

14 A Legal–Infrastructural Framework for Catchment Apportionment

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Abstract

We propose a water management framework for bringing together formal and informal water rights and irrigation intake design to apportion water in catchments. This framework is based on setting and modifying seasonally applied volumetric and proportional caps for managing irrigation abstractions and sharing water between upstream irrigators and downstream users in river basins. The volumetric cap, which establishes the upper ceiling of irrigation abstractions in the wet season, relates to formal water rights and maximum intake capacities. The proportional cap, which functions in the dry season beneath the volumetric ceiling, builds on customary water negotiations and on the design and continual adjustment of intakes by users. Both caps should be viewed as being adjustable in response to dialogue between users. The analysis is informed by conditions found in the Great Ruaha river basin, southern Tanzania, where rivers sequentially provide water for irrigation, a wetland, the Ruaha National Park and for electricity generation. Consequences for catchment interventions in the face of climate, population and land use change are explored.

Keywords: water management, framework, formal, informal rights, irrigation intakes, Tanzania.

Introduction

The apportionment of water between sectors in river basins requires the resolution of three matters: (i) establishing a vision of water allocation (river basin objectives for who gets what water); (ii) creating and sustaining the physical, legal, economic and institutional means of distributing water according to this vision; and (iii) monitoring outcomes so that further adjustments can be made to both vision and means. Of these three, the most difficult is the second, requiring the deployment of a water governance architecture that: (i) utilizes various allocation devices; (ii) involves and recognizes many stakeholders; (iii) selects relevant tech-

nology and infrastructure; (iv) accommodates issues of scale and timing; and (v) is underpinned by an appropriate legal and institutional framework. With regard to the latter, the gaps, overlaps and contradictions occurring between formal and informal legal agreements that fit within that architecture pose particular problems. Arguably, this is the key challenge for integrated water resources management in Tanzania (Sokile *et al.*, 2003), and arguably for sub-Saharan Africa in the face of changes in climate and technology and land use. How this challenge might be met is the subject of this chapter.

Although theoreticians may articulate ideal legal and institutional frameworks, in reality

such frameworks commonly suffer from incongruities that exist between institutional functions, practices, objectives and biogeographic properties (Moss, 2004). Water frameworks have to help achieve river basin objectives, work within the limitations imposed by inherent conditions, fit other economic and infrastructural devices and often build on existing progress made. The scope for rethinking a wholly new institutional matrix may be severely restricted. In this regard, the contribution of this chapter builds on existing legislation in Tanzania. Furthermore, systemic challenges also exist: for example, research may point to the benefits that local user agreements can play at the local level, but how do we ensure that local user agreements collectively result in large-scale and bulk-water redistribution, and how should local agreements that may operate well at the irrigation level be applied to the catchment level? If informal arrangements are not dovetailed into higher-level formalities and other allocation devices, new legislative and institutional frameworks will only partially succeed.

This chapter proposes a framework that fits together legal, institutional and infrastructural water management provisions, recognizing the synergy between different components of water management, building on present-day policy directions and acknowledging contextual properties and processes (Garduno, 2001). The framework emphasizes the division of water management into wet and dry seasons, arguing that formal water rights have a role in the wet season, and that customary or local water agreements relate better to conditions found in the dry season (though clearly a variety of ongoing discussions and consultations are required throughout the year – this is not to propose a mutually exclusive division).

The two key assumptions here are that formal rights relate to access to water quantities measured by a flow rate (e.g. l/s) and that customary agreements relate to access to water quantities described by an approximate share of the available water (e.g. ‘about half of what is present in the stream’). The assumptions are valid because formal rights are denominated in volumetric terms while customary agreements in their original form (an important distinction, since customary rights can be transmuted

during formalization procedures into volumetric measures) are founded on a notion of access to an (unmeasured) quantity of water, combined with the notion that not all the water can be abstracted from a stream or irrigation channel (Gillingham, 1999; SMUWC, 2000). Therefore, customary agreements, for the purposes of this chapter, pertain to negotiations over water *shares* that theoretically range from 0% (no water is abstracted) to 100% (all the water is abstracted), with the observation that stream-flows are divided by trial using proportionally based intakes rather than by measuring flow using gauges, weirs and adjustable gates.

The framework explicitly works with the wet/dry season separation to assist rather than undermine these legal pluralisms and water reallocation objectives. This fits the call by Maganga *et al.* (2003) for an approach that ‘combines elements of RBM and customary arrangements at the local level’ and underpins upstream–downstream transfers of water within an ecosystems services approach. The framework is not a classification as proposed by Meinzen-Dick and Bakker (2001), who examined rights associated with different water purposes. The proposal here concerns mainly agricultural productive use of surface water that also meets domestic purposes in villages within the command area. It should be emphasized that this chapter (which utilizes research from two projects – SMUWC¹ and RIPARWIN² – that have studied river basin management in the Great Ruaha River, part of the larger Rufiji basin) is exploratory in nature. The discussion here applies to the catchment scale³ rather than to the larger basin scale, because it is in the former where the tensions associated with irrigation abstractions and downstream needs are most keenly felt. This chapter also briefly discusses some concerns related to the sustainability and workability of the new arrangement, particularly with respect to irrigation intake design and conceptualization.

River Basin Management Initiatives in Tanzania

The Rufiji and the Pangani are two basins that have been supported by the Ministry of Water and Livestock Development (MOWLD) and a

World Bank Project (River Basin Management and Smallholder Irrigation Improvement Project, RBMSIIP) to manage water at the river-basin scale via the establishment of river basin offices (RBOs). Although details on these projects are available elsewhere (World Bank, 1996; Maganga, 2003), two⁴ key activities of the basin offices are described here.

Formal water rights

Water for irrigation is managed via the issuance of formal water rights (which will be called 'permits' according to the new Water Policy) to water users against the payment of an annual fee, that are expressed in quantitative flow units (e.g. cumecs) (Mwaka, 1999). Associated with this is the registration of users and establishment of water user associations as legal entities. Maganga (2003) outlines the new thinking in the Water Policy (MOWLD, 2002) that has been partly incorporated into the new Water Strategy (MOWLD, 2004), which aims to regulate water use on the basis of statutory legal systems. Therefore, formal water rights are the key means of achieving redistribution in Tanzania (World Bank, 1996). However, as Maganga points out, law-making to date has not recognized the role that customary agreements play at the local level, though space for customary agreements is given in the new putative legislation and, therefore, a future activity will be to incorporate customary arrangements in ways that fit the rubric of the legislation.

Recent research (van Koppen *et al.*, 2004; Lankford *et al.*, 2004) supports the view that customary rights have not been fully recognized and, in addition, shows that the formal statutory rights may be structurally flawed in three ways: first, payment for water is not related to volume actually used, and so they may not dampen demand as they are supposed to do, but instead help increase demand. This lack of fit relates to discrepancies between the water right abstraction rate and the designed intake abstraction rate as is explained below. Secondly, they mainly address water availabilities found in the wet season rather than in the dry season, when important redistribution objectives are equally, if not more, critical. According to the Rufiji Basin Water Office

(RBWO), there is a nominal 50% reduction in the water right during the dry season, but this too is not against measurement, and does not relate to the real decreases found in river flows, which are closer to 10% of the wet season flows. Thirdly, they demand high levels of supervision that are not commensurate with resources available to the basin authorities.

Discussions with the Ministry of Water and Livestock Development seem to indicate that there is no plan to change the policy on the use of statutory rights, and that water rights will continue to be issued. The RBWO has recently been requested by its Board to review the current status of rights already issued with a view to bringing them into line with water availability. An appropriate accommodation of customary agreements might be highly beneficial, as research shows that, in parts of the Great Ruaha basin, local users negotiate and share river flows at the irrigation system level and catchment scale (Gillingham, 1999; SMUWC, 2000).

Irrigation improvement programmes

Where identified, smallholder irrigation systems had their intakes upgraded from traditional construction (e.g. stones and mud) to that of a concrete and steel gate design using a weir to raise water levels and a sluice gate to adjust discharge (see Fig. 14.1). Theoretically, this brings water control and adjustability and makes possible the measurement of water flows – and has long been thought to raise irrigation efficiency (Hazelwood and Livingstone, 1978). This change in – or upgrading of – the intake is usually the single greatest component of the so-called 'irrigation improvement programs' (Lankford, 2004a).

However, such technological change needs to be carefully scrutinized before being termed an 'improvement'. The change can be analysed by examining two related components of the design process: (i) sizing the dimension of the intake (note that main canal sizing is part of the headworks design but, for the sake of simplicity, the discussion here refers to the intake design); and (ii) configuring the operability of the intake – its ability to be operated, adjusted and understood in terms of a volumetric or

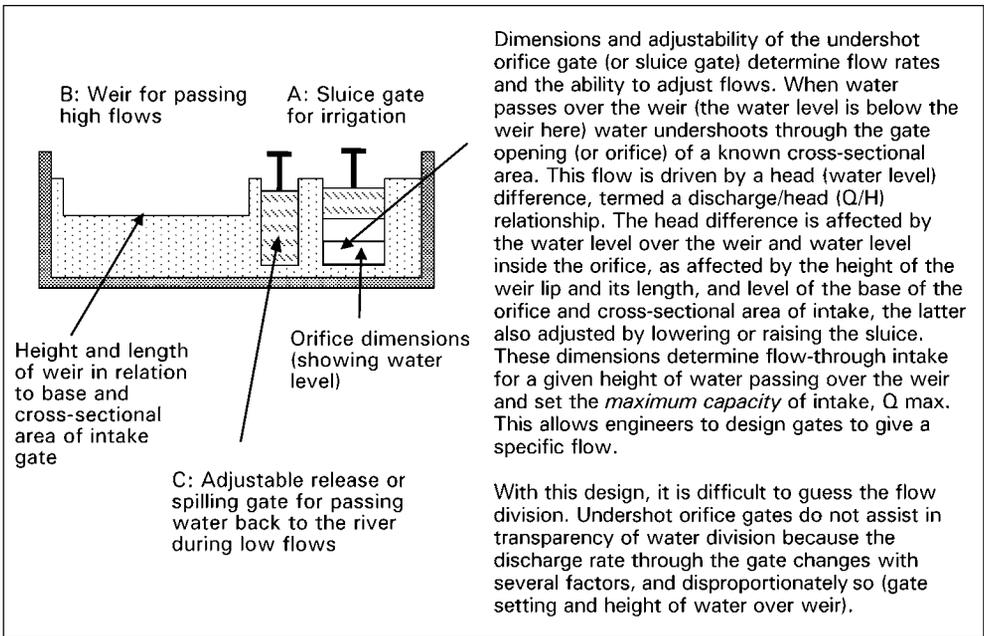


Fig. 14.1. Schematic of commonly used design for an improved intake.

proportional division of the incoming river flow into two outgoing flows – the intake flow and the downstream river flow.

Regarding the dimensions of the intake, as a process, upgrading follows standard procedures for irrigation infrastructure design – the selection and setting of the crop and irrigation system water requirement. This procedure and its rationale are explained in more detail in Lankford (2004b), but it can be summarized as a formulation of a fixed peak water supply to meet a given command area, crop type, climate and efficiency. The key point is that, without better recognition of the total and frequently changing catchment demand, this fixed peak amount becomes *physically embodied* as the maximum discharge rate of the intake, rendering future claims to adjust the share of water between the intake and downstream that more difficult.

As shown in the chapter, it is this maximum discharge design that overrides other considerations such as the amount of legal water right. The maximum discharge when orifices are fully open is one of the most important design parameters, because users tend to default to this setting – meaning that improved gates are normally

opened to their maximum. This is the reason that, when the rivers are in peak flow, intakes tend to take the maximum flow possible, and that in the dry season intakes can abstract all the available water. In theory and ideally, the legal water right should be the same as the maximum discharge (although frequently it is a different value) and, moreover, both should be adjustable in the light of new circumstances.

With respect to intake operability, in many cases problems have arisen, suggesting that this component of design is worth further scrutiny. Undershot orifice gates (see explanation in Fig. 14.1) obscure the ability to guess the proportionality of flow division – termed here transparency. Since in all cases water measurement is lacking (Gowing and Tarimo, 1994; Lankford, 2004a), the lack of proportional division (explained later in the chapter) makes it difficult for users to negotiate fairer shares of available water. The current gate and weir model is designed mainly for the wet season, allowing flood flows to be throttled back so that fields are not surcharged with excess water. However, such events are in the minority and, on the whole, headworks are largely unable to

affect water management and efficiency *within* the irrigation system and therefore should not be designed with the wet season solely in mind. Instead, it is the pattern of water sharing and associated conflicts during the dry season that require more attention, because current structures allow the very small flows found in this season to be completely tapped without allowing any downstream flows (as well as being more likely to be washed away, according to custom, traditional intakes could not be built to block the whole river (Gillingham, 1999)).

We argue that, more than 'paper' water rights, it is the concrete and metal forms of irrigation intakes and the design process leading to them that determine the actual water taken throughout the hydrological year, affecting the share of water between irrigation and downstream sectors, and influencing how easy it is to adjust that share. Incorrectly assigned water rights that do not match intake capacities add complications. Upgrading of intakes and improvement of water control at the intake are commendable objectives, and are desired by

farmers; however, it is the end purpose that should be rethought. As this chapter argues, there is a case for improving intakes so that they work more in harmony with water rights across both seasons within a dynamic catchment, rather than solely, in a rather static manner, for the irrigation system in question. If water rights are to be a key means to allocate water, and formal and informal rights are to be used together, then it is the design process of the mediating irrigation infrastructure that needs to be held to account.

Case study description

The Great Ruaha River basin is found in southern Tanzania (see Fig. 14.2). Previous articles, to which the reader is referred, describe in detail the geography of the area (Baur *et al.*, 2000; Franks *et al.*, 2004).

Some of the conditions relevant to this analysis of river basin initiatives are as follows:

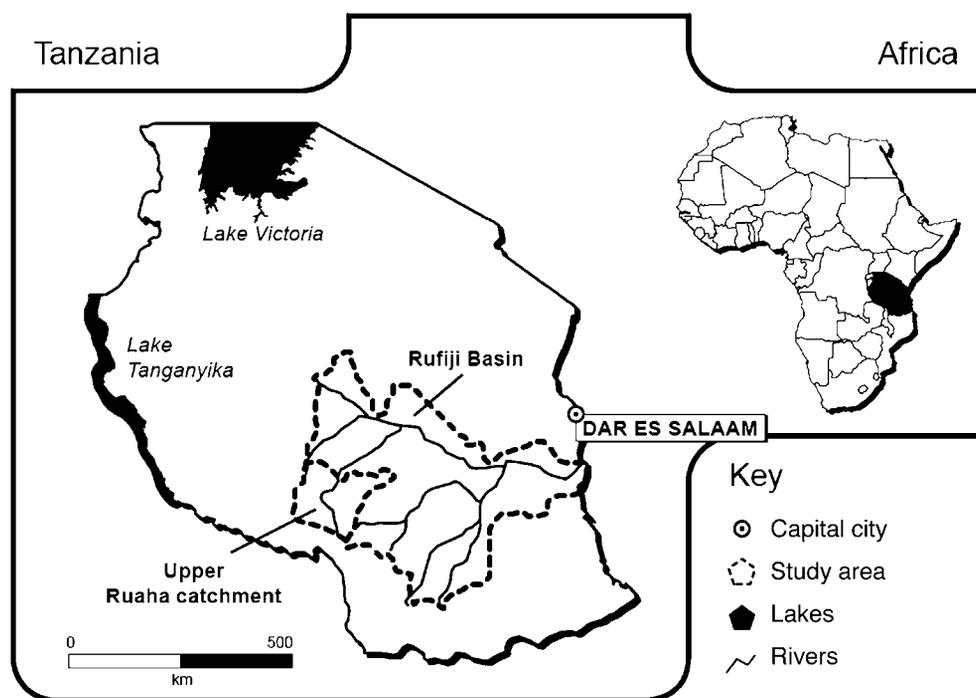


Fig. 14.2. Map of Tanzania.

1. The size of the sub-basin (68,000 km²) poses logistical problems for managing water by formal rights alone that require monitoring and policing. To reduce these costs and to manage conflicts at the catchment scale requires robust forms of subsidiarity.

2. The basin effectively experiences a single rainy season (of about 600–1000 mm average depending on climate and altitude). Rivers swell during this period, but shrink dramatically during the dry season between May and November, a period that suffers from water stress and conflict. This considerable dissimilarity in water availability and associated dynamics suggests that wet and dry seasons need different forms of management and, in particular, the dry season necessitates special care.

3. The area lacks an aquifer or any large-scale storage that can support irrigation (although the downstream hydropower has storage). Irrigation has to rely on run-of-river supplies, and this points to the need to manage surface water resources carefully without the benefit of storage buffering.

4. There is competition between upstream irrigation and downstream; a RAMSAR wetland, the Ruaha National Park and hydropower. This competition exists in both wet and dry seasons, but not on the scale of the competition envisaged by RBMSIIP (Machibya *et al.*, 2003). In addition, the policy for the river – ‘restoring the all-year-round flows’⁵ – presents a goal by which river basin management can be tested. During a normal year, competition is found mainly during the dry season, arising from downstream needs for domestic use, animal watering and ecological functioning provided by in-stream flows, which support aquatic and terrestrial wildlife. Management during the dry season is affected by large wet-season abstractions that make it more difficult to throttle demand during the dry season. This, combined with the changeable climate that brings shortages during the wet season, means that water management is required throughout the year. Furthermore, the authors argue that purposive decisions over upstream–downstream allocation should replace the ad hoc unplanned change in distribution that has arisen within the last 30 years and that may continue in the future.

The challenges ahead

Reviewing the discussion above, we see that there are a number of concerns for water management in the basin:

- To build on the water rights currently provided so that they help achieve river basin objectives.
- To improve the system that caters to both the wet and dry seasons, and that manages the switch in water availability and demand between the two seasons.
- To draw up an arrangement that incorporates without incongruities both formal and customary agreements.
- The necessity of drawing together the water rights and the infrastructural works so that these match and, together, fit the hydrology, water demands and social make-up of the catchments in question.
- That the National Water Policy is implemented effectively, especially with regard to its institutional framework.

This chapter aims to answer these concerns and the call by Moss (2004, p. 87) for ‘creating better fit’ between institutions and other components, and is a contribution to the request in the National Water Policy (MOWLD, 2002, pp. 28–29): ‘Thus the legislation needs to be reviewed in order to address the growing water management challenges.’ It should be emphasized that this chapter does not propose an actual distribution of water but aims to show how available water might be shared between sectors. In addition, the framework described here is relevant in other closing and closed river basins, such as the Pangani in northern Tanzania.

Upstream–Downstream Water Allocation

Definitions and theory

Because irrigation is the major upstream water abstractor in the basin, it is the main determinant explaining the share of water between this sector and downstream sectors. Simply put, water for downstream (for domestic, livestock, fishing and wildlife purposes) is the remainder after irrigation abstraction has occurred (follow-

ing the observation that return flows of drainage water are a minor proportion of abstracted flow or are accounted for). This relationship is captured in Fig. 14.3 and is explained here.

The abstraction flow-rate to feed a single irrigation scheme is a function of four factors (see Eqn 1): (i) the design of the intake capacity; (ii) the number of irrigation intakes feeding that system; (iii) any operation of these intakes that adjusts their discharge; and (iv) the flow of water in the river that affects the head of water at the intake. Intake design incorporates a discharge-head relationship between intake flow, orifice size and head of water at the weir so that for most intakes, without adjustment, intake flow increases as the river flow increases. As has been shown by Lankford (2004b), the intake rate is a function of river discharge rather than of response to changes in irrigated area or of crop water demand, except when intakes are throttled to safeguard fields from rare, extreme damaging floods (see Fig. 14.1 for a further brief explanation of how standard intakes and weirs work and, in addition, web sites or text books on canal irrigation engineering provide additional information, e.g. Kay, 1986).

$$Q \text{ (single irrigation system)} = f \text{ (intake design, intake number, intake operation, flow in river)} \quad (1)$$

Where Q is discharge expressed as a volume of water per time unit (e.g. l/s). By simple mathematical balance, the flow for downstream irrigators is the remainder of the river flow once upstream intake abstraction has occurred (see Eqn 2 and Figs 14.3 and 14.4).

$$Q \text{ (individual downstream irrigator intake)} = (Q \text{ river supply} - Q \text{ upstream intake}) \quad (2)$$

The flow of water being abstracted into the whole irrigation sector (a summation of all intakes within a catchment) is a result of the river supply and the total intake capacity combined with any cumulative effect of operational decisions (Eqn 3):

$$Q \text{ (total irrigation)} = f \text{ (all intakes design, number of intakes, cumulative operation, river flow)} \quad (3)$$

When applied to ‘between sector’ computations (Eqn 4), it is the cumulative upstream irrigation abstraction in a catchment that determines the water available for downstream users:

$$Q \text{ (downstream)} = (Q \text{ river supply} - Q \text{ total upstream irrigation intake}) \quad (4)$$

Over 1 year, abstraction fluctuates as a result of the four factors (intake design, intake number, intake operation, supply in river), creating an abstraction hydrograph (see Fig. 14.4), which follows the river supply hydrograph with greatest abstraction during the wet season and lower abstraction in the dry season. Via mathematical continuity, the downstream hydrograph will be a function of the upstream irrigation abstraction. Figure 14.4 is further explained in the discussion below on volumetric and proportional caps. We can now determine a simple indicator of river basin management, the ‘irrigation allocation ratio’ (IAR) of irrigation abstraction to total supply (Eqn 5), a measure of the equity of distribution between irrigation and other sectors. A proportion of about 50% indicates that water is evenly divided between irrigation and other sectors, while an IAR of 90% tells of a highly skewed supply to irrigation.

$$\text{Irrigation allocation ratio, IAR} = \frac{\text{(irrigation abstraction)}}{\text{(upstream supply flow)}} \quad (5)$$

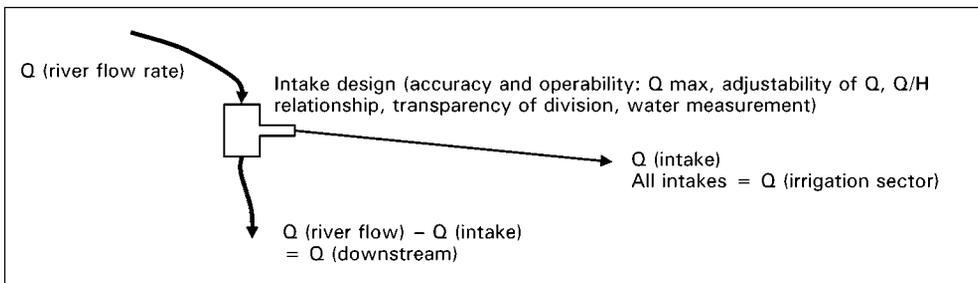


Fig. 14.3. Irrigation abstractions establishing downstream allocation.

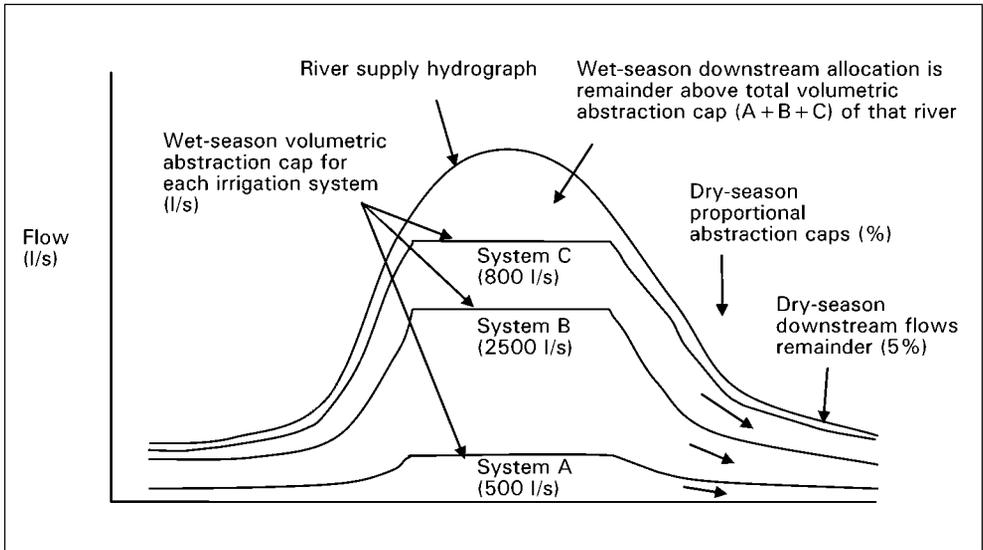


Fig. 14.4. Supply, abstraction and allocation hydrographs.

Introduction to volumetric and proportional caps

To manage the irrigation allocation ratio in Eqn 5 requires an understanding of volumetric and proportional caps. Figures 14.4 and 14.5 and the worked example below show how setting two types of ‘caps’ (equivalent to ‘ceilings’ ‘maxima’ or ‘thresholds’) affects the irrigation allocation ratio (IAR). As explained in the next section on legal–infrastructural framework for catchment apportionment (LIFCA), these two caps relate closely to the properties of intake structures and to the season.

The volumetric cap is determined by the maximum volumetric capacity of the intake, or ‘Q max’. This cap, it is argued, applies during the main part of the wet season when river flows are larger. Figure 14.4 shows this as a *fixed plateau* on each intake hydrograph where the maximum intake capacity stops more water from being abstracted. Note that the height of the cap plateau is only set from the zero on the Y axis for the first intake but, for the others, the level is set by counting up from the previous intake plateau. Figure 14.4 is a stylized rather than an exact representation of the worked example given below. The volume of the water for downstream during the wet season is the

area of the graph between the river hydrograph and the uppermost plateau of intake C.

The proportional cap is determined by the design features of the intake that function when the river flow is lower than Q max. These design features are discussed in greater detail below. More to the point, proportional caps in Fig. 14.4 can be seen as sloping lines, denoting a *constant fraction* (but reducing quantity) being apportioned to intakes A, B and C. The volume of the water for downstream during the dry season is the area of the graph between the river supply hydrograph and the sloping line of intake C.

Worked example

A worked example in Table 14.1 demonstrates the effects that adjusting volumetric and proportional caps have on water apportionment in a catchment (see also Figs 14.4 and 14.5). Three intakes feeding irrigation systems, A, B and C, are located in a single catchment. The current design allows a maximum of 500, 2500 and 800 l/s, respectively, giving a total abstraction of 3800 l/s. During the dry season when this flow is not exceeded, the share for A, B and C is 15, 50 and 30%, respectively, providing 5% for downstream sectors. Under a new modified arrange-

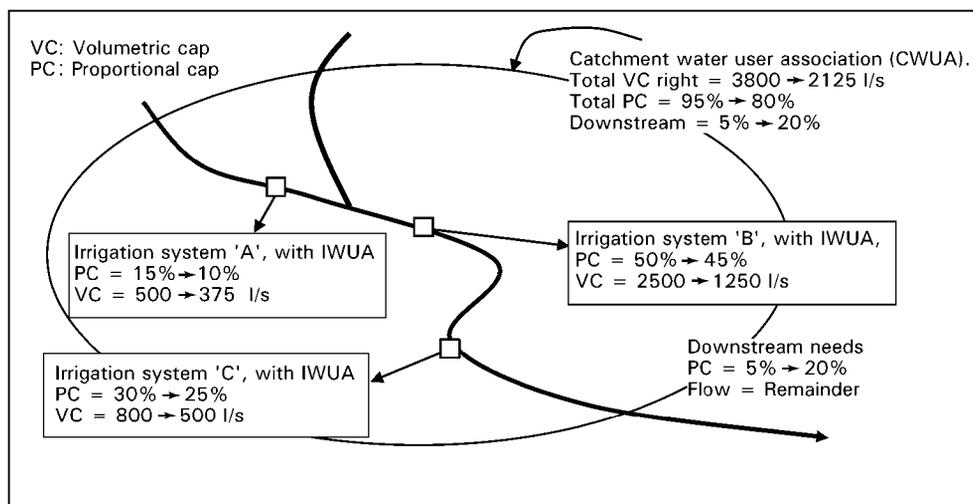


Fig. 14.5. Volumetric and proportional caps applied to irrigation systems.

Table 14.1. Existing and modified settings for volumetric and proportional caps (worked example).

Case	Volumetric cap units (m ³)		Proportional cap units (%)	
	1 (Wet season, existing)	2 (Wet season, modified)	3 (Dry season, existing)	4 (Dry season, modified)
Irrigation system A cap	0.5	0.375	15	10
Irrigation system B cap	2.5	1.250	50	45
Irrigation system C cap	0.8	0.500	30	25
Volumetric (cumecs) and proportional cap (%) for irrigation	3.8	2.125	95	80
Remainder for downstream	Remainder	Remainder	5	20

ment, the volumetric caps are reduced, leaving 375, 1250 and 500 l/s, respectively (giving a total catchment right of 2125 l/s) and, when water does not exceed this volume, the proportional shares of A, B and C are also reduced to 10, 45 and 25%, respectively, providing more water (20%) downstream.

The volumetric outcome can be seen in calculations given by Lankford and Mwaruvanda (2005). In annual volumetric terms, the amount of water diverted for irrigation decreased by 29,352 MCM (million cubic metres), from 75,062 to 45,710 MCM, a drop of 39%, giving an extra 29,352 MCM to downstream. Calculation of the irrigation allocation ratio (IAR) shows that the revised caps decreased irrigation impact on the hydrology of the catchment from

56 to 36%. Furthermore, the downstream share benefited considerably from only slight reductions in each irrigation system's abstraction. This is particularly notable in the dry season and was a result of the relatively low starting fraction given to downstream needs, combined with three intakes releasing water. Each intake needed to give a 5–10% compensation to result in 15–30% total extra water flowing downstream.

Application to the Great Ruaha River basin

In 2000, SMUWC found that about 45 cumecs were the maximum total intake capacity of irrigation. Once this was exceeded, water went to the Usangu wetland, the Ruaha National Park and hydropower stations. In the future, the total intake

capacity could be revised to manage the balance of water heading downstream. This means bringing in a new volumetric cap, which might be determined on the basis of observations and modelling, and might be set at 50 cumecs – which amount was the estimate of abstraction for the year 2005. During the dry season, the improvement of intakes in the last 25 years in the Great Ruaha basin has resulted in some taking all of the dry-season flow. From observations (SMUWC, 2000), the proportional cap in the dry season was about 90–100% – in other words, until the abstraction capacity was exceeded by flood water, nearly all the water was taken by irrigation in those catchments with irrigation. In the future, should LIFCA be applied, catchments would have their dry-season irrigation abstraction altered according to local circumstances, perhaps ranging from 70 to 90%.

Legal–Infrastructural Framework for Catchment Apportionment

Introduction

Having discussed concepts underlying the allocation of water in a catchment, it is possible to propose a synergistic framework of water management, design and legislative dimensions. This LIFCA is presented in Table 14.2. Each column represents either the wet or dry season. For each season a water management arrangement is proposed. This multi-layered arrangement coheres with: (i) the type of water threshold decision to be made (volumetric or proportional); (ii) the design of the maximum capacity; (iii) the operability of intakes; (iv) the type of property right (formal or informal); (v) the level of stakeholder decision making (river or irrigation user association); and (vi) the nature of water payment made. LIFCA is described first before detailing the technology required to support the framework.

Following Table 14.2, in the wet season, to distribute water between irrigation and downstream sectors, first, a maximum cap on abstraction is required. This cap is physically designed in by sizing the maximum apertures of the intakes so that no more water than this cap can be abstracted. This cap is underpinned by the formal water rights sold by the government

(requiring the current system of volumetric water rights to be improved so that this cap is set accurately and legally). In turn, the legal right relates to either individual water user associations that represent irrigation systems or to the catchment water user associations (CWUAs) that represent the irrigation sector within that catchment. If the latter occurs, then the CWUA can divide up the volumetric right to its various constituent intakes, represented by irrigation water user associations (IWUAs). Either way, the individual intake or total intake capacity should be expressly and accurately related to the formal rights and managed both at the individual and catchment level. Water basin officials would then be interacting with representatives of both individual intakes and the whole catchment iteratively to ensure coherence between these water volumes.

In the dry season, (see Table 14.2), arrangements switch because the designed-in maximum capacity for abstraction is now above the river supply; thus, the meagre river supply needs sharing between irrigators, and between irrigation and downstream sectors. This requires a maximum threshold on the share provided to irrigation. This allocation is more likely to be implemented by the regulation (partial throttling) of gated adjustable intakes but would benefit from being ‘designed in’ using proportional weir-type structures (see next section for further information on different types of structures). Since the ‘rights’ to these dry-season flows are below the flow rates set by the formal rights, the dry-season shares (or ‘rights’) have to be negotiated informally as customary rights between all users in and below the catchment and then backed up by a mixture of intake design and adjustment. These latter rights would have to be articulated, not in the form of flow rates (l/s) but as proportions of the water, for example ‘an intake would receive 20% of the river flow water’.

The role of the river basin official would change in the dry season when the formal rights are no longer ‘active’. Greater emphasis would be placed on conflict-resolution services to assist the CWUA in sharing more equitably the available water, altering the proportions of water according to changing circumstances or encouraging stakeholders to permit more water to remain for downstream environmental and domestic flows.

Table 14.2. LIFCA – a framework of seasons, caps, intake design, rights and WUAs.

	Wet season	Dry season
Type of cap	Total volumetric abstraction cap, the flow rate in l/s or cumecs (m ³ /s) abstracted	Proportional abstraction cap, in proportions (%) of flow abstracted
Intake design required	A proportional intake design can accommodate both wet-season volumetric caps and dry-season proportional caps. Proportional intakes can be designed to have a maximum capacity, beyond which no extra water is tapped and below which water is abstracted proportionally; a well-designed intake can be adjustable and transparent, assisting users in knowing the division of water between the intake and downstream	
Part of intake design most closely associated with this season and cap	The design of the maximum capacity of the intake is a critical step, and will generally establish the maximum volumetric cap. Accuracy of design sizing is important here, as is future adjustability if maximum intake capacity is also to be adjusted in the future. Maximum flow (Q), determined from flume dimensions and main canal specifications. Excess flow can be returned to the river. (Q max focus = l/s)	Design can be used to implement proportional divisions (using fixed or adjustable proportional gates). Accuracy of sizing the proportional division important. In addition, design allows on-off shutters for time schedules (focus = % of division)
Part of intake operability most closely associated with this season and cap	Advised to rely on Q max rather than on throttling because gates are opened to maximum setting. Thus the accurate design of the maximum abstraction is very important (see row above). Although Q max will be a flow rate, users should be able to discern the division of water, and therefore transparency will also be key	Incremental adjustments of intakes or on-off adjustments to schedule water are advised. Further alteration of the intakes may be necessary to reflect ongoing negotiations, but if fixed proportional dividers are well designed this need not be a regular or onerous activity. Adjustability and transparency required here
Type of rights most closely associated with this season	Formal water right (volumetric). The design of the maximum flow through the intake matches the flow rate of the water right. In addition, the total intake capacity of all irrigation in the catchment matches the total rights disbursed to the catchment	Customary agreements and rights (proportional, or time schedule basis). These are expressed and negotiated in terms of shares (e.g. 40% of the available water) or time (e.g. 2 days for taking the total supply) or a mixture of the two
Role of irrigation water user association (IWUA) or catchment water user association (CWUA)	Water right to CWUA and division of right to irrigation WUA (IWUA) representatives	Division of river supply agreed between users or irrigation WUAs and agreed apportionment of water between total irrigation and downstream users
Institutional connections	Basin Office to facilitate and mediate catchment water user association negotiations of the total formal water right	Intake to intake representatives of irrigation water user associations plus RBWO mediation explore customary water rights
Payment structure	Fixed payment for formal water right	No payment envisaged for proportional share, though might be possible

With regard to payments for water, in the current legislation, payments for the water right are pegged to the allocated amount rather than to the actual measured amount. This same arrangement could be applied to this framework, which therefore does not, at least in the initial stages, envisage a volumetric basis to determine a water charge, although this would be a future goal that various stakeholders might wish to explore. A more efficient and appropriate step would be to ensure that maximum intake capacity (max Q) is the same as the water right (either for an individual intake or for the whole catchment) so that payment, the right and the maximum amount that could be taken are the same. Following this, it would be necessary only for occasional flow measurement or for stakeholders to report unsanctioned changes to the amount abstracted. The agreements over the dry-season shares do not involve financial transactions, but result from discussions held within the catchment users' organization, mediated by the basin authority.

In summary, the framework can be expressed within five objectives:

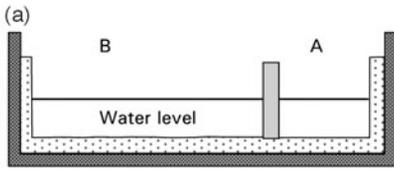
- To match formal water rights with maximum water flows abstracted, at both the intake and catchment level so that the volumetric cap is built in.
- To make the gate design facilitate water sharing during the dry season when flows are meagre, to match customary water rights and build in the proportional cap.
- To bring adjustability and flexibility so that users may frequently adjust flows and turn them on and off.
- To enhance transparency so that users may know how the flows are being divided, either volumetrically or proportionally.
- To empower local users in managing water at the catchment level, including building and adjusting intakes that meet their requirements and wider, downstream allocation objectives. It is proposed that the framework would function best when all five objectives are brought simultaneously together in a coordinated fashion.

Infrastructural design to support LIFCA

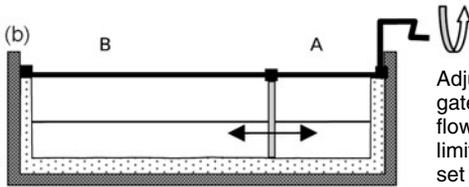
As proposed above, because irrigation is upstream of other demands on the plains of Usangu, it is the presence and type of irrigation intake structures that 'hard-wire' in the apportionment of water and its adjustment. The discussion here explores how this infrastructure, particularly proportional intakes, might solve the five objectives of the LIFCA. To alter water apportionment (or IAR) in both wet and dry seasons requires three parts or functions of intake design and operation to be understood. These are accuracy, operability and operation. All three parts work simultaneously and interrelate and, when carefully considered, support the objectives encapsulated in LIFCA. To meet these objectives, an intake or series of intakes would be accurately sized, fully adjustable, highly transparent and well understood by local users. To explain how the appropriate design of the three parts embody the objectives of LIFCA, the reader is referred again to Fig. 14.1 for the common but problematic design used in current improvement programs, and to Figs 14.6 to 14.8, showing a selection of proposed designs of proportional intakes that better encapsulate LIFCA objectives.

Intake accuracy

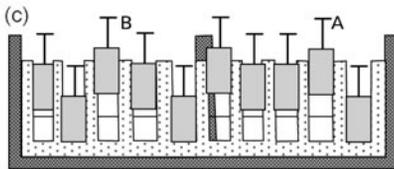
The first part or function is to 'build in' accurate intake dimensions so that the size of the intakes assists in two ways. First, having an accurate 'Q max' means that the maximum flow rate closely equals the water right and matches the volumetric cap. This can be achieved for both individual intakes and by adding up all intakes in a catchment, the total cap for irrigation abstraction. Second, the accurate dimensions of the proportional ratios of the cross-sectional areas of the proportional flumes then match informal water rights proposed by catchment stakeholders and, in combination with other proportional intakes, accurately set the total proportional cap of water abstracted by irrigation during the dry season.



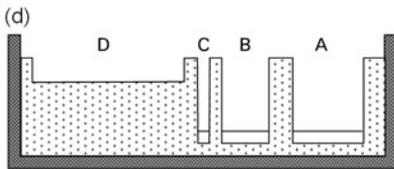
Straightforward proportional flume intake with, in this case, A taking 30% into the intake and B passing 70% water downstream. This is a non-adjustable design, with maximum intake capacity of A set by the design of orifice or overflow return channel back to the river downstream



Adjustable proportional flume intake with a moveable gate worked by an actuating mechanism. Ratio of flow A to B is now constantly adjustable within certain limits. The absolute maximum intake capacity of 'A' is set into the dimensions of the structure



Adjustable proportional multiple-flume intake. Ten flume slots each of 10% of flow allow adjustment between the intake (A) and downstream (B). Shutters are opened and closed accordingly, giving users the opportunity to constantly adjust the division of the flow in increments of 10%.



Castellated flume design divides according to widths of the proportional flumes, say 50% to intake A and 40% to intake B. Intake A is for an irrigation scheme at the site of the weir, but intake B is for an intake further downstream. The design is replicated at each intake down the river. The small slot (flume C) in the weir is for an agreed environmental flow, in this case 10%. The weir (D) passes the flood flows when these occur.

Fig. 14.6 (a to d). Proportional flume intakes; various designs.

Intake operability

The second part is to build in better *operability* of allocation so that intelligent gate adjustments can be made. Operability depends on three factors: the *adjustability*, *water measurement* and *transparency* of the gate flows. 'Adjustability' is designed by considering how the gate orifice (opening) can be set at partial settings and how any head-controlling structure such as a weir can also be adjusted. The actual operation of this intake structure is then the adjustment of the intake flow either by closing and opening the orifice gate, or by increasing or decreasing the height of any weir structure. It is this adjustability that also explains why, in the wet season, farmers will throttle down their

intake when very high floods threaten their systems and why, in the dry season, negotiations between upstream and downstream farmers can be physically transformed into gate adjustments that release water downstream. The current improved gate technology chosen in Usangu does enable flows to be adjusted (see Fig. 14.1), but the same technology is not very transparent for reasons described below.

Without much difficulty, as seen in Figs 14.6b, c and 14.7, proportional gates can be made adjustable. The adjustment of the cross-sectional area ratio between A and B is either actuated by a constantly moveable dividing plate (see Fig. 14.6b) or by an array of on-off shutters giving incremental steps (see Fig. 14.6c). With respect to the fifth LIFCA objective

Using shutters or old car tyres gives water abstractors a means to continuously but transparently adjust river abstraction. The car tyres would be filled with concrete and chained or bolted together to stop them from floating away. The section of the weir A is for the irrigation intake flow, while the section of the weir B is for passing the river flow downstream. Each tyre would have the same dimensions, and so if 20 of them were used, each tyre added or subtracted would incrementally adjust 5% of the river flow. Note base of weir on both sides (A and B) is the same, assisting in the transparent adjustability of distribution of water between A and B.

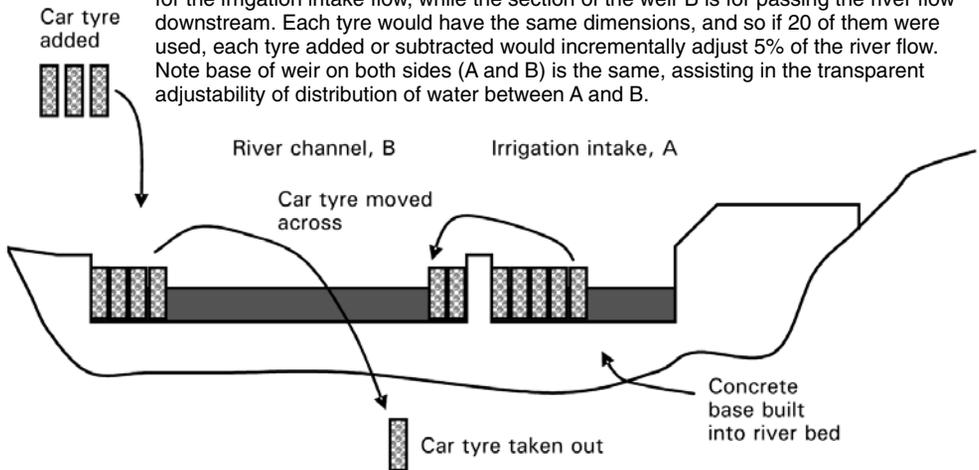
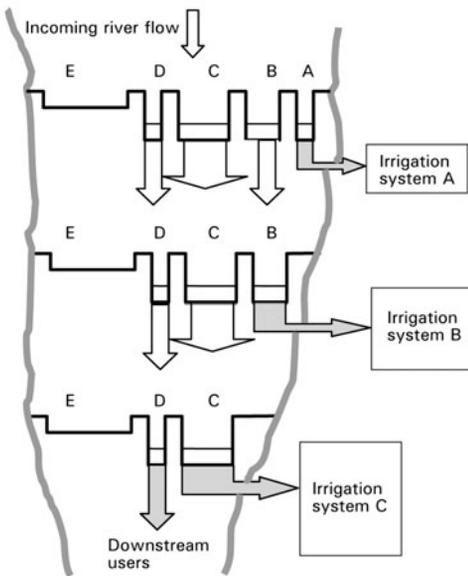


Fig. 14.7. Continuously adjustable intake using local technology.



A castellated weir design is replicated down the river at each intake. There are three irrigation systems to be supplied, A, B and C from three flumes, A, B and C. There is also a small flume (D) for downstream users (e.g. cattle keepers) and a flood weir to pass high flows (E).

Each system receives a flow in proportion to its cropped area or other negotiated agreement, which in turn gives rise to the designed-in ratio of cross-sectional areas of the flumes apportioned to A, B, C and D. Regardless of the incoming flow (except in flood periods), the four flumes divide a percentage of the flow consistently, which in this case might be A, 20%, B, 30%, C, 40% and D, 10%.

The benefit of castellated weirs is enhanced transparency of water apportionment; irrigators from systems C and B can walk up the river to the first weir and observe that their water is coming through their particular flume without being tampered with.

The flumes' cross-sectional areas could be fixed or adjustable.

Fig. 14.8. Castellated weirs for proportional distribution of water.

of local water management, Fig. 14.7, showing a 'local technology' concept, is worth explaining here. It is an example of incremental steps embodied by the movement of old car tyres into and out of the two parts of the weir, A and B. The use of car tyres here is conjectural and is proposed as a potential example of how stake-

holders might use local artisans, discussions and material in arriving at a satisfactory structure. The key point with the car tyre concept is that the *functions* of flexible intakes can be captured (accuracy, operability and transparency) without being fixated on *form* – the use of old tyres rather than concrete and metal.

The car tyre intake specifically endorses local construction, knowledge and ongoing adjustments of water allocation to match rapidly changing catchment circumstances.

However, stakeholders might decline adjustability, so that the intakes are more 'tamper-proof'. Proportional intakes can be fixed (see Figs 14.6a, d and 14.8). Here, the dimensions of the flumes would be agreed with representatives of the irrigation and downstream users – but it is possible that such fixed dimensions may in time not represent the share of the demand due to ongoing growth of water use in the catchment.

'Water measurement' is made possible by having specialized structures, such as gauging plates and recorders. Measurement is a large topic (see Kraatz and Mahajan, 1975), and is not discussed or proposed here because it is seen by the authors as a future option, complicated, currently lacking in Usangu and not immediately integral to the functioning of LIFCA. In the future, however, as concerns over water escalate, local users may end up requesting water-measurement structures to arbitrate in disputes. Robust and simple water-flow measurement is possible in such cases so that users can compare each other's shares. However, enhancing transparency of comparison would be a satisfactory precursor or alternative to water measurement.

'Transparency' is supported by having the dimensions of the weir and intake relate directly to the proportion of flow division. Transparency must be considered in the absence of water measurement so that the intake dimensions (adjustable or not) and their resulting discharge outcomes are closely connected and transparent. Transparency of water division is part of gate operability, even if this simply supports, in the absence of possible adjustment, observation of the water division between the intake and downstream river. This is because visual clues should be given to the operator that his or her adjustment results in an increase or decrease of the intake flow by a given and knowable amount. Transparency negates the need for water measurement, but brings intelligent purposive operation of the intake.

The current design of intakes (see Fig. 14.1) obscures knowledge of flow division, because the incoming river flow is not simply divided

between two flows. The intake divides the flow, with one flow going over a weir which is long and high up and the other going through an orifice which is set lower down. Also, incremental adjustments to the sluice gate do not bring pro rata changes in flow; the changing head difference and changing cross-sectional area combine to bring unpredictable flow changes (hence the need to have a gauging plate with such structures, a device that is missing from nearly all intakes in Usangu). In contrast, the designs in Figs 14.6 to 14.8 employ 'flume'-type gates (a flume is a small channel with two parallel straight sides and is open at the top in contrast to orifices that, by definition, are enclosed either as round or square orifices).

Constructed carefully, flume gates bring enhanced proportionality and transparency because the open top of the flume, combined with its straight sides and equal base height with the weir, make the relationship between water height (H) and water discharge (Q) more linear – that is, with an increase in water depth comes an increase in discharge. For any given incoming river flow the division between flow into the intake (given as 'A') and the flow passing downstream ('B') is a function of the ratio of cross-sectional area between A and B; it is this proportion between the area of A and B and the simplicity of the division design that provides the advantageous visual clues and feedback to the irrigators.

In Fig. 14.7, transparency is assured by using car tyres of the same dimensions, so that each tyre acts to block or open a set and known fraction of the total weir length across the intake and river sections (A and B). In Fig. 14.8, we explore another level of transparency provided via a novel arrangement of proportional flumes, termed 'castellated weirs' (whose details are given in Fig. 14.6d). Each castellated weir is replicated down the river, so that users from both upstream and downstream areas may come together at any given weir to observe that their particular portion of water is being passed down without being obstructed. More description of the weir system is given in Fig. 14.8.

Intake operation

The third factor, arising out of accuracy and operability, is to rely on the *operation* of intakes

by water users to frequently regulate any infrastructure so that these adjustments generate the intended outcomes. Regulation involves adjusting and closing intakes so that downstream flows are altered, or open and closed completely so that flows are scheduled against time windows (e.g. '3 days all river flow for this intake, 3 days for the next intake and 1 day sending the river flow downstream'). Scheduling, over a given time period, is therefore another way upstream or downstream users share the available water, and is an alternative expression of a customary right.

In addition, operation of the existing under-shot orifice gates is another way of adjusting the dry-season proportion taken by irrigation so that, rather than have proportional gates achieve this, users manipulate the sluice gate to arrive at mutually agreed divisions of water. The aim of LIFCA, however, is to have these shares built in and more transparent by employing different designs of intakes. The nature of the operation (opening and closing of shutters, turning a valve or moving car tyres) is an outcome of the design process of the operability and accuracy of the gate, and hence it is the latter that needs careful thought if operation is to support LIFCA. The foremost aim of an improved design process is to give all catchment users, not just upstream irrigators, intakes that meet the five objectives expressed in LIFCA.

Discussion

Although theoretically the framework resolves the contradictions of how formal and informal rights can operate together by splitting them into different seasons, in reality this may present some problems. It is difficult to foresee all complications, but some are identified here.

The setting of thresholds

Setting the caps will inevitably create winners and losers, as shares increase for some and drop for others. The process by which the caps are set would benefit from being participative and informed by good-quality hydrology and observations of current patterns of water use. Incremental adjustments might be advisable

during different parts of the river hydrograph; indeed, for the very lowest and driest part of the year, local users might agree that all water should be kept in the river with only domestic (rather than productive) quantities tapped.

Sharp-eyed readers will have noticed that, by definition, the wet season begins once the total abstraction capacity of all intakes in the catchment has been exceeded by river flows, and that a dry season is that time period when the river is lower than this threshold. The dry season is, by definition, the period when the river flow no longer exceeds intake capacity, and that negotiated customary agreements need to interject. This can be realized by setting conditions with the rights that recognize these negotiations. These definitions do not follow other ways of naming the two seasons (start of rains, based on long-term records or related to other farming activities). It follows that, the higher the abstraction capacity the shorter the wet season, until the point where total abstraction might grow to exceed all but the highest peak flows, in which case throttling and adjustment are necessary nearly all the time. Clearly, the thresholds and resulting design modifications have to be set so that expectations of irrigators and other sectors match the hydrology and climate of the area. Other ways of adjusting the caps to take into account varying flows from one year to another can be built into the intakes, with the maximum cap being adjusted by the addition or subtraction of a special shutter or plate to the intake gate.

Information transparency

The test of the arrangement will be the switch from the wet season to the dry season, a transition period of care and attention. The switch will not happen automatically – though it could be very much assisted by a combination of appropriate intake infrastructure, sharing information up and down the catchment and, in the future, water measurement. Problems might arise when a river flow has exceeded the capacity of the uppermost intake but not the capacity of all the intakes combined. The upper irrigators will probably feel, on observing 'good flows', that it is their right to tap this water with their gate set at maximum, even though this will skew their proportion above

that agreed. Key to this transition, and to the management of the arrangement as a whole, will be water measurement or transparent water division (structures that split water without the need for measurement).

Allowing flexibility and change

It would be mistaken to impose this arrangement on water users without allowing them to bring their own ideas and suggestions (even rejecting it!). Each catchment has its own properties and dynamics, necessitating a flexible, situational response. In addition, the system should be allowed to change over time responding to shifts in demand, problems arising and possibly changes in supply. It is possible that in the future, the volumetric and proportional caps might be traded between intakes and sectors, a facility now recognized in the new water legislation, expressed as tradable water rights. Flexibility is a key part of the framework, acknowledging how rapidly both the demand and supply of water have changed in the recent past and may continue to change in the future.

Institutional ownership and sustainability

It would be a truism to argue that the arrangement would depend on all stakeholders meaningfully agreeing to the constraints and benefits imposed by it. However, some significant factors that promote institutional sustainability might be:

- The four concerns above (process of setting thresholds, information needs, the role of design, allowing flexibility) are important.
- The river basin office would need to focus on delivering a variety of services, including conflict resolution, resetting the caps and ensuring follow-up modifications to infrastructure.
- The chapter has focused on the question of 'share management' rather than 'supply management' (in the usual sense of augmenting supply), or 'demand management' (persuading farmers to be more efficient so that intake flows can be reduced).

Although demand and supply management are often connected, the success of managing shares via abstraction flow reduction for a particular user would depend on whether their productivity of water can be raised, which research in the area suggests it can (Mdemu *et al.* 2003).

Retuning river basin infrastructure

Central to the success of the framework is a commitment to revising the existing intake infrastructure in each catchment. Many objectives of the Legal Infrastructure Framework for Catchment Apportionment would not work without intake infrastructure being rethought. A redesign programme could, in promoting the manageability of river basin allocation via the framework, draw on an extensive literature based on irrigation designs (e.g. Yoder, 1994).

Moreover, intake design should move from being the domain of irrigation engineers to being a negotiated process with and by local representatives of the total catchment. Each individual intake would have to be designed so that it relates iteratively to a number of factors: area of irrigation, crop types, renegotiated shares, population density and so on. Deriving irrigation intake designs on the basis of crop water requirements would appear to be an anachronistic methodology in this highly dynamic multi-user environment (Lankford, 2004b). Being able to adjust the maximum cap to account for hydrological and demand-side changes would benefit the workability of the arrangement and fit the principle of continuous and flexible adjustment that this framework is built upon.

Conclusions

This chapter shows how two decisions – setting the maximum volumetric cap and maximum proportional cap – embodied in flexible intake designs determine the allocation of water in a river basin characterized by an order of abstraction and the presence of wet and dry seasons. These decisions allow us to think of ways how (if irrigation is upstream of wetlands and hydro-

electric plants) irrigation abstractions could be managed and modified by both intake design and operation. Moreover, this analysis provides possible means to rationalize the interface between formal water rights (that establish and relate to the volumetric cap) and customary agreements (that relate to negotiations over shares of the in-stream water). These coordinated arrangements are termed here 'legal–infrastructural framework for catchment apportionment' (LIFCA). Thus, with respect to the latter, this chapter demonstrates how, if strengthened and supported, local customary negotiations combined with water management interventions, might help set and relate to the proportional cap of water abstraction that applies during the dry season.

Furthermore, this chapter argues that the design of irrigation intakes, in terms of maximum capacity, adjustability and transparent proportional capability, needs to be revisited and retuned so that the intakes fit and help support any newly modified caps and their associated sharing arrangements. At the heart of this framework is the belief that intakes should be designed to encourage and facilitate the continuous negotiation of intake settings so that their iterative and frequent adjustment is an ongoing part of water allocation at the catchment and basin scales.

These conditions, which invoke this framework as an option, are found in the wider Rufiji basin, and in parts of the Pangani basin. The latter also suffers from considerable conflicts that have arisen due not only to increasing demand but also to the imposition of a formal water rights structure that has yet to be further refined. Although one option is given here, various possibilities include managing the status quo, an outright return to customary rights, constructing storage or building in volumetric water measurement to charge for water used. Substantively, the authors therefore call for further discussions on how a more equitable allocation is to be effected and made relevant to the issues found at the catchment scale. We believe that solutions to water shortages in a sub-Saharan Africa affected by climate change and population growth cannot be met only by storage or institutional reform, but by combining those synergistically with the apportionment infrastructure to foster catchment manageability.

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Endnotes

- ¹ SMUWC – Sustainable Management of the Usangu Wetland and its Catchment, a natural resources research and development project funded by DFID during 1999–2001.
- ² RIPARWIN – Raising Irrigation Productivity and Releasing Water for Intersectoral Needs, a research project funded by DFID KAR during 2001–2005.
- ³ In the Great Ruaha basin, the term actually used is 'sub-catchment' but, for the sake of simplicity, 'catchment' is used here.
- ⁴ A third activity is the monitoring of river flows in selected sites using automatic gauging stations, although some of these are now non-functional. Although this is a vital part of river basin management, such measurements are not related to demand or management of water, and consequently users have no stake in this information being collected and distributed.
- ⁵ Up to 1993/94, the Great Ruaha was a perennial river flowing through the Ruaha National Park. Since that date, the river has dried up for between 2 and 8 weeks each year during the tail end of the dry season. The main explanation for this is continuing abstraction into irrigation intakes for a variety of productive, domestic and non-productive purposes. RIPARWIN and RBWO (and other stakeholders) share a common vision of water

distribution, which can be distilled down to the need to return the Ruaha river to year-round flow by 2010. This directly relates to the statement by the Prime Minister of Tanzania, Frederick Sumaye, in London (6 March 2001), made with UK Prime Minister Blair for the Rio+10 Summit: 'I am delighted to announce that the Government of Tanzania is committing its support for a programme to ensure that the Great Ruaha River has a

year-round flow by 2010. The programme broadly aims at integrating comprehensive approaches towards resources planning, development and management so that human activity does not endanger the sustenance of the Great Ruaha ecosystems.' Achieving year-round flow would be, from a number of perspectives, a marker of success in achieving integrated water management in the basin.

References

- Baur, P., Mandeville, N., Lankford, B. and Boake, R. (2000) Upstream/downstream competition for water in the Usangu basin, Tanzania. *Seventh National Hydrology Symposium, BHS National Hydrology Symposium Series*, University of Newcastle, UK. British Hydrological Society, London.
- Franks, T., Lankford, B.A. and Mdemu, M. (2004) Managing water amongst competing uses: the Usangu wetland in Tanzania. *Irrigation and Drainage* 53, 1–10.
- Garduno, H.V. (2001) *Water Rights Administration, Experiences, Issues and Guidelines*. FAO Legislative Study 70, Food and Agriculture Organization of the United Nations, Rome, pp. 17–19.
- Gillingham, M.E. (1999) *Community Management of Irrigation*. Working Paper for SMUWC, DFID Project: 'Sustainable management of the Usangu Plains and its catchment', Ministry of Water and Livestock Development, Dar es Salaam, Tanzania.
- Gowing, J.W. and Tarimo, A.K.P.R. (eds) (1994) Influence of technology and management on the performance of traditional and modernised irrigation schemes in Tanzania. *Proceedings of XII World Congress on Agricultural Engineering*, International Commission of Agricultural Engineering (CIGR), Milan, Italy, August–September 1994, pp. 360–368.
- Hazelwood, A. and Livingstone, I. (1978) *The Development Potential of the Usangu Plains of Tanzania*. Commonwealth Fund for Technical Co-operation, The Commonwealth Secretariat, London.
- Kay, M. (1986) *Surface Irrigation: Systems and Practice*. Cranfield Press, Cranfield, UK.
- Kraatz, D.B. and Mahajan, I.K. (1975) *Small Hydraulic Structures*. FAO Irrigation and Drainage Papers Nos 26/1 and 26/2, Food and Agriculture Organization, Rome.
- Lankford, B.A. (2004a) Irrigation improvement projects in Tanzania; scale impacts and policy implications. *Water Policy* 6 (2), 89–102.
- Lankford, B.A. (2004b) Resource-centred thinking in river basins: should we revoke the crop water approach to irrigation planning? *Agricultural Water Management* 68 (1), 33–46.
- Lankford, B.A. and Mwaruvanda, W. (2005) A framework to integrate formal and informal water rights in river basin management. In: *International Workshop on 'African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa'*, 26–28 January 2005, Gauteng, South Africa.
- Lankford, B.A., van Koppen, B., Franks, T. and Mahoo, H. (2004) Entrenched views or insufficient science? Contested causes and solutions of water allocation; insights from the Great Ruaha River Basin, Tanzania. *Agricultural Water Management* 69 (2), 135–153.
- Machibya, M., Lankford, B. and Mahoo, H. (2003) Real or imagined water competition? The case of rice irrigation in the Usangu basin and Mtera/Kidatu hydropower. In: *Tanzania Hydro-Africa Conference*, Arusha, Tanzania, 17–19 November 2003.
- Maganga, F.P. (2003) Incorporating customary laws in implementation of IWRM: some insights from Rufiji River Basin, Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, 28 (20–27), 995–1000.
- Maganga, F.P., Kiwasila, H.L., Juma, I.H. and Butterworth, J.A. (2003) Implications of customary norms and laws for implementing IWRM: findings from Pangani and Rufiji basins, Tanzania, *4th WaterNet/Warfa Symposium: Water, Science, Technology and Policy Convergence and Action by All*, 15–17 October 2003. WaterNet. (<http://www.waternetonline.ihe.nl/aboutWN/4thProceedings.htm>).
- Mdemu, M.V., Magayane, M.D., Lankford, B.A., Hatibu, N. and Kadigi, R.M.J. (2003) Conjoining rainfall and irrigation seasonality to enhance productivity of water in large rice irrigated farms in the Upper Ruaha river basin, Tanzania. *WARFSA/WATERnet Symposium Proceedings* 15–17 October 2003, Gabarone, Botswana, pp. 97–101.

-
- Meinzen-Dick, R. and Bakker, M. (2001) Water rights and multiple water uses: framework and application to Kirindi Oya irrigation system, Sri Lanka. *Irrigation and Drainage Systems* 15, 129–148.
- Moss, T. (2004) The governance of land use in river basins: prospects for overcoming problems of institutional interplay with the EU Water Framework Directive. *Land Use Policy* 21 (1), 85–94.
- MOWLD (Ministry of Water and Livestock Development) (2002) *National Water Policy*. MOWLD, Dar es Salaam, Tanzania.
- MOWLD (2004) *National Water Sector Development Strategy (Circulation Draft)*. MOWLD, The United Republic of Tanzania, Dar es Salaam, Tanzania.
- Mwaka, I. (1999) *Water Law, Water Rights and Water Supply (Africa): TANZANIA – Study Country Report*. Cranfield University, Silsoe.
- SMUWC (Sustainable Management of the Usangu Wetland and Its Catchment) (2000) *Supporting Volume A on Water Management*. For the Directorate of Water Resources, Ministry of Water, Government of Tanzania, The SMUWC Project, Mbeya Region, Tanzania.
- Sokile, C.S., Kashaigili, J.J. and Kadigi, R.M.J. (2003) Towards an integrated water resource management in Tanzania: the role of appropriate institutional framework in Rufiji Basin. *Physics and Chemistry of the Earth, Parts A/B/C* 28 (20–27), 1015–1023.
- van Koppen, B., Sokile, C.S., Hatibu, N., Lankford, B., Mahoo, H. and Yanda, P. (2004) *Formal Water Rights in Rural Tanzania: Deepening the Dichotomy?* Working Paper 71, International Water Management Institute, Johannesburg, South Africa.
- World Bank (1996) *River Basin Management and Smallholder Irrigation Improvement Project (RBMSIIP)*. Staff Appraisal Report, Washington, DC.
- Yoder, R. (ed.) (1994) *Designing Irrigation Structures for Mountainous Environments: a Handbook of Experiences*. International Irrigation Management Institute, Colombo, Sri Lanka, 206 pp.