison of yields attained more generally within the catchment, by including schemes on which the program was not implemented, and makes no comment on the increased inter-annual variability (World Bank 2004).

FIGURE 7.
Comparison of the a) annual area of paddy, b) rice production, and c) yields, in Mbarali district (i.e., the district in which most of the Usangu Plains lie) with variation in Plains rainfall (expressed as a percentage of the long-term mean).



Source: Rice data provided by Mbarali District Agricultural Office.

and both smallholder and irrigation schemes have struggled to get sufficient water. In such situations the temporal distribution of rainfall events through the rainy season may be a critical factor in determining yields. Thus, even in years of similar total rainfall, yields may be extremely different.

It is also possible that the variability in recent years can, in part, be accounted for by the increased pressure on farmers to harvest rice, out of season, to maximize income. As a result, some field preparation for rice nurseries and transplanting has been brought forward and, in some places, farmers attempt to grow two crops a year, despite the fact that climatic conditions (i.e., temperature) are not really suited. Thus, although the main period remains the same, overall, the total rice-growing season has been extended by bringing forward the start of the season to the beginning of September. Thus, attempts are now made to grow rice almost all year round, from September to the beginning of August (i.e., approximately 330 days). Although, the watering of each field does not occur for that long (on average it is estimated that each field has water in it for between 180 and 250 days), it is possible that production is affected by whether or not climatic factors, other than rainfall, facilitate the growing of a second crop.

In addition to rice there is also increased dry season irrigation of vegetables, made possible by the modern irrigation intakes, which enable abstraction during low flow periods (see section, *Impact of Irrigation on River Flow*).

Comparison of Modern and Traditional Systems

Detailed investigations of water use in the NAFCO farms and smallholder plots indicate that, at the field scale, smallholder farmers, utilizing traditional irrigation techniques generally apply less water. A study conducted over two growing seasons (i.e., 1999/2000 and 2000/2001) on two NAFCO plots and two traditional plots found that in both cases the farmers applied less water, and so were more efficient, in the drier year (Machibya 2003). However, across both years, the field application efficiency on the modern NAFCO farms ranged from 35 to 50 percent whereas that of the traditional farmers varied from 56 to 69 percent (Table 1). The differences were attributed to the fact that NAFCO farmers tend to use about 650 mm of water for wetting up soils[7] prior to transplanting, maintain water depths of approximately 220 mm throughout the growing period and typically maintain water in the fields for between 150 and 300 days, well beyond the harvest date. One possible reason for maintaining water in the harvested fields is to suppress weeds, but it is not clear if this was indeed the reason why NAFCO farmers kept fields flooded. By comparison, the smallholder farmers, because they have less access to water, used approximately 250 mm for wetting up, maintained standing water depths of only about 120 mm and typically kept fields flooded only when the rice was growing, typically 120-150 days (SMUWC 2001)[8].

Although based on a small sample, but nevertheless one observed to be representative of wider systems of production, these results support the contention that, at least at the field scale, traditional smallholder farmers use less water and, as a result, their efficiency is greater than that of the NAFCO farms. They do not support the contention of the World Bank that traditional smallholder irrigation is less efficient.

On many NAFCO farms the irrigation channels provide domestic water supply. Consequently, intakes are left open and the

[7] This is, in part, because delivery to the field is via sunken channels which need to be full before water spills over the field. Furthermore, the head is low, so it takes a long time for the water to spread.

[8] Since evaporation and percolation from ponded water will be approximately the same whatever the depth maintained in the field, the difference in water use is largely accounted for by the water applied for wetting up and by differences in duration of evaporation.

TABLE 1.
Comparison of plot level irrigation efficiency between modern and smallholder farmers.

Location	Water use 1999/2000 (dry year)				Water use 2000/2001 (wetter year)			
	NAWU (mm)	GAWU (mm)	Efficiency (%)	Yield (kg/ha)	NAWU (mm)	GAWU (mm)	Efficiency (%)	Yield (kg/ha)
NAFCO farms	985	2,038	48	3,333	1,063	3,010	35	4,770
NAFCO smallholders	989	1,993	50	3,550	986	2,327	42	4,218
Traditional	1,151[1]	1,668	69	3,666	1,095	1,722	64	3,681
Traditional	999	1,789	56	2,853	976	1,730	56	4,037

Sources: adapted from Machibya and Mdemu 2005; and Machibya 2003.

Notes: [1] The greater water requirement for these fields is not explained, but is believed to be associated with normal variation around approximately 1,000 mm net requirement.

NAWU = net annual water use (i.e., crop water demand)

GAWU = gross annual water use (i.e., water applied to the field)

channels kept full even when the water is not being used for irrigation. In the absence of alternative sources for domestic water supplies this is clearly an important use of the irrigation channels. However, in many cases abstractions greatly exceed domestic requirements (see section, *Impact of Irrigation on River Flow*). Recent flow studies conducted in the Mkoji sub-catchment found that flows abstracted per hectare of cropped land (averaged over the growing season) varied between 0.928 liters per second (ls^{-1}) and 2.41 ls^{-1} in two schemes with traditional intakes and between 3.759 ls^{-1} and 4.297 ls^{-1} in a scheme with a modern intake (Rajabu et al. 2005).

Not only was smallholder irrigation found to use less water, it was also discovered to be similarly productive, particularly in dry years (Table 1). Consequently, productivity of rice per unit of water was found to be higher on the smallholder farms (Machibya 2003). The relatively low productivity of the NAFCO farms was attributed to low fertilizer application[9], weed infestation and poor water level control in fields (due to large uneven fields and lax management practices). By contrast, because their income is totally dependent on, and directly related to, the production from their fields, the smallholder farmers tend to be much more diligent in their day to day farming practices in order to maximize yields.

Impact of Irrigation on River Flow

Total mean annual flow into the Ihefu, under natural conditions, is estimated to be approximately 3,330 million cubic meters (Mm^3). Currently, average annual water withdrawals are estimated to be approximately 834 Mm^3, by coincidence just slightly more than the mean annual volume of evapotranspiration from the wetland (790 Mm^3) (Table 2). However, both the annual and the dry season volume abstracted vary considerably from year to year, both in absolute terms and as a proportion of the flow.

Surveys indicate that, historically, the gates on the modern irrigation intakes tend to be left open throughout the year, with no attempt to throttle back abstractions in the dry season. This is despite the fact that much water was simply going to waste by being spread on harvested fields (SMUWC 2001). Since 2001, a partial canal closure program has been introduced on

[9] This is also a problem for traditional farmers.

the largest irrigation schemes in an attempt to increase dry season river flows into the Ihefu. Under this program, the canals on the four largest NAFCO irrigation schemes are partially closed by the end of June each year. A maximum abstraction of 1 m^3s^{-1}, for domestic purposes, is permitted, with the exception of one scheme, which is allowed to withdraw up to 1.5 m^3s^{-1}, because it is also engaged in livestock keeping. These remain significant diversions solely for the purposes of domestic and livestock requirements, but are possibly necessary as a consequence of conveyance losses[10]. Normal operation of the canals is supposed to start gradually in November for establishment of rice nurseries, with full-capacity operation resuming in December. The RBWO is supposed to monitor and enforce this program (Rajabu et al. 2005).

Average dry season inflow to the Ihefu between 1986 and 2004 was estimated to be 75.5 Mm^3 compared to 199.9 Mm^3 between 1958 and 1973. Although rainfall over these two periods was not exactly the same, this nevertheless indicates a reduction of approximately 60 percent and, in some months (i.e., September and October), the reduction was closer to 70 percent (Kashaigili et al. 2006b). However, these data cover the period when the gate closure program was coming into effect and hence slightly underestimate historic water withdrawals. Flow measurements, made by the SMUWC project at the end of the dry season in 1999, found that 91 percent of upland flow was being abstracted and, overall, it was estimated that on average 85 percent was being withdrawn in low flow months (SMUWC 2001). More recent studies conducted in 2003 and 2004, in the Mkoji

TABLE 2.
Human withdrawals from the rivers flowing onto the Usangu Plains.

	Water use ($x10^6$ m^3)		
Sector	Wet season (December to June)	Dry season (July to November)	Total
Irrigation[1]	775.6	24.3	799.9
Livestock	8.2	19.6	27.8
Brick-making	-	0.2	0.2
Domestic	2.6	3.5	6.1
TOTAL	**786.4**	**47.6**	**834**
Natural flow onto the Plains[2]	3,027	200	3,227
Measured flow onto the Plains 1998-2003[3]	1,405	112.6	1,517.6
Wetland evapotranspiration[2]	636	154	790
Evaporation from Mtera and Kidatu reservoirs	381.9	712.5	1,094.4

Source: adapted from Cour et al. (2006) unless otherwise indicated.

Notes: [1] Total demand – comprises crop water requirement, water used for land preparation + conveyance losses.

[2] Computed from wetland model for period of near natural flow (i.e., years 1958-1973) (Kashaigili et al. 2006b).

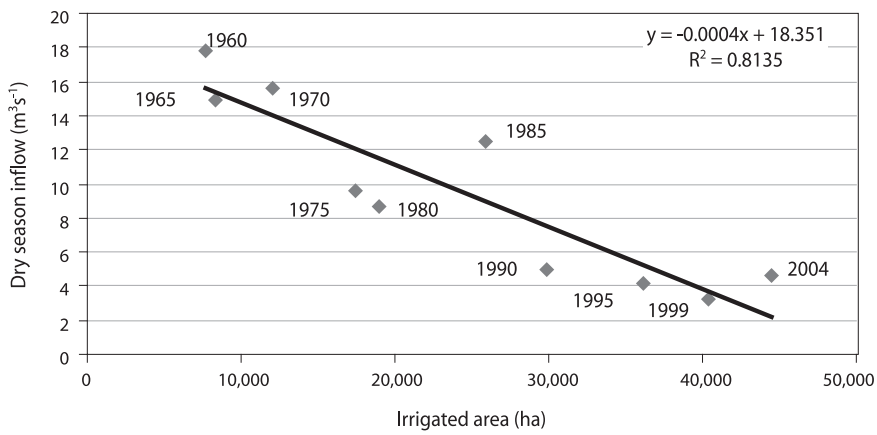
[3] Measured at gauging stations located on the perennial rivers upstream of the irrigation intakes.

[10] Scope exists here for further savings; including cleaning of canals, and eventually switching to piped supplies for those villages peripheral to the NAFCO farms.

sub-catchment, the most heavily utilized for irrigation, continue to show dry season abstraction levels in excess of 90 percent on some rivers (Rajabu et al. 2005). Although it does not prove causation, there is a clear statistical link between declines in the dry season inflow to the Ihefu (simulated using a computer model (see section, *Usangu Wetlands*) and the irrigated area in the catchment (Figure 8).

One of the objectives of the RBMSIIP was to replace traditional irrigation intakes with modern ones, in the belief that this would improve irrigation efficiency and free water for downstream uses. However, despite the presence of bypass structures to ensure some downstream flows, in general, the modern intakes are more effective at diverting flows than the traditional structures. Unless the intake gates are closed or partially closed, the modern intakes often enable a large proportion of the dry season river flow to be diverted. By contrast, traditional intakes leak a lot so that a significant proportion of the river flow always continues downstream (Figure 6a). Furthermore, traditional weirs only enabled diversion when river levels were relatively high (i.e., commencing in December or January). However, the combination of relatively high concrete weirs, and lower intake orifices in the modern intakes, effectively raises water levels so that water can be abstracted, almost irrespective of the flow in the river. This has facilitated the change in cropping patterns that has been observed in recent years with increased late season irrigation and dry season cropping. It has also resulted in upstream farmers depriving downstream farmers of water. In a survey conducted in the Mkoji sub-catchment, 80 percent of respondents believed that the modernizing of traditional irrigation intakes had resulted in the increased drying of the river during the dry season and consequent shortages of water for domestic use (Rajabu et al. 2005)[11]. Hence, although farmers are pleased to get modern intakes, because they reduce maintenance and labor requirements, in the absence of robust monitoring and regulation, they have resulted in neither the predicted improved downstream flows nor greater equity in its distribution (Lankford et al. 2004a; Lankford 2004a).

FIGURE 8.
Comparison of the dry season inflow to the Ihefu wetland and irrigated area in the Usangu catchment.



Source: irrigated area from SMUWC (2001).

[11] It is unfortunate that the modern diversions have been installed and operated throughout an extended dry period (Figure 7). To some extent, people's perceptions of their impacts may have been skewed by this fact.

Improving Irrigation Efficiency

Improving local irrigation efficiency by reducing non-beneficial losses, particularly in the NAFCO farms, could reduce the amount of water abstracted from the rivers. If the NAFCO farms and schemes using modern intakes reduced water use per hectare to the current average of the traditional smallholder schemes, it is estimated that withdrawals could be reduced to approximately 760 Mm^3 (i.e., a saving of about 40 Mm^3). If all schemes reduced water use per hectare to the current best achieved by smallholder farmers in dry years, withdrawals could be reduced to approximately 700 Mm^3 (i.e., a saving of about 100 Mm^3). Since the productivity of the smallholder farms is approximately equivalent to that of the NAFCO farms (see section, *Comparison of Modern and Traditional Systems*) these savings would not necessarily entail reductions in yield. In theory, providing the liberated water was not simply used to increase irrigated areas, the water saved would be freed for downstream uses.

The research conducted in the RIPARWIN project indicated that, in the absence of adequate monitoring and mechanisms for enforcement, water rights and fees *per se* are ineffective in controlling water withdrawals (see section, *Water Fees*). With a lack of mechanisms for monitoring and enforcement, the design and form of irrigation intakes becomes extremely important in determining the volumes of water diverted (Lankford 2004b). In modern intakes the gates tend to be left fully open so that, just as with the traditional intakes, the water diverted is a function of river discharge rather than either the actual area irrigated or crop water requirements. Alternative designs that limit the maximum volume of water that can be diverted at times of high flow and simultaneously facilitate the diversion of variable proportions of river flow during the dry season have been proposed (Lankford and Mwaruvanda 2006). Such structures, which include proportional and castellated flumes, would both increase the transparency of water divisions (i.e., between irrigation schemes and downstream users) and facilitate greater flexibility in operation. It is surmised that, in conjunction with more adaptable arrangements for water management (particularly in the dry season) based on local arrangements, continuous consultation and negotiations, such structures would improve the 'manageability' and assist in better and more equitable utilization of water. A study of smallholders in the Mkoji sub-catchment indicated that they would be willing to use such structures (Vounaki and Lankford 2006). Nonetheless, mechanisms to ensure compliance with agreed operating procedures are still likely to be required[12].

[12] Past experience shows that, in the absence of enforcement mechanisms, such structures are relatively easily manipulated by users (e.g., by blocking the sections that allow flows downstream).

Water Valuation: Economic Efficiency and Livelihoods

Since the Dublin Principles were agreed in 1992, an international consensus has emerged on the need to integrate economics into water resource planning and management. This is predicated on the fact that water resources provide multiple benefits to society, so any specific use of water will be associated with opportunity costs (i.e., the benefits foregone from alternative uses). Consequently, water resource managers are required to balance allocation between competing wants and needs. Although decisions concerning water allocation should not be guided by concerns of economic efficiency alone, economic valuation can help to improve allocations by at least providing a common point of reference to decision-makers. This can be used to assess the trade-offs involved in the allocation of water resources between competing needs (Turner et al. 2004). In Tanzania, two key objectives of the government are attaining food security and poverty reduction. Irrigated agriculture is perceived as one of the most important strategies to achieve both these objectives (IMF 2006). However, in catchments such as the Great Ruaha River, where water provides multiple benefits and there is already significant competition, it is not clear how limited water supplies are best used. Clearly there is the need for a 'pragmatic but principled' approach to resource evaluation and allocation.[13]

Estimated Values of Different Water Uses in the Great Ruaha Basin

Placing a value on water for different uses is extremely complex and there are numerous economic techniques. These include analysis of market-like transactions, use of production approaches that consider the contribution of water to the production process, estimation of the costs of providing alternatives, and approaches to estimating the value of environmental resources more generally (Turner et al. 2004). Many of the techniques require extensive data, which are often unavailable in developing countries.

In the current study, estimates of the value of water in a number of sectors were made (Table 3). Much information was obtained from interviews conducted in household surveys and then extrapolated to cover the whole basin. As far as possible, market prices were used, but where this was not possible alternatives were deduced. Although efficient allocation of water is ideally based on its marginal economic value (i.e., taking into account the value of the last unit of water used in any process), sufficient data were not available to enable this comparison in this study. Consequently, the results, presented in Table 3, are not marginal values, but are gross values (i.e., excluding costs). With the exception of the estimates derived for the Ihefu wetlands, which were computed specifically for this report, all other results are based on the productivity estimates of Cour et al. (2006). All the values are based on 'depletion' of the river's water resources (i.e., water consumed) except that computed for the Ruaha National Park, which is effectively an 'in-stream' value. No allowance is made for changes in water quality. The results provide an initial appraisal of the economic value of water in different uses and are indicative of the orders of magnitude of water use in different parts of the basin (Figure 9).

The main difficulty in attempting to value the water 'used' in the Ihefu and other Usangu wetlands is that many of the water-related environmental services they provide are not valued by markets and, for the few that are, data are extremely scarce. Table 3 provides an estimate of the value for just three services for which some data are available: fisheries, beekeeping and livestock grazing. In each case,

[13] In this instance 'principled' means giving due consideration to issues such as equity and sustainability as well as social and cultural aspects of water use.

TABLE 3.
Gross value (i.e., excluding capital and production costs) of water for different uses.

Use	Annual volume used[1] (Mm^3)	Estimated gross value (US$ million)	US$ m^{-3}	Basis for calculation
Irrigated rice	775.6	11.91	0.02	Recorded yields, unit market price and total water consumed (i.e., evapotranspired, conveyance losses and water percolating to groundwater)[2].
Irrigated dry season crops (i.e., tomatoes, onions, beans and maize)	24.3	2.08	0.12	As above
Livestock	27.8	11.59	1.16	Livestock consumption (estimated to be 40 and 20 liters per day for a cow in the dry and the wet season, respectively[3]) and household income generated from livestock. No allowance was made for the water requirements of livestock feed (but see livestock grazing in Ihefu wetland).
Brick-making	0.2	0.251	1.66	Household production of bricks and water utilized in the manufacturing.
Domestic	6.1	5.73	0.94	Population data and estimates of willingness to pay determined through a contingent valuation methodology. This found that, on average, households were willing to pay the equivalent of US$0.94 m^{-3}, which corresponds well with the market prices of local sellers who carry water to villages.
Ruaha National Park	6.6	0.37	0.06	Estimates of lost revenue as a consequence of the river drying (i.e., based on entrance fees and the hunting value of animals such as crocodiles and hippos) and assuming an absolute dry season minimum flow requirement of 0.5 m^3s^{-1} (see below) through the Park.
Hydropower	1,094	232.62	0.21	Average electricity tariff for 2002 and 2003 of US$0.0656 kWh^{-1} and water evaporated from the Mtera-Kidatu reservoirs[4].
Ihefu wetland - fisheries - beekeeping - livestock grazing	790	 0.022 0.007 9.31	 $2.8x10^{-5}$ $0.8x10^{-5}$ 0.01	Estimates of fisheries and beeswax and honey production in the Ihefu from the Mbarali District Fisheries Office and Beekeeping Officer, prior to the wetland being gazetted (Kashaigili 2003). Also prior to the gazetting, 80% of cattle in Usangu were grazed in the wetlands during the dry season.

Source: with the exception of those for the Usangu wetlands, all results have been adapted from Cour et al. (2006).

Notes: [1] In all cases, the volume used is depleted from the water resources of the catchment, with the exception of the Ruaha National Park, where it is based on minimum in-stream flow requirement.

[2] Although, strictly speaking, water percolating to groundwater is returned to the system and thus may be used for other beneficial uses, in the current study it was considered a loss because it is unlikely to return to the river, when most required, during the dry season.

[3] Cattle require more water in the dry season because forage has lower moisture content than in the wet season.

[4] Total electricity produced from Mtera-Kidatu in 2002/2003 is 1.84 Gigawatt-hours (GWh). Tariffs may not necessarily reflect the true economic value of electricity. However, it was the best information available for this study. Furthermore, because hydropower can be turned on and off very rapidly, the value of water can be significantly increased if it is used for supply during periods of peak tariffs. However, in Tanzania, 96.5% of electricity produced is hydropower, so this option is less available than in countries that have a number of production alternatives. Consequently, simply using the average tariff was deemed to be appropriate.

the value is computed using data derived prior to the incorporation of the Ihefu into the Usangu Game Reserve, in 2000. Since then many human activities within the wetlands have been prohibited (see section, *Usangu Wetlands*). In each case, the unit value computed is based on the estimated mean annual volume of water evapotranspired from the whole wetland (i.e., 790

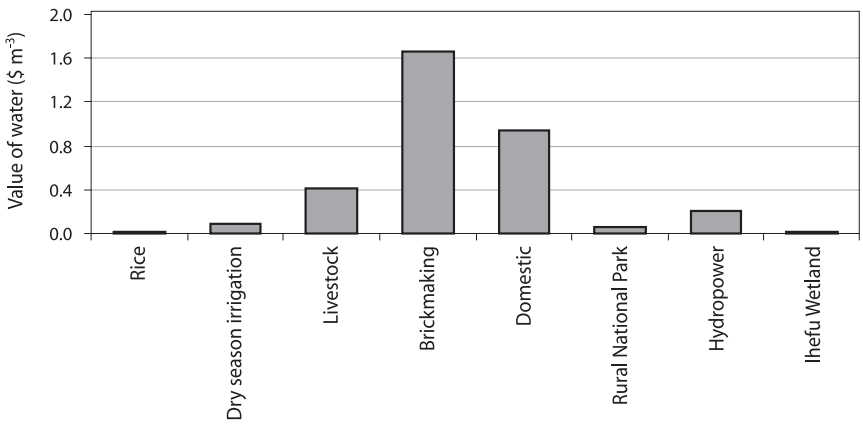
Mm^3 – see Table 2), which explains why these values are very low.

Other direct benefits provided by the wetlands, for which no data are available, include fuelwood, building materials (e.g., thatching grass, wood, reeds and clay), materials for crafts (e.g., mats, seats and baskets made from reeds) and medicinal plants (Kashaigili 2003). In some villages, it is estimated that up to 95 percent of households benefit in some way from the wetlands. They also make a vital contribution to coping strategies during times of food scarcity (Kashaigili and Mahoo 2005). Furthermore, the wetlands provide a range of other non-direct benefits in relation to hydrological, chemical and biological functioning that are extremely difficult to quantify in monetary terms. These include: flood attenuation, sediment trapping, improvements in water quality and considerable biological productivity (SMUWC 2001). These functions contribute to human well-being globally as well as locally in Usangu and downstream. Hence, the total value of wetland services is likely to be significantly greater than that presented in Table 3.

To enable a direct comparison with other uses, the value for hydropower presented in Table 3 is based on evaporation from the Mtera and Kidatu reservoirs (i.e., depletion as for all the other uses, except the Ruaha National Park). Other researchers have computed the value of water in hydropower schemes in Tanzania, by defining the water "used" as the sum of evaporation and the outflow from the dam (e.g., Turpie et al. 2003). Since in the Great Ruaha River, the irrigation and other principal uses are located upstream of the hydropower schemes, all water flowing into the hydropower reservoirs represents water that could possibly have been used upstream. Thus, water that is allowed to flow downstream to the dams effectively represents an 'opportunity' cost to these upstream users. For the Great Ruaha River hydropower scheme, if the water used is taken to be the sum of the evaporation and outflows from the reservoirs, this decreases the value of hydropower water to US$0.06 m^{-3}.

The results presented in Table 3 indicate that, simply based on monetary considerations, hydropower produces higher economic returns per cubic meter of water than most other commercial activities in the Great Ruaha River Catchment. The exceptions are brick-making, livestock drinking water and domestic water supply. However, these three use almost insignificant quantities of water in comparison to hydropower. Furthermore, if water requirements to feed are included in the livestock water needs the returns are considerably reduced, as indicated by the low figure for cattle grazing in the Ihefu wetland (Table 3). A detailed analysis of the relative value of water in hydropower and rice irrigation, that incorporated scrutiny of different farming systems and different approaches to estimating electricity value, confirms the higher returns for hydropower (Kadigi et al. 2005).

FIGURE 9.
Value of water ($ m^{-3}) estimated for different water uses in the Great Ruaha River Basin.



Source: adapted predominantly from Cour et al. (2006).

Implications for Allocation between Uses

To date, the debate on water allocation within the Great Ruaha River Catchment has focused almost exclusively on the largest water users; rice irrigation and hydropower (World Bank 2004; Kadigi et al. 2005; Mdemu and Magayane 2005). Both deplete large amounts of the basin water resources; 800 Mm^3y^{-1} and 1,094 Mm^3y^{-1}, respectively[14]. Based on the simple economic analysis presented, transferring water from rice to hydropower would seem a logical decision. However, since water allocation also has social and cultural impacts on society, economic efficiency is not the sole criteria on which the decision should be based. Other aspects need to be considered, including equity and pro-poor returns as well as the implications for national food security and the environment. Both, the rice produced in Usangu and the hydropower, are extremely important to the national economy of Tanzania. The rice produced in the basin represents between 14 and 24 percent of the national rice production. Furthermore, by providing an average gross income of US$912 per annum (per family) to some 30,000 poor agrarian families, it makes a significant direct contribution to poverty alleviation (Kadigi et al. 2005). The contribution to the national economy is also likely to be enhanced by both forward and backward linkages to other sectors. In contrast, the Mtera-Kidatu hydropower stations produce between 54 and 69 percent of the country's electricity (Kadigi et al. 2005), which is vital for broad national development, with both direct and indirect benefits for poor people. Although less than 10 percent of the total population of Tanzania has access to electricity[15], this still represents approximately 3.6 million people of whom approximately 2 million can be said to be supplied from the Mtera-Kidatu power plants. Furthermore, although electricity from hydropower provides just 9.0 percent of the total energy used in the country, a rough estimate is that US$554.6 million (i.e., 5.4%) of the country's gross domestic product (GDP) is directly dependent on the Mtera-Kidatu scheme (Table 4).

Clearly, making a decision about the allocation of water between rice production and hydropower is extremely difficult and is ultimately a political choice. The RBWO is attempting to increase irrigation water productivity. Clearly, this will, if successful, equate to higher basin-level returns in total. Additional flows to Mtera and Kidatu of between 40 Mm^3 and 100 Mm^3, which seem possible through improvements in irrigation efficiency (see section, *Improving Irrigation Efficiency*), even allowing for likely evapotranspiration in the Ihefu wetland and transmission losses further downstream, would equate to annual benefits of between US$2.4 million and US$6 million (using the figure of US$0.06 m^{-3} for the value of water in hydropower). Although occurring predominantly in the wet season, this additional flow would also assist in maintaining the ecological condition of both the Usangu wetlands and the Ruaha National Park (see section, *Ruaha National Park*). However, effective incentives are required to encourage farmers to increase irrigation efficiency. Current water pricing mechanisms are not working (see section, *Water Fees*). Alternative financial instruments, including benefit-sharing mechanisms (e.g., at the very least providing communities with subsidized

[14] Evaporation from the reservoirs is high. Most is from the Mtera Reservoir, which is extensive and shallow. At full supply level it covers an area of 620 km^2 and averages just 8.5 meters (m) in depth. By comparison, at full supply level, the Kidatu Reservoir covers an area of just 9.5 km^2 and is on average 17 m deep. Average open water evaporation in the area is approximately 1,920 mmy^{-1} (Yawson et al. 2003).

[15] Total energy use per capita is 408 kilograms (kg) oil equivalent, of which 90.7% is from biomass products. Electricity power consumption per capita is just 62 kilowatt-hours (kWh) (cf. 12,183 kWh in the USA) (World Bank 2005). Concerted efforts are being made to reduce charcoal burning, which is widely blamed for widespread deforestation in recent years. However, current electricity production is insufficient to meet demand and blackouts are common.

TABLE 4.
Estimating the proportion of Tanzania's GDP dependent on the electricity from the Mtera-Kidatu scheme.[1]

Data from World Bank (2005)			
GDP (US$ billion)	10.3		
GDP per unit of energy use (US$/kg oil equivalent)	1.4		
Energy from biomass products and waste (% of total)	90.7		
Electricity generated by coal (% total)	3.5		
Assumptions			
Electricity contribution to total energy use (% total)	9.3		
Electricity generated by hydropower (% total)	96.5		
Electricity generated by Mtera-Kidatu (% total hydropower)	60.0		
Calculations			
Energy used to generate GDP (billion kg of oil equivalent)	10.3 / 1.4	=	7.357
Electricity (billion kg of oil equivalent)	0.093 * 7.357	=	0.6842
Electricity from hydropower (billion kg of oil equivalent)	0.965 * 0.6842	=	0.6603
Total hydropower contribution to GDP (US$ billion)	0.6603 * 1.4	=	0.924
Contribution of Mtera-Kidatu to GDP (US$ billion)	0.6 * 0.924	=	0.555
Result			
Proportion of GDP dependent on Metera-Kidatu (% total)	0.555 / 10.3 * 100	=	5.4

Source: data largely obtained from World Bank (2005).

Note: [1] the calculation assumes that all energy sources contribute to GDP equally.

electricity) could be considered.[16] In addition, consideration should also be given to promoting alternatives to irrigation that provide comparatively high returns but utilize relatively small volumes of water. For example, if markets exist for more bricks, and more detailed economic analyses indicate that marginal values are indeed relatively high (i.e., not just the average values as presented in Table 3), then the establishment of small brick-making enterprises would seem to be a logical proposition.

[16] Sharing part of the benefits, generated by the dams, with communities living in the Usangu Plains (e.g., through the establishment of a long-term regional economic development fund, financed from dam revenue) could effectively develop a partnership between TANESCO and the communities, that could bring benefits to both parties.

Environmental Concerns: Conservation and Sustainability

In many developing countries, improvements in natural resources management (including water) are widely perceived to be critical to sustainability and central to overcoming both developmental and environmental problems. Past experience shows that, although irrigation can considerably enhance livelihoods by improving food security and reducing poverty, irrigation undertaken without full consideration of potential negative environmental impacts can have serious adverse repercussions. If inappropriately managed, the negative impacts can result in net costs to society and may be a major constraint to development (McCartney et al. 2007; Millennium Ecosystem Assessment 2005). One of the major challenges of sustainable water resource management is to assess how much water can be taken from a river before its ability to meet social, ecological and economic needs is reduced. In the Great Ruaha River Basin, this issue has been brought to the fore by the fact that the catchment contains two very important conservation areas, the Usangu wetlands and the Ruaha National Park, both of which are highly dependent on water.

Usangu Wetlands

Ecologically the Usangu wetlands are amongst the most valuable ecosystems in Tanzania, providing habitat for over 400 bird species and numerous other flora and fauna (Kamukala and Crafter 1993). The wetlands comprise the Western and Eastern Wetlands, which are divided by higher ground in the centre of the Plains and only joined by a narrow band of land along the Great Ruaha River at Nyaluhanga (Figure 1). In the past, the Western Wetland was composed of non-contiguous seasonally flooded areas and the Eastern Wetland comprised seasonally flooded grassland and the perennial Ihefu swamp. In recognition of its biological importance, the Usangu area has been designated an Important Bird Area by Birdlife International (Mtahiko et al. 2006). In 2000, the Ihefu and its surroundings were incorporated into the Usangu Game Reserve and more recently the Reserve has been incorporated into the Ruaha National Park. However, the designation of the Ihefu as a Ramsar Wetland of International Importance has been postponed because of its currently degraded state (Mtahiko et al. 2006).

In the Ihefu, the increase in cattle has led to degradation of soil and vegetation and many mammalian wildlife populations have decreased significantly as a consequence of increased human activity (Mtahiko et al. 2006). Despite the lack of statistical significance, lower wet season flows in the Great Ruaha River (see section, *The Study Area*) have reduced inundation upstream of the Nyaluhanga restriction, and consequently the western wetlands are now experiencing far fewer periods of inundation (Mtahiko et al. 2006).

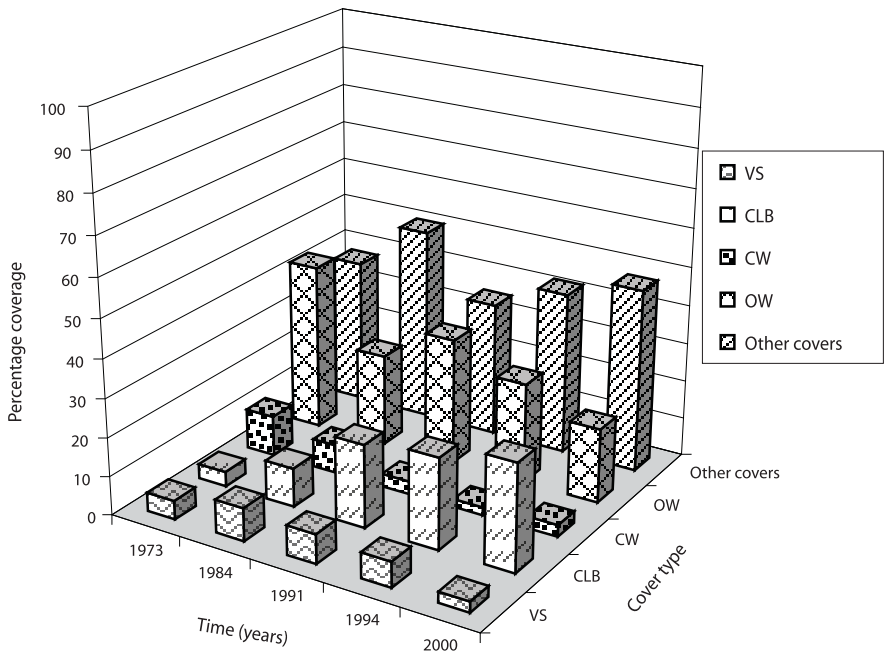
Analyses of satellite images indicated significant changes in land cover in the catchment and seasonal and inter-annual variation in the area of the Ihefu swamp (Box 1). A simple computer model was developed to simulate the water balance of the Ihefu. Based on conceptualization of the swamp as a reservoir (Figure 10), the model simulated wetland area and water storage as well as hydrological fluxes to and from the wetland for the period 1958 to 2004 (Kashaigili et al. 2006b). The results were analyzed to indicate changes over time.

The results of the model confirmed the satellite image analysis of significant inter-annual variation in area, depending on both amount and temporal distribution of rainfall. They also showed that there was significant variation in the maximum, but much less variation in the minimum, area of the wetland each year (Figure 11). Furthermore, between 1958 and 2004 the dry season minimum area decreased significantly, but there was no clear trend in the wet season maximum area (Figure 12). Overall, the dry season minimum area was found to have

Box 1: Use of remote sensing to investigate temporal variation in land cover and the size of Ihefu swamp.

Landsat images were used to investigate changes in land cover between 1973 and 2000 (Kashaigili et al. 2006b). Seven major land-cover types were identified and classified: closed woodland, open woodland, vegetated swamp, closed bushland, open bushland, bushed grassland, cultivated land and bare land. Post-classification techniques were used to determine land-cover changes. The results indicated:

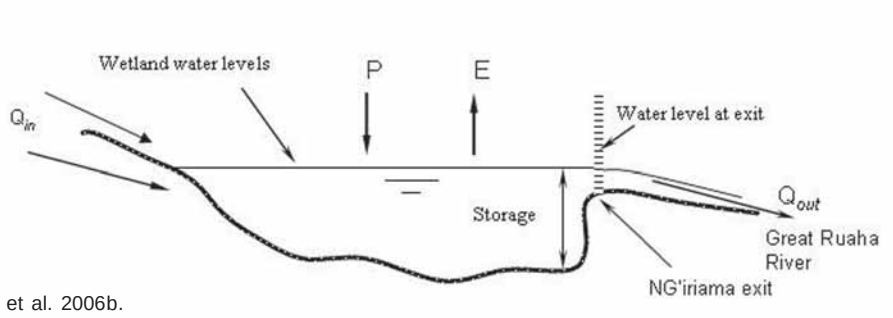
- a steady increase in cultivated area from 121 to 874 km^2
- a decline in closed woodland from 332 to 97 km^2
- a decline in open woodland from 1,369 to 609 km^2
- considerable inter-annual variability in the area of dry season vegetated swamp (i.e., primarily Ihefu) which was correlated with annual rainfall



Percentage coverage for different land-cover (VS = vegetated swamp, CW = closed woodland, OW = open woodland, CLB = cultivated and bare land, and other covers = closed bushland, open bushland and grassland).

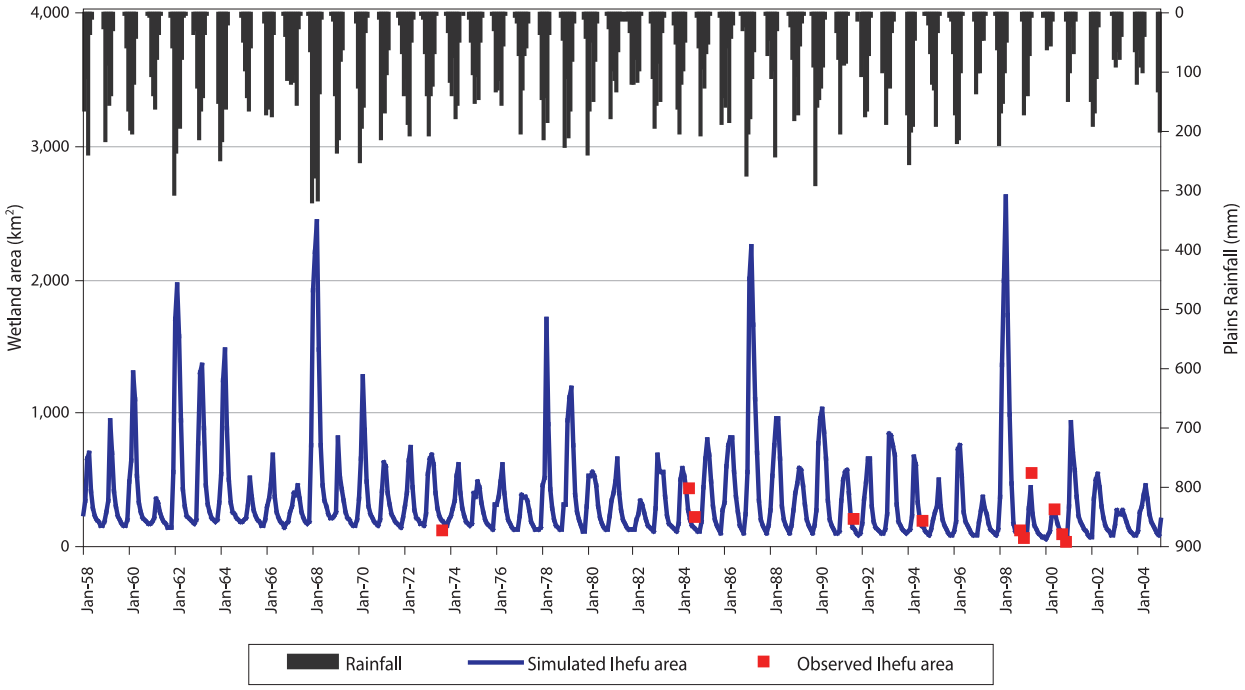
decreased from an average of about 160 km^2 (1958-1973) to approximately 93 km^2 (1986-2004), i.e., a proportional decrease of approximately 40 percent (Kashaigili et al. 2006b).

FIGURE 10.
Conceptualization of the Ihefu wetland as a simple reservoir.



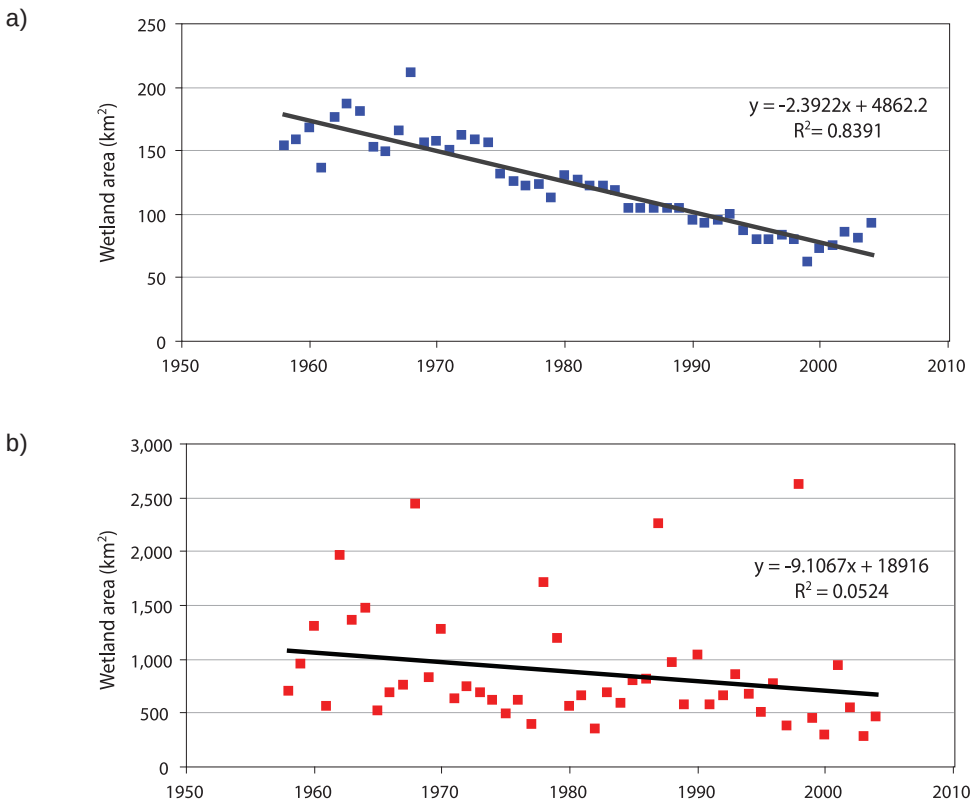
Source: Kashaigili et al. 2006b.

FIGURE 11.
Simulated time series of the Ihefu area (i.e., derived from the wetland model), compared to the few "observed" areas (i.e., derived from satellite images and Global Positioning System (GPS) observations).



Source: own analysis

FIGURE 12.
Change in the area of the Ihefu between 1958 and 2004 a) dry season minimum, and b) wet season maximum. Results obtained from the wetland simulation model.



Source: own analysis

Ruaha National Park

The Ruaha National Park is one of Tanzania's premier parks, referred to as the "Garden of Eden" in the late 1880s (Fox 2004). Currently, Tanzania National Parks (TANAPA) is promoting tourism in the Park in order to reduce pressure on the more famous parks (e.g., the Serengeti and Ngorongoro Crater) in the north of the country.

The drying of the Great Ruaha River in recent years has considerably altered the ecology of the Park near the river. It has directly caused the death of many wild animals (e.g., hippopotami, fish and freshwater invertebrates) and disrupted the lives of many others that depend on the river for drinking water. WWF report that freshwater oysters have disappeared from the river along with the clawless otters that lived on them. It is estimated that for animals that must remain within one kilometer of water to survive (e.g., buffalo, waterbuck and many waterbirds) the lack of water has reduced the dry season habitat by nearly 60 percent (Coppolillo et al. 2004). The concentration of animals around the few remaining water holes in the riverbed, during the dry season, has resulted in over-utilization of vegetation and consequent erosion of riverbanks at the start of the rainy season. This has led to widening of the river and silting of water holes in the riverbed, thereby exacerbating the problem in subsequent years. 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 waters as a result of which many animals have succumbed to infectious diseases (Mtahiko et al. 2006). There is concern that the

death of so many animals and reduction in the aesthetic appeal of the river may reduce the number of tourists visiting the Park (Fox 2004). Since the early 1990s the Friends of Ruaha Society has been strongly advocating for measures to be introduced to maintain dry season minimum flows through the Park (Fox 2004).

Environmental Flows

Lack of data is often a constraint to estimating environmental flows. This is true for the Great Ruaha River, where limited data and a lack of understanding of the linkages between different flow regimes and ecological impacts, make estimating flow requirements difficult. However, to compensate for the lack of ecological information, several methods of estimating environmental flows have been developed that are based solely on hydrological indices derived from historical flow data (Tharme 2003). Although it is recognized that a myriad of environmental attributes influence the ecology of aquatic ecosystems (e.g., temperature, water quality and turbidity), the common assumption of these techniques is that flow regime is the primary driving force (Richter et al. 1997).

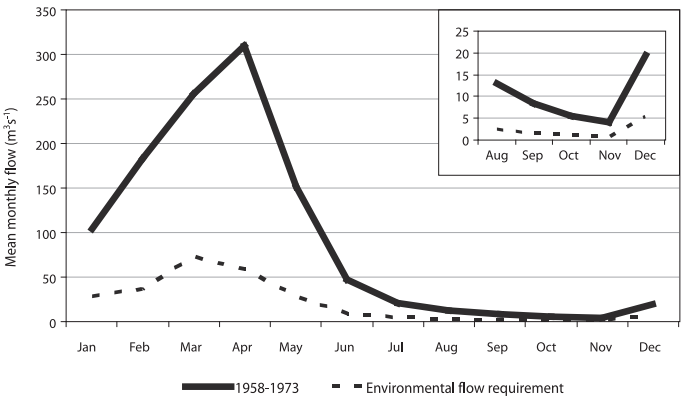
The "desktop reserve model", which was developed in South Africa, is one such approach. It was developed to quantify ecological flow requirements in situations where a rapid appraisal is required and data availability is limited (Hughes and Hannart 2003). To date, the model has not been used extensively outside South Africa, but because, unlike most other approaches, it was developed specifically for conditions experienced in African rivers, it was felt to be the most appropriate tool to be used in the RIPARWIN project. The model is built on the concepts of the building block method (King et al. 2000), which is widely recognized as a scientifically legitimate approach to setting environmental flow requirements (Hughes and Hannart 2003). The model estimates low flows, as well as high flows, required for channel maintenance, and differentiates flow requirements in "normal" and "drought" years (Hughes 2001).

The model was applied to the Great Ruaha River at Msembe Ferry (Figure 1). To estimate the environmental flows, the model requires a naturalized flow series as input[17]. A completely naturalized flow series was unavailable, so monthly flows for the years 1958 to 1973 (i.e., the period over which flows were least modified) were used instead. Over this period, mean annual flow (MAF) of the river was 2,933 Mm^3 (i.e., 93.0 m^3s^{-1}). The model results indicate that to maintain the absolute basic ecological condition of the river requires an average environmental flow allocation of 635.3 Mm^3, which equates to 20.1 m^3s^{-1} (i.e., 21.6% of MAF), and the absolute minimum flow (in November) should not be lower than approximately 0.6 m^3s^{-1} (Figure 13). The minimum flow is very similar to the estimates of the Ruaha National Park ecologist, who, based on expert judgment, proposed an absolute minimum of 0.5 m^3s^{-1} (personal communication), and that proposed by SMUWC hydrologists (SMUWC 2001).

Having determined dry season minimum flow requirements, the wetland model (see section, *Usangu Wetlands*) was used to estimate the inflows to the Ihefu, needed to create these outflows at NG'iriama. Average dry season inflows required to maintain outflows of 0.6 m^3s^{-1} and 0.5 m^3s^{-1}, without consideration of minimum flow requirements in other months, were 7.22 m^3s^{-1} and 6.98 m^3s^{-1}, respectively. This suggests an absolute minimum dry season inflow of about 7.0 m^3s^{-1}. This is approximately 3.25 m^3s^{-1} greater than the current average dry season inflows. To maintain this average inflow would

[17] In South Africa, 70-year time series of naturalized flows are available for all quaternary catchments (i.e., the principal water management units in the country).

FIGURE 13.
Comparison of mean monthly observed flow (1958-1973) and estimated environmental flow requirements for the Great Ruaha River at Msembe Ferry.



Month	Observed flow 1958-1973 (m^3s^{-1})	Environmental flow required (m^3s^{-1})	Absolute minimum flow[1]
Jan	104.3	27.2	5.0
Feb	183.7	35.6	8.4
Mar	255.0	71.7	31.1
Apr	309.8	57.8	36.1
May	151.5	27.7	21.3
Jun	47.6	8.5	7.0
Jul	21.2	3.8	3.4
Aug	13.1	2.3	1.9
Sep	8.3	1.5	1.4
Oct	5.5	1.0	0.8
Nov	4.1	0.7	0.6
Dec	19.4	5.2	1.9

Source: adapted from Kashaigili et al. 2006b.

Note: [1] Assurance level 0.99

require the available dry season surface water resource to be divided in the ratio of 80 percent for the environment (i.e., 7.0 m^3s^{-1}) and 20 percent for anthropogenic water needs (i.e., 1.50 m^3s^{-1}). In absolute terms this would require current dry season abstractions to be reduced from approximately 4.25 m^3s^{-1} to about 1.50 m^3s^{-1} (i.e., a 65% reduction). More details on the calculation of environmental flow requirements of the Great Ruaha River within the Ruaha National Park are presented in Kashaigili et al. (2006b).

Options for Achieving Environmental Flows

A global assessment of environmental water requirements found that, typically, they range from 20 to 50 percent of mean annual flow (Smakhtin et al. 2004). However, because it was a global survey, it made no allowance for setting different ecological standards for rivers. An annual environmental flow requirement of more than 20 percent, and typically 80 percent in the dry season, as has been found in the current study, seems like a high proportion of flow to maintain the basic ecological condition of the river. It arises because, although there is significant seasonal difference, day-to-day variation in flows at Msembe Ferry is relatively low[18]. Hence, although it can be assumed that river biota are adapted to high inter-seasonal variation, it is probable that they are not adapted to rapid changes in flow or to the extended periods of zero flow, that occur at present.

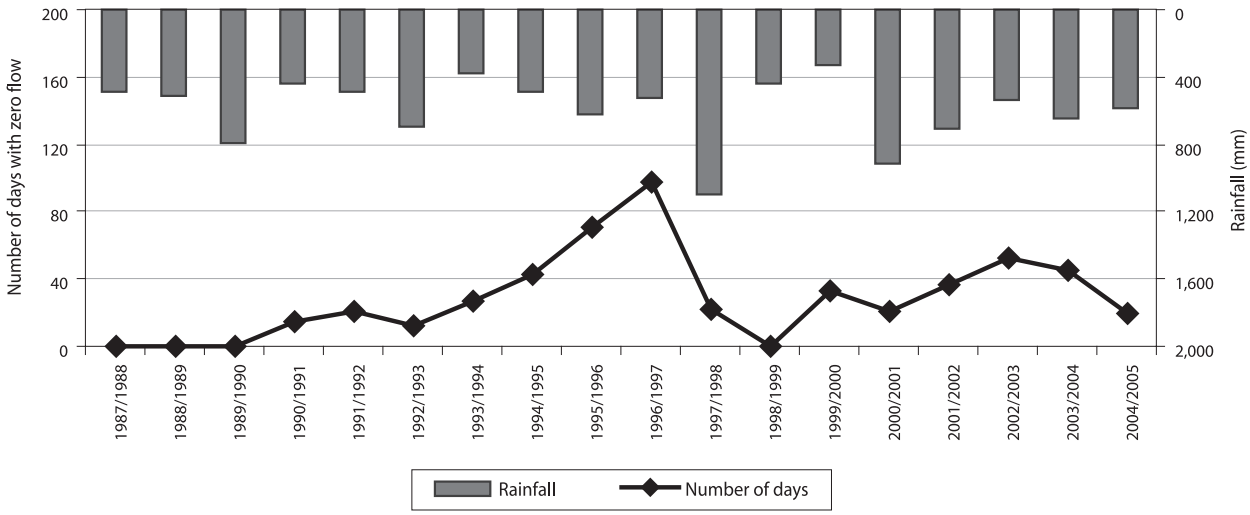
There is much scope for improving water use efficiency in the Great Ruaha River Catchment, particularly in the dry season. The partial canal closure program (see section, *Impact of Irrigation on River Flow*) is having some impact.

[18] Flow variability is a key factor in determining environmental flow requirements. A major assumption of the desk top reserve model, which emerged from an analysis of comprehensive environmental studies in South Africa, is that rivers with more stable flow regimes (i.e., a relatively high proportion of their flow occurring as baseflow) have relatively higher low-flow requirements, than rivers with more variable flow regimes. This assumption is based on the premise that, in highly variable flow regimes, the biota will have adapted to relative water scarcity, while in more reliably flowing rivers, the biota are sensitive to reductions in flow (Hughes and Hannart 2003). The baseflow index (i.e., the proportion of total flow that can be considered to occur as baseflow) of the Great Ruaha River at Msembe Ferry is 0.92, a high value arising as a consequence of both the relatively large size of the catchment (24,620 km^2) and the flow regulation effect of the Eastern Wetland (Kashaigili et al. 2006b).

Measurements indicate that dry season abstractions from the Mbarali River, a tributary of the Great Ruaha River, decreased from 1.454 m^3s^{-1} in 2003 to 0.577 m^3s^{-1} in 2004. The same trend was observed in the Kimani River where average dry season abstractions declined from 0.914 m^3s^{-1} in 2003 to 0.580 m^3s^{-1} in 2004 (RIPARWIN 2006). Since it was instigated in 2001, the inflows to, and hence the minimum dry season area of, Ihefu have increased slightly (Figure 12a). The result is that downstream flows have also improved to some extent and the number of zero flow days have been fewer than would have been anticipated, based on the rainfall in recent years (Figure 14). However, given the socioeconomic importance of the diversions it may not be possible to achieve a significant further reduction in the near future. Consequently, consideration needs to be given to alternative options, including trade-offs between different environmental needs.

Although many benefits are derived from the wetland, evaporation from it depletes the water resources of the catchment. It is estimated that average annual evapotranspiration from the wetland is approximately 790 Mm^3 (i.e., 27% of the natural MAF at Msembe Ferry) (see table 2). Hence, a trade-off that can be contemplated is between the wetland and downstream flows. This trade-off can be expressed in terms of evaporation in the wetland versus maintenance of downstream environmental flows or, alternatively, in terms of benefits for fisheries, livestock and biodiversity in the wetland versus wildlife conservation and hydropower generation. In effect, it is a decision about the size of the permanent wetland: Either a relatively large wetland and downstream flows that are insufficient to satisfy basic ecological requirements or a smaller wetland enabling downstream environmental flow requirements to be attained. In the second option the objective becomes to manage the wetland in a way that, despite limited inflows, the benefits of the wetland are retained as far as possible and simultaneously a flow from the wetland to the Ruaha National Park is facilitated. Such a strategy can only be achieved if greater inflow to the wetland is secured and evapotranspiration from the wetland is reduced so that a proportion of the inflow passes through to the outlet. This requires active management of water within the wetland; specifically, better control of flows within it.

FIGURE 14.
Rainfall and number of zero flow days in the Great Ruaha River, measured at Msembe Ferry between 1987 and 2005.



Source: data provided by the Rufiji Basin Water Office (RBWO).

Currently, dry season evaporation from the wetland is estimated to be approximately 5.8 mmd^{-1} over an average area of approximately 124 km^2. Since 1985, the minimum dry season area of the wetland has varied between approximately 62 and 104 km^2 depending on inflow and rainfall, with an average of 93 km^2 (Kashaigili et al. 2006b). A reduction in the average dry season area of the wetland to 115 km^2 would reduce evapotranspiration by 7.1 Mm^3, which corresponds to an additional downstream flow of 0.5 m^3s^{-1}. It is estimated that the consequent decrease in the minimum dry season area would be from 93 km^2 to approximately 85 km^2.

A reduction in area could be achieved by the better channeling of water through the wetland. Channels are distinct and navigable towards the southern end, where the Ruaha enters, but further north, channels become broken and water moves as sheet flow through reed beds. More rapid flows could be achieved by ensuring that major pools within the wetland are linked by channels and the major channels are kept clear of reeds and other aquatic vegetation. Before they were expelled from the wetland, at the time it was incorporated into the Usangu Game Reserve, the local fisherfolk were very effective at blocking and unblocking channels. If they endorsed the plan and were allowed to return to the Reserve, they could be encouraged to keep channels open, especially if the practice resulted in improved fisheries. Otherwise, mechanical removal of reeds, and/or dredging of channels, might be considered. Comprehensive analyses of the social, economic and environmental implications of reducing the area of the wetland would need to be conducted prior to implementation. This would need to include detailed analyses to more rigorously determine the changes in the wetland area, the likely losses in ecosystem services and the impacts on both local people and downstream water users.

Careful consideration also needs to be given to alternative options for providing water to users, including the use of groundwater and rainwater harvesting for dry season domestic supply, thereby reducing withdrawals from the river. As a last resort, the construction of a multi-purpose dam on the Ndembera River (a tributary of the Great Ruaha River), which could be used for irrigation, but would also enable the release of dry season flow, could be considered (Kashaigili et al. 2006b). For all options, detailed environmental and health impact assessments need to be conducted prior to implementation and the long-term impacts should be monitored by the RBWO to ensure that intended objectives are realized.

Formal Management: Water Rights, Fees and WUAs

Successful development of water resources requires investments in both infrastructure and institutional arrangements for effective management. For this reason, since the 1990s, Tanzania has adopted a dual approach to water resources development, investing in both. World Bank funded programs, such as the RBMSIIP (see section, *Background to the Research*), were intended to assist this twin-track approach. However, the relative importance of the two will not always be the same. Currently, much perceived wisdom is that although concomitant investments must be made at all times, when stocks of hydraulic infrastructure are low, as in many African countries, investment in infrastructure should be given priority (World Bank 2004). This is based on the premise that this will provide both the greatest economic development and greater benefit for the poor with additional infrastructure to store and deliver water

and manage flows, and provide further incentives and conditionalities for more sophisticated management structures and practices. As part of the RIPARWIN project, research was conducted to evaluate the effectiveness of the institutional and management restructuring being piloted in the Great Ruaha River basin. The aim of this research, which largely focused on the Usangu Plains, was to assess whether there were differences between the anticipated and actual outcomes of implementation.

Water Management in the Great Ruaha River Catchment

Contemporary arrangements for water allocation and use within the Great Ruaha River Catchment are built upon a history of water management. Traditionally, rural water use was managed under the customary authority of tribal chiefs (locally called *Mwene*). In many places they established a rotation-based water sharing arrangement, locally known as *Zamu*, which specified when people were given access to water (Mehari et al. 2007). This was not an equitable system, but favored the chiefs, their families and closest associates (usually men). However, it was a system that many older residents of the catchment still recollect with some fondness (Mehari et al. 2007).

German and British settlers introduced formal water law into Tanzania in the early 1900s. This included the establishment of a water 'rights' system, which vested legal control of water to the colonial rulers, and, at least in theory, provided a basis for water allocation. However, in reality, the system was predominantly an administrative measure with only limited implications for large-scale users and no impact for small-scale users. In practice rural water use continued under customary authority (van Koppen et al. 2004).

After independence in 1961, the Tanzanian Government inherited the colonial water rights system and re-affirmed it within the Water Utilization (Control and Regulation) Act of 1974 (Mwaka 1999). This Act not only ignored the existence of customary water law, it also stipulated that only registered water use was legal (Maganga et al. 2003). Strictly, customary water use was illegal. However, in practice, full application of the law was widely ignored and most small-scale water users continued without applying for water rights. In fact, the biggest practical change came following the Arusha Declaration in 1967, which made the village central to development planning in Tanzania. As a result, from the early 1970s the *Mwene* lost influence and elected village administrators took over responsibilities for water sharing and conflict resolution. However, the village administrators tended to neglect water resources development, largely due to their involvement in many other aspects of local government, and as demand and competition increased, the weakest in society (i.e., the poor, women and elderly) lost out (Mehari et al. 2007). More recently, traditional water rights have again been recognized and the latest National Water Policy (MWLD 2002) calls for Basin Water Officers to institutionalize statutes relevant to customary law and practices.

Since its establishment in 1993 the RBWO has officially been responsible for water resources development and management in the Rufiji Basin. To this end, as well as investing in modern irrigation intakes (see section, *Background to the Research*), and in line with government policy, the RBWO has:

- enforced the existing water rights system, which originated in the colonial era, to facilitate water allocation;
- introduced a water fees system to promote 'wiser' use of water and improve cost-recovery for water resources management services; and
- attempted to enhance community involvement in water management, through the establishment of Water User Associations (WUAs) and, in areas with growing upstream-downstream conflicts, so called 'apex' bodies of all users along the stressed river stretch.

Water Rights

In Tanzania, water rights, which provide a legal entitlement to access and use water for specified purposes and at specified times, are required for all productive uses of water. Rural domestic water use is exempted from the need for a water right. However, smallholder irrigation, even using traditional intakes, is required to obtain a water right (Rajabu et al. 2005). The water rights do not guarantee that the specified quantity of water will always be available; during low flow periods the RBWO can suspend or vary water rights as deemed necessary. Close to 1,000 water rights (out of an estimated total of 1,514 water users) have been registered in the Rufiji Basin of which 100 are upstream of NG'iriama (van Koppen et al. n.d.). In many cases, villages have applied for, and obtained, water rights to legally protect the abstraction needs of their irrigation schemes.

The primary objective of water rights is to facilitate the better control and regulation of water in the catchment by enabling the RBWO to sanction new withdrawals, to stop unauthorized abstractions and to prevent over-abstraction. In theory, the aim of insisting on water rights even for very small-scale users is to provide them with a legal tool to safeguard their water resources against infringement by large-scale commercial water users. However, the effectiveness of this tool is yet to be really tested through the courts, primarily because people in Usangu demonstrate a deeply held preference for conflict avoidance and less adversarial approaches to conflict resolution. Despite the history of in-migration and erosion of traditional authority, research indicates that the preferred channels for resolving disputes over water are existing social and cultural structures; only if these fail do people resort to more formalized and transparent conflict resolution mechanisms (Cleaver and Franks 2005).

Studies conducted in the Mkoji sub-catchment indicate that communities are generally willing to formally legalize their abstractions despite the fact that it costs money (see section, *Water Fees*) and is a complex and lengthy procedure with many bureaucratic problems. This is possibly because they appreciate that water is increasingly scarce and suspect that they will lose out to other villages if they do not do so. It is also clear that in many cases communities anticipate that registering water use, and paying the requisite water fees, will result in investment in water infrastructure (e.g., conversion of traditional to modern irrigation intakes and lining of canals) (Mehari et al. 2007). However, these same studies also indicate that, to date, issuing water rights has not had the anticipated impact on controlling withdrawals. Flow measurements indicate that in some schemes abstractions are up to twice the legal water right (Mehari et al. 2007) and even where water rights are not being exceeded, considerable volumes of diverted water continue to be wasted (Rajabu et al. 2005). In some places abstractions are constrained not by the water right, but simply because there is insufficient water in the river. This is perhaps not surprising, given the current inability of the RBWO to effectively police the system due to lack of reliable data on flow volumes and monitoring of water diverted, even in the larger irrigation schemes (van Koppen et al. 2004).

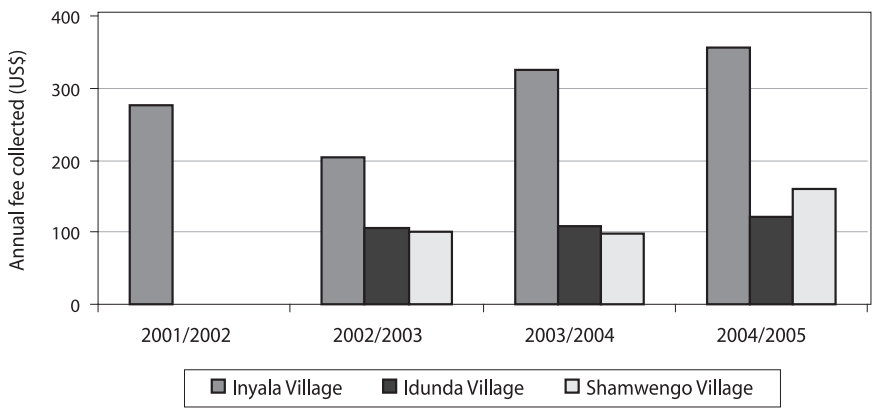
Water Fees

In Tanzania, for small-scale irrigation a one-off administration charge of US$40 is charged for water right applications and a flat rate of US$35 per year is charged for water use less than 3.7 ls^{-1}. Above 3.7 ls^{-1} an annual increment of US$0.035 is charged per 100 cubic meters (m^3) of additional water used. For large-scale irrigation, the corresponding figures are US$150 for the application, US$70 for water use up to 3.7 ls^{-1} and US$0.070 per 100 m^3 of additional water used (van Koppen et al. n.d.). In theory, these fees have a dual purpose. First, to improve the cost recovery of water management activities. Second, to provide a financial incentive to communities, schemes and individuals to reduce waste and optimize water use (i.e., promote more effective use of water) (Sokile and van Koppen 2004).

It is the desire of the government that ultimately the RBWO should be financially autonomous (Mehari et al. 2007). In relation to cost recovery, the RBWO estimated its operating costs in 2006 to be about US$1 million. Of this, approximately one-third is anticipated to be obtained from water fees. The World Bank estimates that of the 1,514 abstractions in the Rufiji, 1,050 are billed, and of these, 70 percent pay. Currently, the total amount of money derived from water user fees amounts to US$52,600 per year (World Bank 2004). However, this excludes US$165,500, which is the royalty paid by TANESCO for all hydropower stations in Tanzania (i.e., in the Great Ruaha River and Pangani River basins), which goes directly to government.[19] The shortfall in costs is currently being covered by the government (i.e., through taxation) and from donors.

In communities in the Mkoji sub-catchment, fees are shared amongst those in the community deemed 'able to pay', i.e., those with access to labor and other resources to actively cultivate at least 0.1 ha of irrigated land. Those deemed 'unable to pay' include the elderly, children, disabled as well as those with persistent diseases and those who do not own irrigated land. These people, identified by the Village Administration, are also exempt from other local taxes and school fees. Thus, a form of 'safety net' protects the weakest in society from having to pay fees that they might not be able to afford. Typically between 30 and 50 percent of village populations contribute between US$0.3 and US$2.0 to the annual fees (Mehari et al. 2007). In interviews, up to 80 percent of all users (including those least well-off) indicated that the fees were affordable and many respondents indicated that they accepted the need to pay fees providing: i) they were furnished with an adequate and reasonable supply of water; ii) there was some investment; iii) there was transparency in water fee assessment; and iv) local water user associations were able to retain some of the money. These findings seem to be borne out by analyses of actual fees collected between 2001 and 2005. This indicates that although fees collected vary significantly between villages, as well as in wet and dry years (presumably reflecting availability of water), there was generally an upward trend in water fees collected, suggesting an overall increasing willingness to pay (Figure 15).

FIGURE 15.
Water fees collected in three villages in the Mkoji sub-catchment.



Source: derived from data presented in Mehari et al. 2007.

Note: no data available for Idunda and Shamwengo villages in 2001/2002.

[19] The royalty paid is independent of electricity production and water use. In 1997, it amounted to just 0.1% of TANESCO's power sales and about 0.14% of the cost of electricity production. In 2002, a drought year which significantly impacted production, the royalty amounted to 11% of the cost of production and about 2% of the total cost of sales (World Bank 2004).

The current water fees do not contribute to more effective use of water in the catchment. In many places irrigators are currently expanding their irrigated land to maximize benefits from water they have “paid for” (Sokile and van Koppen 2003; Mehari et al. 2007).

A survey conducted in the Inyala village, which has two modern intakes and a water right of 500 ls^{-1} (Mehari et al. 2007), indicates that total annual income generated from irrigated agriculture and brick-making (the two primary uses of abstracted water) is approximately US$8,641, compared to US$4,821 generated from rainfed agriculture (Table 5). Thus, the fees collected in 2004/2005 (i.e., US$356, out of a possible total of US$449 if all those ‘able to pay’ did so) amounts to 4.1 percent of the income generated.

With the exception of the partial canal closure program negotiated by the RBWO, there is no evidence of water regulation. Farmers are not reducing demand to save on water fees. The World Bank argues that, currently, the monetary allocations from the government are too small to allow the RBWO to function properly and water user fees should be the most important source of revenue. It also proposes that to be effective as a tool for controlling water use, water user fees for irrigation (as well as hydropower production) need to be increased significantly (World Bank 2004). However, while monitoring of abstractions is so limited, there is no way to link the fees to the water abstracted. Furthermore, in a country in which rural development is high on the list of government priorities and the majority of voters are rural dwellers, there is a clear political incentive to keep fees low. The danger is that, as clearly illustrated by the electricity-water nexus in South Asia, once politicized it can be extremely difficult to increase charges however legitimate the reason (Shah et al. 2003)[20]. Consequently, as a mechanism for controlling water use the utility of fees would seem to be strictly limited.

TABLE 5.
Annual income (for 2003) generated in Inyala Village.

	Number of households	Average area per household (ha)	Average income per household (US$)	Total area (ha)	Total income (US$)
			Irrigated agriculture		
Maize	52	0.365	119.4	18.98	6,208.8
Beans	46	0.470	21.8	21.62	1,002.80
Tomatoes	34	0.273	24.2	9.28	822.80
Onions	27	0.4128	19.8	11.15	534.60
			Brick-making		
	15	-	4.8	-	72.0
				Total	8,641
			Rainfed agriculture		
Maize	53	0.3825	57.5	20.27	3,047.50
Beans	26	0.3025	48.7	7.87	1,266.20
Tomatoes	19	N/A	26.7	N/A	507.30
				Total	4,821

Source: survey data adapted from SWMRG (2004).

[20] In Southeast Asia, considerable volumes of groundwater are pumped for irrigation from tube wells using subsidized electricity. As a result, groundwater resources are being depleted at unsustainable rates. However, opposition from the farming community has frustrated efforts to rationalize energy prices, largely because politicians realize that increasing prices will lose them substantial votes.

Institutional Arrangements

A key component of the RBWO strategy is increased community participation in water management, facilitated through the establishment of Water User Associations (WUAs). Founded on principles of institutional design (e.g., Ostrom 1990)[21], the need for WUAs is based on the concept of 'nested' structures, in which small local systems form the building blocks, which come together to create larger management institutions. Thus, in theory, nesting is a mechanism for multiple layers of management, to link small-scale local interactions to larger, and ultimately basin-scale, actions (Cleaver and Franks 2005; Lankford 2007).

In the Mkoji sub-catchment, the first in which WUAs are being established, WUAs have been set up in 24 out of 91 villages. Elected representatives on the WUAs are tasked with establishing and implementing water sharing, managing conflict resolution mechanisms and collecting water fees. An Apex Water User Association (AWUA) was established in 2003 primarily to resolve conflicts between WUAs and also to implement soil and water conservation measures. Members of the AWUA are elected from the WUAs (Mehari et al. 2007).

In many villages the WUAs have reverted to a form of *Zamu* as the core of water sharing mechanisms. It is not clear to what extent historic inequities of this system (see section, *Water Management in the Great Ruaha River Catchment*) have been avoided, but it is reported to have significantly reduced within-scheme conflicts (Mehari et al. 2007). However, in contrast, although the AWUA has made significant advances in educating local communities on environmental measures, there is little evidence that it has been effective in its primary mandate of inter-scheme conflict resolution. In fact, in at least one instance, the AWUA is reported to have withdrawn from dealing with a conflict between two villages, which was subsequently left to the individual village WUAs to try to reach a resolution (Mehari et al. 2007). There is a perception that the AWUA is already organizationally cumbersome and too heterogeneous in composition to be effective in mitigating inter-scheme conflicts, factors that will only get worse as more WUAs are formed (Mehari et al. 2007).

The likely effectiveness of the newly established water management institutions has been questioned for a number of reasons. First, the complex nature of livelihoods and their relationship to linked systems of natural resources make it difficult to identify and define authority structures that can take overall responsibility for resource use and management. Authority is not simply vested in government structures (which are themselves fragmented) but, in common with other African countries, dual legal systems incorporating customary and modern arrangements exercise jurisdiction over natural resource use. Within Usangu, traditional elders and remnants of the *Mwene* chieftainships still wield authority and influence the formulation and implementation of local byelaws affecting access to, and the use of, water. Second, formal enforcement of water regulations is complicated, both by the lack of monitoring and by the prevalent social norms, which places greater emphasis on non-confrontational approaches to dealing with non-compliance. Third, the physical size of the basin means that local level institutions dealing with local issues find it difficult to acknowledge issues facing others in the basin, who may be located many hundreds of kilometers away, and for whom the key issues may be very different. For instance WUAs in the upper part of the basin, primarily engaged in allocating water for irrigation, may not fully appreciate the differing needs of pastoralists and certainly have no idea of hydropower requirements[22]. Hence, it seems that the institutional design principles that have been

[21] These emphasize the formalization of institutional arrangements, the codification of rules and regulations, the need for clear authority structures and the strict enforcement of sanctions against rule breakers.

[22] Many local people living within the Usangu have no conception of what a large dam looks like or how it functions in relation to hydropower (Cleaver and Franks 2005).

applied in the development of the contemporary water basin management institutions are not well suited to either the existing institutional arrangements or the livelihood strategies and understandings of local people. What seems probable, and is already happening to some extent, is that institutions will evolve over time as hybrids of modern and traditional arrangements linked together in complex and fluid networks (Cleaver and Franks 2005).

Decision Support Systems: The Ruaha Basin Decision Aid and the River Basin Game

The complexity of water resources management and the difficulties of making decisions about the allocation of water resources have been highlighted above. In such situations, decision support systems (DSS) are intended to assist water managers to make rational decisions. In theory, a DSS helps structure decision processes and support the analysis of complex situations. In Tanzania, the National Water Act highlights "water resources models and decision support systems" as instruments required for the implementation of water policy and a means of achieving an integrated multi-sectoral approach. However, concerns have been expressed about the utilization of DSS for decision-making. These concerns focus on the lack of communication between developers and users, lack of documentation and support services and the lack of involvement of a subjective and value-dominated human element (Loucks et al. 1985). As a consequence of the emphasis almost exclusively on the development of more sophisticated, complex and bigger models, they often end up not being fully accepted by planners and managers (Savic and Simonovic 1991). Furthermore, although in the past water resources planning and management was left solely to technical professionals, this is no longer the case. The need to satisfy societal requirements has expanded beyond the simple objective of water supply and increasingly a diversity of concerned parties and organizations (only a fraction of whom may be represented by technical professionals) want input into the decision-making process. This requires different approaches and new types of DSS, for example, non-computer tools, such as role-playing games, which facilitate the involvement of communities in decision-making processes. In the RIPARWIN project, two different types of DSS were developed: i) the Ruaha Basin Decision Aid (RUBDA), and ii) the River Basin Game (RBG).

The Ruaha Basin Decision Aid (RUBDA)

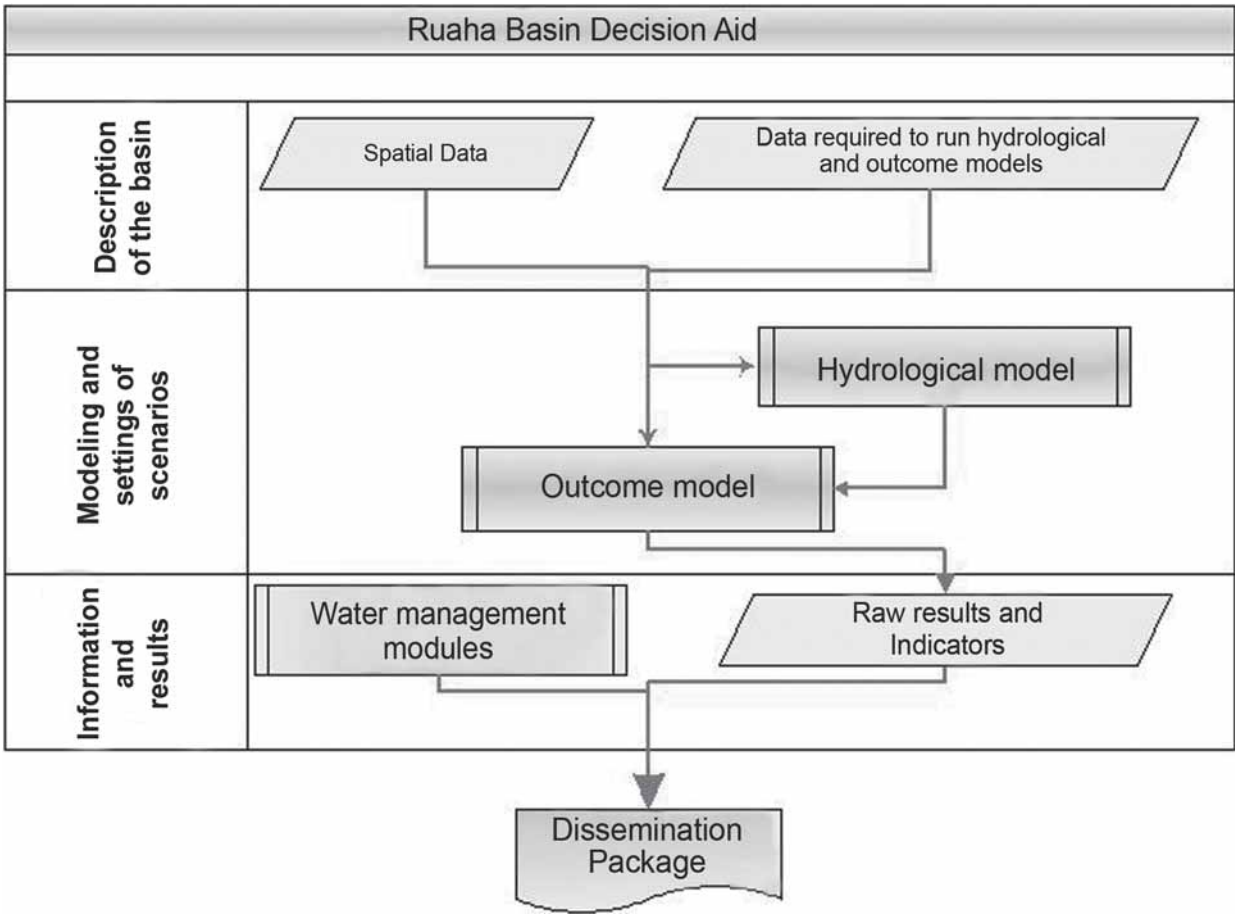
RUBDA is a computer software program intended to support water resource managers in the RBWO and District Councils to make decisions about the allocation of water between sectors. It is based on several components, comprising a hydrological model, an outcome model and a water management module, and is accompanied by a 'Geographical Information System' (GIS) user interface (Figure 16). It provides a means of comparing the impact of different scenarios, whether these are policy-driven, physical change or water demand scenarios. Results are presented in the form of a number of different indicators (Cour 2005).

An innovative aspect of RUBDA is that it was designed and developed in consultation with many basin stakeholders. The overall structure was first adopted during the project steering workshop in September 2002, where key policy

stakeholders from government ministries and representatives of most of the Great Ruaha River Basin's stakeholders were present. Subsequently, RUBDA has evolved in accordance with discussions held during various seminars and workshops, as well as interviews that were conducted with stakeholders. In addition, RUBDA has been modified in accordance with user requests made during the several training courses that have been held. Although these focused primarily on making the front-end of the system more user-friendly, substantive suggestions on the modeling approach were also received and acted upon.

In part, because of the lengthy process of consultation and the complexity of linking the various components together, RUBDA took much longer to develop than originally anticipated[23]. However, at a training workshop in June 2006, the Rufiji Basin Water Officer expressed satisfaction with the consultation process. It is anticipated that, when finalized, RUBDA will significantly enhance the ability of the RBWO to perform one of its core functions, namely, assessing new applications for water rights and matching water abstractions to available water resources. By using the hydrological and socioeconomic information that it provides, the

FIGURE 16.
Structure of the Ruaha Basin Decision Aid.



Source: Cour 2005.

[23] This is another common problem with DSS development.

impacts of different scenarios of resource allocation can be determined and users will be able to evaluate different water allocation decisions, including options for transferring water between uses. Involving the key stakeholders in the design of RUBDA has ensured that it provides information that is appropriate to the decision-making processes ongoing in the basin and gives confidence that it will be used.

The River Basin Game (RBG)

In contrast to RUBDA, which is a DSS designed specifically for water resource managers, the RBG is intended as a tool to facilitate dialogue between decision-makers and water users and between users themselves. The concept of the RBG is underpinned by the premise that successful management of water resources in environments experiencing water stress is dependent on the success of acquiring and sharing knowledge. The importance of knowledge development and balancing perceptions held by different stakeholders has increasingly been the subject of discussion (e.g., Dwivedi 2001). In this instance, it is argued that participation in knowledge sharing is a fundamental prerequisite because of the cumulative effects of individual actions on patterns of water use. Furthermore, it is surmised that collective behavior may be altered by changing the actions of individuals through provision of new knowledge (Lankford and Watson 2006).

Initially designed as a teaching tool for students, the RBG comprises a physical representation of a catchment in the form of a large wooden board. The central river flows between the upper catchment and a downstream wetland, and has on it several intakes into irrigation systems of varying sizes. Glass marbles that 'flow' down the channel represent the river water. Participants place small sticks (like weirs) across the river to capture the marbles and scoop them into the irrigation systems where they sit in small holes—thereby meeting the water requirement of that particular plot of rice or irrigation activity (Figure 17). The players learn that being at the top of the river has advantages, whilst tail-end systems experience water shortages. The implications of different and new management strategies can be evaluated in detail by different stakeholder groups (Lankford et al. 2004b).

FIGURE 17.
Participants playing the River Basin Game.

Source: photo credit: Bruce Lankford.

Throughout the RIPARWIN project, the RBG was used extensively with communities in the Great Ruaha River Basin, as part of two-day workshops on water resource conflicts and management issues. It was modified based on knowledge gained and has subsequently also been used in Nigeria, India, Kenya and South Africa. Recently it has been adopted as a dialogue tool by a Non-Governmental Organization (NGO) project, called the Traditional Irrigation Improvement Programme (TIP) dealing with irrigation located in northern Tanzania. Experience indicates that the game promotes mutual understanding of different people's levels of access to water and allows participants to actively react to scenarios. During the game participants often become highly animated indicating an emotional as well as an intellectual response to playing. By the end of the game, they usually have a good understanding of system dynamics and common property pitfalls, which issues are most critical and, by drawing from their own and outsider's knowledge, what solutions might be possible. Furthermore, participants are often able to contribute in detail to new solutions and propose new institutional arrangements.

The value of the game has been considered and its success is attributed to the quality of the 'metaphor' that it provides. It is surmised that the behavior of marbles in the game is sufficiently close to that of water (since they are limited in number and move) to ensure that rules evolved through the game are clearly applicable to 'real life'. At the same time they are just sufficiently removed from reality to permit situations of conflict and tension to be approached in a constructive and less adversarial manner. Thus, players are able to practice both conflict and cooperation. Furthermore, because the results of actions and choices of players are transparent and measurable (i.e., simply by counting marbles) it can lead to rules that are clearly unambiguous in their supporting rationale of equity and the distinction between wants and needs (Lankford and Watson 2006).

In relation to knowledge, the game appears to impact in two areas: 'knowledge organization' and 'knowledge building'. With regards to the first, the game assists participants to make their knowledge, regarding their daily experience, explicit and organized and, hence, more useful. In respect to the second, the game promotes a sharing experience of shifts in understanding. The outcome of this sharing is believed to be greater confidence in how to deal with knowledge collectively and, hence, how to manage water more effectively (Lankford and Watson 2006).

Impacts of the game are difficult to quantify, but it is hoped that two kinds of change will occur: material and social. The material changes hoped for include improved management of water resources, improved partition of crop yields, less poverty and other benefits. The social changes hoped for include improved insight by players into the problems of partitioning water resources equitably and, hence, improvements in the relationships between upstream and downstream users (i.e., in part, addressing the problems of scale outlined above). Preliminary analyses indicate that the RBG has had some impact. A recent study found that communities where the game has been played are more likely to implement strategies to improve water management than communities where the game has not been played (Kayombo 2007).

Concluding Remarks

In the face of growing water stress and increasing concerns over the sustainability of water use, Tanzania has, in compliance with the current widely accepted notions of best practice, and in common with many other countries, focused largely on the development of more integrated catchment-wide approaches to water management. In the Great Ruaha River Basin, considerable effort has gone into increasing water productivity and the promotion of mechanisms for more efficient allocation of water resources among different uses. Because it is such a large user of water, and widely perceived to be inefficient, attempts to increase irrigation productivity have been at the forefront of these endeavors.

Over a period of five years, the RIPARWIN project investigated water management in the basin and evaluated the effectiveness of some of the mechanisms that have been introduced. The project found that, while in theory increasing irrigation water efficiency is a good idea and it is technically feasible, it has proved very difficult to achieve in practice. To date, changes to irrigation infrastructure have seemingly compounded water shortages. Changes in institutional and management arrangements, particularly the canal closure program, have had some impact but there is still a long way to go to achieve the objective of returning the Great Ruaha River to year-round flow. Problems of water conflict and environmental degradation have not yet been resolved. In summary, the following specific findings were derived:

i) Contrary to assumptions made prior to the RBMSIIP, smallholder farmers tend to be more water use efficient than the large NAFCO farms. This is primarily because their access to water is often constrained so that they have no choice but to be more careful with their supply. It was also found that their yields, although very variable, also tended to be similar to those of the NAFCO farms, so that the overall productivity of rice per unit of water on the smallholder farms was higher or approximately the same (certainly no lower) than that of the NAFCO farms.

ii) Current technological impediments and the lack of incentives to improve irrigation efficiency mean that on many farms water is being lost in a non-beneficial way. Increasing local irrigation efficiency in the Great Ruaha River Catchment, by reducing non-beneficial losses (i.e., nonproductive evaporation from bare plots), is technically feasible. If the efficiency of all the farmers was increased to that of the currently most efficient smallholders, it is estimated that this would 'release' approximately 100 Mm^3 of water (i.e., equivalent to 12% of the water currently 'used' in irrigation) which could potentially be used in other ways, thereby increasing the overall water productivity of the basin.

iii) The implementation of water rights and water fees for productive uses of water was supposed to facilitate allocation and promote increased efficiency. However, in the absence of effective monitoring, enforcing compliance with water rights is impossible and in some places withdrawals are up to 200 percent of the permitted level. Furthermore, although people generally accept the need to pay fees (providing they see improvements in supply and there is a safety net to protect the poorest), the current pricing mechanisms fail to provide an adequate incentive for regulating water use. In fact, the evidence is that, contrary to expectations, rather than curtailing water use, farmers are instead expanding their irrigated land to utilize the water that they have 'paid for'.

iv) Modernization of irrigation intakes is popular with farmers (because they reduce labor requirements and facilitate withdrawals at lower flows), but because the gates are usually simply left open, they abstract more water than traditional structures, increase losses and deprive downstream users of water at critical times. Hence, the modern

intakes have had the reverse of their intended impact. Alternative designs, that limit the maximum volume of water that can be diverted at times of high flow and simultaneously facilitate the diversion of variable proportions of river water during the dry season, could contribute to better upstream-downstream water sharing. However, the key to better water use remains improved mechanisms for monitoring and enforcement of water rights, particularly of large water users.

v) Although very difficult to evaluate in financial terms, both the Usangu wetlands and the Ruaha National Park provide ecosystem services that bring benefits to many people. For example, it is estimated that up to 95 percent of households living on the Usangu Plains benefit in some direct way from the wetlands. Upstream water withdrawals are causing considerable environmental degradation of both ecosystems. The minimum dry season area of the Ihefu wetland has decreased by approximately 40 percent and the dry season cessation of flows within the Ruaha National Park has resulted in the death of many animals and the destruction of habitat.

vi) To maintain the basic ecological condition of the river within the Ruaha National Park requires an annual environmental flow allocation of 635 Mm^3 (i.e., 22% of the mean annual natural flow at Msembe Ferry) and an absolute minimum flow of not less than 0.6 m^3s^{-1}. To attain these flow requirements necessitates a minimum dry season flow into the Ihefu wetland of about 7.0 m^3s^{-1}. This would require a reduction in dry season withdrawals of approximately 65 percent. Although increased efficiencies are possible, and are occurring as a result of the canal closure program, given the importance of withdrawals for livelihoods in the area, such a decrease is unlikely to be achievable in the near future. In light of this, one option to increase downstream dry season flows is active water management that would reduce the size of the wetland and thereby decrease evapotranspiration. However, although hard to quantify, the value of the ecosystem services provided by the wetland may be substantial. Consequently, prior to implementation, detailed environmental impact assessments to assess the full environmental and social implications of such a change, including the implications on downstream users, are essential.

vii) Gross mean economic returns on depleted water from rice irrigation and hydropower are estimated to be US$0.02 and US$0.21 m^{-3}, respectively. Although these figures neglect costs, they nevertheless provide an indication of the relative value of water use in the two sectors. Consequently, if based simply on criteria of economic efficiency, water would be allocated away from irrigation to the downstream hydropower schemes. However, in deciding allocations, other issues need to be considered, including equity and pro-poor returns as well as the implications on national food security. Ultimately, in this instance, water allocation is a difficult political choice.

viii) Benefit-sharing mechanisms (e.g., through the establishment of a regional economic development fund, financed from dam revenue) would be one way of creating incentives for farmers to release water to the downstream hydropower plants. In addition, more geographically-defined sharing might be possible, if wetland users were paid to keep channels open to deliver water to the Ruaha National Park. For poverty alleviation, consideration should also be given to the promotion of enterprises that use relatively small amounts of water, but have relatively high returns (e.g., brick-making).

ix) Changes to institutional arrangements (i.e., the establishment of nested structures with WUAs providing the basis for local level water management) have been based on modern principles of institutional design, but

do not appear to be well suited to the livelihood strategies, social norms and understandings of local people. It is anticipated that the institutions will evolve over time into amalgamations of modern and traditional arrangements. Indeed this is already occurring and where WUAs have reverted to traditional approaches to water sharing (i.e., *Zamu*) the incidence of intra-scheme conflict is reported to have been significantly reduced. However, there is no evidence that the WUAs are focused on improving water use efficiency.

x) The project demonstrated the value of different types of decision support system to both assist water resource managers to make rational decisions about water allocation and to facilitate the involvement of non-specialists in the decision-making process. Involving a range of stakeholders throughout its development enhanced the value of RUBDA and the likelihood that it will provide useful information. The value of the RBG is believed to arise from its role in knowledge organization and knowledge building within communities, and it is anticipated that it will facilitate improved water management by modifying collective behavior. However, the long-term effects of such tools need to be fully evaluated through further research and monitoring.

Despite the many complex problems, it is clear that there is significant political will, and the RBWO is making determined efforts to find pragmatic and equitable solutions to the many water related problems in the Great Ruaha River Basin. The basin was selected by the Government of Tanzania as a test case with the specific intention of enabling contemporary policy and management frameworks to be evaluated in the national context. Through the research conducted by the RIPARWIN project, and other studies, many lessons have been learned that should contribute to better water management in the future. The research has highlighted many important aspects of water management that are relevant to similar situations of growing competition for water set against a backdrop of accelerated rural growth, elsewhere in Tanzania and, indeed, Africa. With this in mind, the following generic messages are believed to be most pertinent:

1) **Improving local irrigation water efficiency and productivity can, in certain circumstances, be important.** In water stressed catchments, where irrigation is located upstream of other uses and significant amounts of water are being lost in non-beneficial ways, improving the efficiency and productivity of irrigation is an important means of ‘freeing’ water for other uses. Lessons can be learned from smallholder farmers who often have no choice but to irrigate efficiently and effectively.

2) **Care is needed in the design and planning of irrigation infrastructure.** In water stressed catchments, where the intention must be to increase catchment level productivity and simultaneously improve the equitable sharing of water resources, careful consideration needs to be given to both the physical design and the management of intakes. This is particularly important in the absence of strong monitoring and regulation, when the opportunity for over-abstraction of water is high.

3) **Trade-offs between different ecosystems may be necessary.** Where water is important for poverty reduction and socioeconomic development, it is not reasonable to plan only environmentally favorable allocations and it maybe necessary to manage trade-offs between different ecosystems. Such trade-offs need to be based on detailed understanding of the consequences for ecosystem services, and their role in supporting the livelihoods of the poor.

4) **Economic valuation alone is not sufficient for determining water allocation.** Although the allocation of water should be informed by an understanding of

its full economic value in various uses, this needs to be bolstered by consideration of equity and development needs. Sustainable water resource management requires that water be treated as both an economic and a social good. Mechanisms for benefit-sharing need to be sought.

5) **Contemporary systems for water management need to be cognizant of, and, where appropriate, build on existing indigenous arrangements.** Enhancing community involvement in water management through, for example, Water User Associations is most effective when they build on and strengthen local water management approaches, while recognizing that customary arrangements can perpetrate inequitable sharing based on gender or poverty. Pragmatic mixing of new and existing management arrangements, to deal with contemporary problems of water allocation, can help to improve services and reduce conflicts.

6) **Water management can be enhanced through tools that promote stakeholder dialogue.** Tools such as the River Basin Game and the Ruaha Basin Decision Aid, which facilitate mutual understanding of system dynamics and social learning, provide a basis for discussion, which allows stakeholders to contribute directly to ideas for improved water management. It is anticipated that decisions made with the assistance of such tools are more likely to be sustainable and potentially reduce conflict in the long-term.

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