Scarcity and the politics of allocation
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Chapter contribution

Responding to water scarcity – beyond the volumetric

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Abstract

The chapter examines water scarcity through a facilitative 'share' response, arguing that scarcity is often seen as a problem of volumetric imbalances dealt with by logical solutions that seek to save, or store and deliver more water but in effect may be partial instruments that fail to understand how water is shared and that therefore continue to exacerbate scarcity and inequity. In emphasising a 'para-volumetric' response to scarcity – one that recognises water volume imbalances but also incorporates sharing dimensions – the chapter contains a framework of supply, demand and share management responses and argues that in a world where water may be committed and demand and supply solutions limited, an emphasis on allocation of water between users and sectors increases in comparative significance. An additional significant dimension of scarcity beyond the 'volumetric' occurs in dynamically supplied environments where water is variably apportioned between users semi-automatically as a result of existing institutions and infrastructure. To demonstrate the importance of sharing on scarcity distribution, just as Falkenmark's Water Scarcity Index reflects a volumetric focus, this analysis proposes a 'Water Apportionment Index' to express shortages arising from allocation of water between users. The paper concludes on the scarcity debate suggesting that while scarcity might indeed be a universal backdrop, it is society's experimentations with scarcity through the selection of various water management interventions that are the acid tests of how scarcity is understood.

Introduction

For the purposes of political expediency, water scarcity, seen as limited or decreasing water supply in the face of existing or increasing demands[1] proves to be useful in two ways. First, it is easier to blame a natural shortage of water than to accept an inability to manage and share limited amounts. Second, volumetric concerns allow 'lack of water' rationales for policies that in turn are not so much related to how water can be managed and shared but more to concerns about how to fix or solve the lack of supply. A concern with volumetric shortages rather than to the details of water management, particularly with improving the sharing and allocation of water between users and sectors, is nurtured by the material realities of water politics and policies (budgets to be spent), policy making ('a desire to keep things simple'[2]), and a political milieu of lobbying, ballot intentions, donor-client agendas and public accountability. This chapter attempts to show differences between the volumetric logics of redressing demand-and-supply balances, and approaches that seek to facilitate transitions to different conditions of sharing available water in highly-varying supply conditions. In so doing, the paper re-enforces the idea of 'share management' as a means to work more effectively alongside volumetric preoccupations about scarcity.

In this chapter I seek to judge scarcity as a socially and politically constructed term closely bound up with 'volumetric' thinking and solutions by contrasting this paradigm with a facilitative, sharing viewpoint. The issue of whether users truly face temporary or semi-permanent water scarcity in comparison to periods of greater, relative abundance is accepted because water supply in nature is inherently variable. Furthermore, the objective is not to comment on the efficacy of demand and supply solutions as others have done so admirably (Mehta 2006, Molle and Berkhoff 2007). As will be seen, I move beyond the *volumetric* concerns of supply, demand and allocative origins and solutions of scarcity. Thus while Mehta identifies two anthropogenic influences on water scarcity in her 2001 paper (exploitation of groundwater and devegetation) these are volumetric commentaries on supply and demand. I very carefully attempt to highlight the extra magnification of, and failure to mitigate, natural and social scarcity mediated by anthropogenic structures designed to *share* water.

An overview of commentaries on the construction of scarcity is provided before moving onto a brief examination of the (understandable) tendency towards a volumetric concern. From a seemingly neutral definition of a mathematical conception of balance between supply and demand, we can reflect on scarcity in three main ways as shown in Table 1; disciplinary viewpoint, resource and level, and intervention balance. Reflecting on these perspectives, a mathematical balance or 'volumetric' conception of scarcity, although politically expedient, is in many ways too limited to draw upon when designing managerial and governance responses; that a wider recognition of sharing water in the face of water scarcity is necessary – particularly since water-scarce regions also experience high variability of supply.

[1] Water scarcity has become a socially constructed term to some extent; water sufficiency could be used here and is defined as a decrease in the volume of water available per capita or area over time. Except in this introduction, the essay does not deal with the debate surrounding social meanings of water scarcity.

[2] The author commonly hears this refrain at water policy workshops and meetings attended by policy agencies and scientists.

The first column in Table 1 discerns the disciplinary leanings of the analysis of problems or of the solutions to be applied. Three are given, beginning with hydrological analyses by natural scientists of changes in supply and demand. I partly distinguish between scientists who study water balances as hydrologists might, and technical instrumentalists who reflect on the role of the built environment (e.g. lack of storage) in determining scarcity. Second are political and social scientists concerned with relationships between society, power and access to and distribution of water. One of Homer-Dixon's (1999) categories is 'Distributionists' that focus on the effects that various distributions of wealth and power can have on economic growth and well-being. Again, I suggest a departure between them and the legal-institutional instrumentalists who reflect on social technologies in resolving water scarcity suggesting new forms of participation, services, laws, organisations and institutions to reconcile causes of inequity or overuse of water. Third, are economists who endeavour to understand water scarcity as an expression of finance and market behaviour. These are not disciplinary silos, there is an increasingly inter-disciplinary understanding of how scarcity can be approached from a mix of these viewpoints.

Table 1. Types of water scarcity commentaries

Cate-gories	**Disciplinary viewpoint**	**Resource type and level**	**Origin and response**
Sub-classes of analysis	1. Natural scientists & technical instrumentalists 2. Political & social scientists with social & legal instrumentalists 3. Economists & financiers	1. Primary (water) 2. Secondary (finance and economic) 3. Tertiary (Human, technical, adaptive capabilities) 4. Political and persuasive capabilities and willingness	1. Supply management 2. Demand management 3. Share management

In the second column, four types of scarcity that drive water scarcity are listed, whether they be water itself or the argument that other forms of deficit (e.g. financial or political will) drive water shortages. Turton and Ohlsson (1999) termed a focus on water shortages a first order analysis of scarcity and other types of capabilities as second order analyses. This second column also draws from Mehta (2006) who explored four types of resources, primary to quaternary; physical, economic, adaptive and political. Mehta's capability and well-being approach to scarcity is an example of a multi-strand examination of scarcity that cuts across some of the types given in Table 1, and moreover argues for a detailed look at underlying capabilities, moving beyond first order resource solutions that often propose that 'more water' via supply technologies help solve water imbalances.

I also suggest that this second column represents the detail explored by natural and social scientists, suggesting that primary superficial observations can be contrasted to deeper composite analysis of underlying problems, for example Ohlsson (1998, 1999) argued for a social water stress index to reflect adaptive capacity. In other words, our understanding is not simply related to a range of incorporated disciplinary perspectives as suggested by Turton, Mehta and others but by a combined depth and breadth within those disciplines.

In the third column, scarcity analyses either emphasise a supply side or demand side (or conservation), or engage with manner by which water is shared between sectors, which I term here ‘share management’[3]. Although I draw on Homer-Dixon’s use of this third category (which he termed ‘structural’), on the Comprehensive Assessment of Water Management in Agriculture use of this as a third response to scarcity (Molle et al, 2007) and on the widespread water literature on allocation within an integrated water resources management (IWRM) framework, I make a case for the special nature of share management alongside demand and supply management, proposing furthermore that allocation and demand drivers such as economic pricing are not grouped together (Hellegers, 2005).

The bias towards supply management (e.g. building dams) or the demand management (fixing leaks) is highly revealing not only of trends amongst donor thinking but also of how scarcity response narratives are constructed alongside the other two categories in Table 1. Of late, for example IWMI and the World Bank have argued that per capita storage is low in Sub-Saharan Africa and that additional storage is required, which are signs of economic scarcity of investment (World Bank, 2007; also Rosegrant et al, 2002). The ambivalent treatment of share management in these literatures suggests that a more profound look at the technical management of scarcity adds to demand and supply thinking and enriches our engagement with the political construction of scarcity.

As well as shortages of water and degrees of access to water supplies, inequitable allocation of water is identified in the literatures surrounding water scarcity as a ‘crisis’ (Clarke et al., 1991; Gleick et al., 1993; Brown, 2001). For example the causes of the ‘crisis’ of the Aral Sea (Micklin, 2007) are directly attributed to upstream irrigation. While allocation is acknowledged to play a role in scarcity in such writings, this tends to occurs via a broad volumetric analysis of which sectors are provided with water using long time window sum-balances. This chapter shifts beyond dualistic supply/demand and ‘sum balance’ allocation perspectives to the contemporaneous sharing of water in dynamically complex environments.

Tending towards volumetric responses to water scarcity

A volumetric response to water scarcity is a natural logic. Indeed the evolution of this logic response to scarcity can be seen in the last 40-50 years, with the supplanting of supply management (“if water is scarce, increase the supply”) by demand management (“if water is scarce, then reduce demand”). This ‘logic’ evolution has continued with both supply and demand management now being promulgated, alongside emerging ideas about allocation within an IWRM framework (GWP, 2000). With ‘allocation’ we tentatively see an evolutionary move from a volumetric sum-balance logics towards a facilitative share logic. This chapter attempts to frame this evolution more clearly.

As indicated above, the quality of ‘scarcity thinking’ is most revealed when either indicators of scarcity or recommendations are promulgated. The water stress index, one of the most widely adopted, (Falkenmark et al., 1989) proposes a threshold of 1700 m^3 of renewable water resources per capita in an annual basis. Thus, when countries are not able to maintain or provide this amount of water, they are said to be

[3] ‘Share’ is preferred more than the word ‘allocation’ which has already acquired other meanings in IWRM, and for its tonal and grammatical verbal similarities to the words ‘demand’ and ‘supply’.

water stressed. Furthermore, when water supply per person per year falls below 500 m^3, absolute scarcity is declared (Rijsberman, 2006). This index functions when boundaries are carefully defined (e.g. basin, country level) but cannot express the extent to which water is shared between a bounded unit's population or sectors.

The same omission applies to the Water Poverty Index (WPI) (Sullivan, 2002), constructed from five main indicators (water availability, access to water, capacity for sustaining access, the use of water and the environmental factors which impact on water). Putting aside the data concerns in terms of how the five indicators are reliably obtained, the WPI nevertheless attempts to move away from purely a volumetric measure but it outright fails to deal with the allocative and structural issues of how water comes to be shared between users and between sectors in a given area.

A facilitative approach to scarcity – share management

I theorise that share management is an important origin and response to scarcity alongside demand and supply management. It is immediately important to note that parts of this three-part framework (Table 2) are not new; scarcity is often constructed in terms of the problems or politics of allocation of water. For example the shrinking of the Aral Sea is correctly seen as a result of allocation of environmental water towards upstream irrigation. I seek to bring some additional perspectives on how scarcity and water apportionment interact, before returning to broad set of concepts that serve to distinguish between volumetric 'balance' approaches to scarcity and those that emphasise how we apportion water between users[4].

The theoretical starting point - supply and demand management

A deeper understanding of responses to scarcity is predicated on fully understanding the relationship between water supply and demand, requiring a careful specification of the two concepts, as guided by Table 2 and Figure 1. In this analysis, water supply is taken as the amount of water extraneous to a user, while water demand is the amount of water utilised and managed 'within' a user from the point of abstraction. We can describe 'amount' of water supplied, used or saved in three ways; *volumetrically* which includes three sub-types of depth (in millimetres), total volume (cubic metres) or discharge (litres/second); second as an *intensity* calculated as a specific or tertiary ratio, a common one being the hydromodule in litres/second/ha; third as a *proportion* (%) of total supply or total demand. Without formulating water use as an intensity, or recasting demand as a proportion of supply or total demand, water wastage and over-use is difficult to judge accurately.

'Supply management' suggests the augmentation of water to sectors or a sector, while 'demand management' describes the reduction in demand for water via the improved management of water within a sector to fit the available supply (Radif, 1999). Thus, integrated water resources management (IWRM) proposes that a switch to the demand management paradigm (as well as or even rather than supply management) as this helps increase headroom (Carnell, et al, 1999). Often mental agility is required

[4] In this chapter, the term 'user' is employed to cover all types of stakeholders; individuals, groups, and sectors.

because demand management within one user frees up water for another user, and thus could be seen as a supply management solution or because tangible visible alterations to the 'supply' such as exchanging an open channel for a pipe can save water, are in effect demand solutions because they 'save' a user's water use (hence the confusion over definitions shown by Merrett, 2004).

Supply management can be understood as increasing the amount of water either by extending access to existing flows, or by increasing the reserve volume (or buffer) by capturing flows that otherwise would have been lost to beneficial use. Examples include reservoirs and groundwater recharge systems. Conceptually, supply management should be seen in terms of shifts of existing water, either spatially, temporally or through changing quality and phase. Thus storage is can be seen as an inter-annual shift in the hydrograph, while accessing groundwater is a shift on a longer-time scale, possibly even geological. Desalinisation results in more water from improving water quality, while pollution, representing a decline in water quality, reduces water availability. Condensation technologies for drinking water represent a phase shift from vapour to liquid, and may become increasingly important supply-side approaches (Lindblom and Nordella, 2007).

Multiple concepts of demand management also require careful unpacking. Much work has been done on this by for example the International Water Management Institute (Molden et al 2003). Table 2 attempts to go further, identifying ten dimensions to demand management. There are three components to water use and savings; net, tare and gross. Net is the component of gross water use that generates benefits to the user, and arises from consumptive or non-consumptive use. Tare is the 'inefficiency' component arising from delivering water to provide the net requirement, and gross is the combination of net and tare and leads to a gross requirement at the point of abstraction. Confusingly, water demand in a sector can be expressed from the point of view of the resource whereby returned water has to be computed – this can be termed the 'final gross'. Thus the final gross demand calculated for a user can be seen as the net demand from point of view of the hydrological cycle.

Two drivers affect how demand management occurs; the first is that demand reductions are driven by the availability of water, meaning that a reduced supply, either from natural variation or growing competition, forces a reduced demand. The second, less likely option, is that savings are made within the sector without reference to the supply of water. In keeping with IWMI's framework, demand management thinking should refer to, amongst other dimensions, depletion, non-depletion, beneficial and non-beneficial components.

Table 2. Framework of supply, demand and share management

Scarcity response	Sub-type	Definition
Amount descriptors	Volumetric (depth, volume or discharge)	Water supply, usage or saving within a sector expressed as a depth equivalent (mm), volume (cubic metres), for or discharge (litres/second).
	Proportion	Water supply, usage or saving within a sector expressed as a percentage of total water supply
	Intensity or specific	Water supply, usage or saving expressed as a ratio (field, person or per hectare)
Supply management	Access	Establishing infrastructure that *extends access* to existing freshwater, for example deeper borehole
	Buffer (or capital)	Establishing or managing infrastructure to store or create freshwater, for example a reservoir.
Includes five types of shifts	'Mining' – long time shifts	Acquiring and accessing geological water that moves slowly within the hydrological cycle
	Storage – short time shift	Acquiring water that represents a shift of water within the hydrological cycle over a short time span
	Place shift	Managing water that entails a move of the resource, e.g. inter-catchment transfer
	Quality shift	Cleaning up or improving otherwise unusable water; e.g. desalinisation.
	Phase shift	Rain-cloud seeding and condensation technologies to provide drinking water from vapour
Demand management	Net	Net water saving within bounded area or sector used directly for benefits
	Tare	Savings of water in the portion of water between gross and net, non-beneficial savings, including both consumed and returned water.
Includes three types of measures	Gross or cap diversion	The total amount of water required by a sector at the point of diverted supply including the inefficient part (tare).
	Final gross depletion	This describes the gross amount of water removed by a user after return flows have been computed. From the source's point of view this can be seen as a net depletion.
Includes two types of drivers and two outcomes from demand	Supply-driven	Demand fluctuates as a result of short or long-term changes in the availability of supply
	Sector-driven	Demand adjusts as a result of purposive measures taken within a sector to save water.
	Process-consumption	Water consumed or used to produce benefits (e.g. crops). Non process consumption also occurs.
	Non-beneficial	Water consumed or used that produces no or few benefits.
	Consumptive	Water is depleted from the hydrological cycle during usage – irrigation is an example
	Non-consumptive	Water is minimally depleted but its water quality might be changed during usage (industrial use is an example)
Share management (determining both current and future allotment of water)	Allocation	Explicit allocation of water between sectors or users by using allocation decision-making and devices (markets, rights), normally within IWRM framework.
	Translation	Implicit and unintended seasonal change in share of water between sectors or users as a result of new or altered supply infrastructure integrated over a longer time period of the hydrograph.
	Modification	Implicit and unintended contemporaneous change in share of water between users or sectors as a result of an on-going changing supply mediated by existing institutions & infrastructure.
	Scheduling	Short time period management of water scheduling to between users and sectors but within the shares determined by the allocation of water to users and sectors.
Includes three types of water movement	Surface	Movement of water via channels, pipes and rivers
	Sub-surface	Movement of water via soil water and geological water
	Vapour	Movement of water via atmosphere

A third response – water share management

Critically for this analysis of responses to scarcity, a third option exists, depicted in Figures 1, 2 and 3. The management of 'share' determines how a stable or varying supply is apportioned between users resulting in currently-supplied proportions of water and in future changes in proportions in either short or long time scales. Following Table 2, changes in apportionment occurs via four mechanisms:

1. The first is the *allocation* of water between sectors or users by using allocation decision-making and devices (markets, rights) within IWRM framework. This is how most commentators perceive the sharing of water alongside demand and supply management. There are three types of allocation; where an external regulator creates the conditions for a change in apportionment, where demand management arises from within a user that then 'automatically' provides more water for other users, and where prior appropriation combined with growth appropriates more water for a user, that then 'automatically' reduces water for other users.

2. *Translation* covers the implicit and unintended changes in share of water between sectors or users as a result of new or altered supply infrastructure integrated over a longer time (seasonal) period of the hydrograph. For example, surplus water stored during the wet season in effect takes environmental water and holds it back for another sector, perhaps irrigation. Translation implies a temporal shift in water usage with a concomitant shift in apportionment between sectors.

3. *Modification* describes implicit and unintended contemporaneous changes in the share of water between users or sectors as a result of a changing supply being modulated by existing institutional and infrastructural architecture. This type of share is more significant in variable climates, and is explained in more detail later.

4. *Scheduling* is concerned with the short time-period management of water moved between users but within the shares determined by the allocation of water to users and sectors. Scheduling does not result in any net changes, but can critically resolve inter and intra-sectoral water shortages where timing of delivery is important. For example, water flows can be scheduled between an irrigation system and a downstream wetland to sustain their respective ecologies.

These four definitions are about *how* water is moved between users and sectors and not to whether water is 'inter-sectorally' or 'intra-sectorally moved'. In other words the four share options equally apply for example to a series of irrigation intakes on a river within an irrigation sector as to the allotment of water between irrigation, industry and the environment on the same river. This is an important distinction to be made because it distinguishes 'sharing processes' from 'sharing claimants'.

Figure 1. Schematic of supply, demand and share management

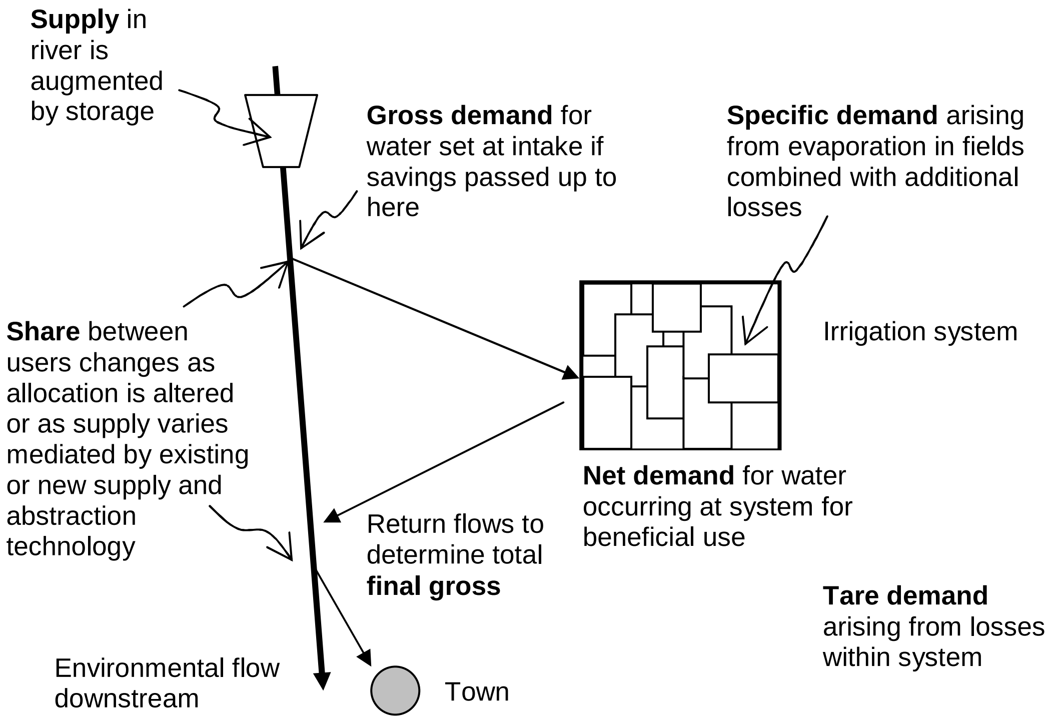


Figure 2. Supply and demand curves deemed to be in broad equilibria

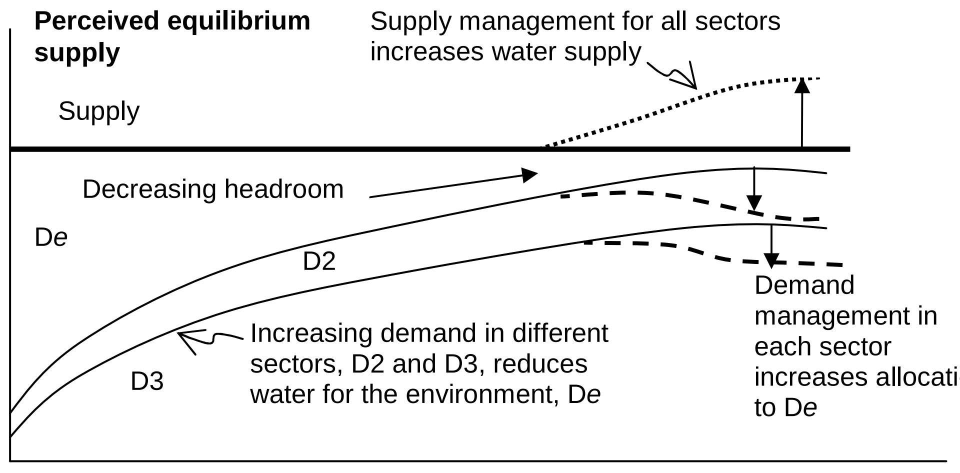
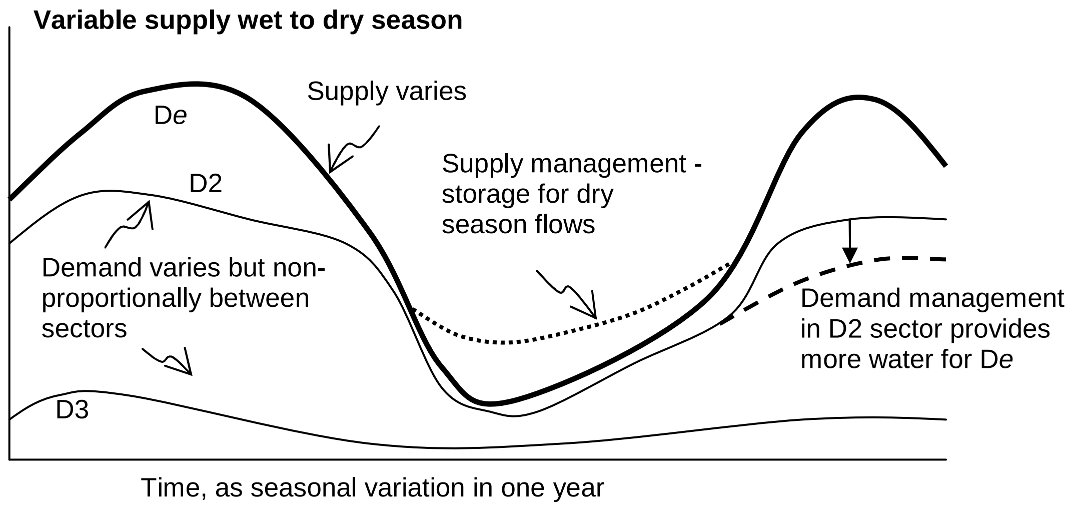
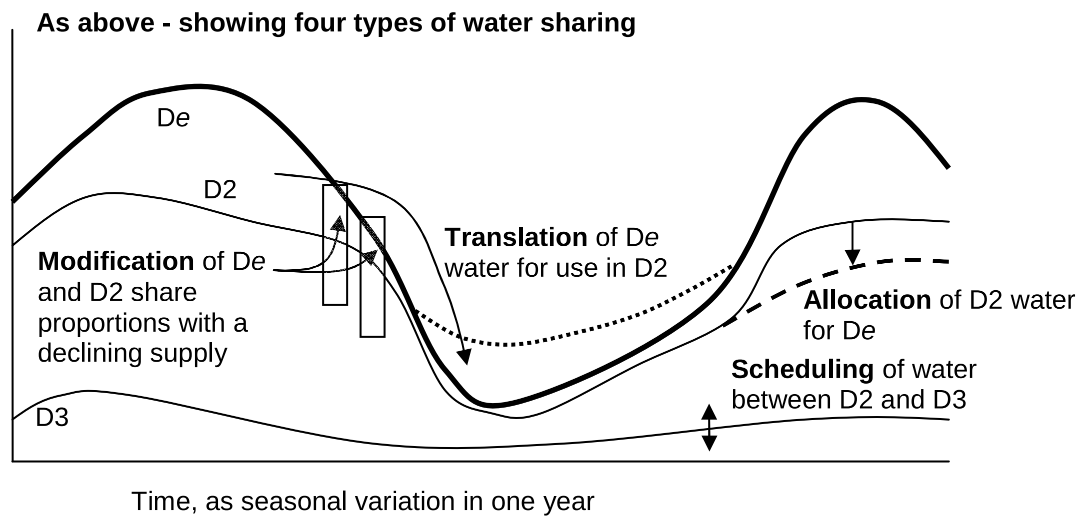


Figure 3 Varying supply, demand and share management under a variable climate





Categorised with share management are the three ways in which water moves between users; surface, subsurface and vapour. This provides resource scientists and managers with an understanding of the likelihood of saved water being made available to another sector, or whether it is captured by the same sector depending on the spatial and hydrological route the water takes (see Molle, et al 2004). The route that water takes also affects notions of certainty and timing, in that water that moves via groundwater flow back to a river is slow and difficult to gauge and water that moves between users as atmospheric vapour is even less 'knowable'.

Note that 'allocation' and 'scheduling' involve changes to the institutions and infrastructure while 'translation' and 'modification' describe the behaviour of water sharing through a variable supply modulated by existing institution and infrastructure.

In other words a change in water apportionment in both allocation and scheduling arises from active management and governance, while a change in water apportionment arising via translation and modification occurs primarily from changes in supply interacting with an existing and therefore passive management.

The four dimensions of share management vary in influence in different types of river basin conditions. I theorise that allocation applies to longer-term applications of inter-sectoral sharing, or where equilibrium climate exists (e.g. oceanic, temperate). On the other hand, modification and translation of shares of water have greater relevance to non-equilibrium, pulse-driven semi-arid climates. Such distinctions might have profound implications for how water is governed. In equilibrium conditions where supply is fixed or variable but in a predictable manner, the share between sectors is determined by purposive demand or supply management in one or more sectors linked with allocation share management. Thus water saving in irrigation, cascaded up to a cap on abstraction, adds water to other sectors.

However, as climate and supply increases in complexity via increased variability, leading to greater amplitude of hydrological events as found in semi-arid environments, translation and modification share management becomes more important (Figures 2b and c). Here, a variable water supply (where supply increases or decreases over orders of magnitude within relatively short periods of time) 'forces' shifts in demand but disproportionally upon different sectors depending on how users differentially access the increasing or decreasing rate of supply[5]. This can be seen as a *modulation* of the supply variability upon demand variability, and therefore of the share proportions of users.

A water apportionment index

I propose an index to capture the scarcity dimensions of inequitable sharing of available water. The index, described below, captures the range of shares between different users within a given situation, and as such is not a straightforward ratio between a sector's demand and the renewable water supply (c.f. criticality ratio in Rosegrant et al, 2002).

While variation in supply might be viewed as an indicator of lack equity of supply, and therefore as measure of poor governance, the problem is that most measures of dispersion (such as the coefficient of variation or the Gini coefficient - see Cullis and van Koppen, 2007) cannot easily be used without carefully thinking through what variation or inequity should be captured by an index[6]. This is because three types of variation readily occur – variation that need not be viewed as 'maldistribution'. The first is that different sectors and users use different quantities of water depending on type of use, size, population and so on. Thus agriculture uses larger amounts of water related to its hectarage and evapotranspiration. The second, related to the first, is that the units to describe water use vary considerably between users, which although not insurmountable, add to the complexity of the computation. The third is that the supply

[5] An example demonstrated in Table 3 and seen in the Tanzanian case study later on found irrigation intakes sequentially abstract water upstream to downstream.

[6] Cullis and van Koppen (2007) partly recognise that the Gini Coefficient measure equality of distribution and not equity of distribution. Note that the WAI measures observed equity against intended equity, and does so for each selected time window, or for an average of 'j' time windows.

of water to different users varies considerably due to climate and weather. This also means that demand changes quite naturally as systems undergo a natural intra-annual cycle. Thus during winter or a dry season, irrigation systems quite normally use less water. Forms of variation ascribed to poor management need to separated from these forms of variation that occur over time and space. A Water Apportionment Index (WAI) has been formulated describe variation of water supply between users arising from governance of the resource.

The Water Apportionment Index is defined as the weighted average of the observed proportions of water given to users when below or deficit from an ideal proportion. Table 3 and Equation 1 describe how this is calculated. The WAI, essentially a measure of mean distance from an intended apportionment of water, varies from 0 to 1, where 0 describes good water management, defined as ‘water sharing that directly mirrors the calculation of an ideal apportionment of water despite variations in supply’, and ‘1’ describes poor management depicting highly skewed disproportionate supply because most water is captured by one or two users while others receive very much less than their required share. Figure 3 captures the relationship between increasing aridity and variability (both go hand in hand in semi-arid climates) and the WAI. A steep upward curve suggests a relationship in which water equity drops markedly as water supply decreases, while a flatter curve suggests resilience to aridity, and a capacity to meter out ever declining amounts to users in equitable amounts.

$$WAI = \sum_{j=1}^{s}\sum_{i=1}^{n} \left| \frac{\left(P_{ij}^{'} - P_{ij}^{o}\right)}{t} \right| \quad \text{When } P'_{ij} <= P^{o}_{ij} \qquad \text{Eq. 1}$$

Where
P’ = ‘ideal’ proportional division of water given to each sector for a given time window during a changing supply

P^o = ‘observed’ or actual proportional division of water given to each sector for a given time window during a changing supply

i = the number of users or sectors with a maximum of n

j = the number of time slots, with a maximum of s

This equation calculates the weighted average WAI from individual ‘share deficits’ of each sector, i, calculated in a series of time slots, j. The share deficit is (P’-Po) when P’ij is less than or equal to P^oij.

The ideal (P’) is determined as a separate calculation. The ideal P’ can be determined in a number of ways, and in Table 3 are the proportions at the top of the table calculated from Equation 2. Here the ideal proportion, P’, is calculated for each sector, as the ideal volumetric abstraction or supply for each sector, i, divided by the total idea abstraction by users in the sub-catchment (or bounded area defined by a total supply). Although in the example the ideal proportion is calculated once, it could be calculated for each time slot to reflect changing priorities as the water supply fluctuates.

$$P' = V'i / \Sigma V'i \qquad \text{Equation 2}$$

Where V'i, is the ideal volume of water abstracted for a given sector, i.

And, ΣV'i is the total ideal volume of water abstracted for all sectors, i to n.

The observed share, P^o is determined from the observed volumetric abstraction for each sector, i, as a proportion of the total observed supply (equation 3).

$$P^o = V^o i / \Sigma V^o i \qquad \text{Equation 3}$$

Where $V^o i$, is the observed volume of water abstracted for a given sector, i.

And, $\Sigma V^o i$ is the observed total volume of water abstracted for all sectors, i to n, for each time slot, j.

The WAI only calculates variations (or distances) from an ideal share if the proportional share is less than its ideal. Hence the (if $P' <= P^o$) logic. It therefore does not calculate surplus shares as a measure of dispersion. This is for three reasons. First averaging plus shares and minus shares introduces an additional level of complexity into the equation when calculating averages. Thus, the averages are only of the spread of minus shares. Second, experimentations with formulations of the index reveals that surplus supply is best omitted if the index is to range from zero to 1. Third, the only way in which deficits (minus values) arise occurs when other sectors capture an excessive share of the remaining water. Thus, surplus shares for one or two sectors are expressed as a negative shares for others. The consequence of these computations is that WAI expresses the magnitude of deficits for users rather than variance around a mean.

Finally, to create an index that lies between zero and 1, Equation 1 calculates the absolute values of the negative differences between the ideal and actual, and determines the weighted average of these. (An alternative would be square the differences and then square root the result).

Table 3. Calculations of the Water Apportionment Index

t	River flow l/sec	Irrig 1 400 l/sec	Remainder l/sec	Irrig 2 50 l/sec	Remainder l/sec	Irrig 3 350 l/sec	Remainder l/sec	Irrig 4 200 l/sec	Remainder l/sec	Downstream 20 l/sec	Surplus water l/sec	Total abstracted l/sec
1	1200	400	800	50	750	350	400	200	200	20	180	1020
2	1100	400	700	50	650	350	300	200	100	20	80	1020
3	1000	400	600	50	550	350	200	200	0	0	0	1000
4	900	400	500	50	450	350	100	100	0	0	0	900
5	800	400	400	50	350	350	0	0	0	0	0	800
6	700	400	300	50	250	250	0	0	0	0	0	700
7	600	400	200	50	150	150	0	0	0	0	0	600
8	500	400	100	50	50	50	0	0	0	0	0	500
9	450	400	50	50	0	0	0	0	0	0	0	450
10	420	400	20	20	0	0	0	0	0	0	0	420
11	410	400	10	10	0	0	0	0	0	0	0	410
12	400	400	0	0	0	0	0	0	0	0	0	400

t	River flow l/sec	Share/total P' = 39%	Share deficit	Share/total P' = 5%	Share deficit	Share/total P' = 34%	Share deficit	Share/total P' = 20%	Share deficit	Share/total P' = 2%	Share deficit	WAI
		P^o	(P'-Po)	P^o	(P'-Po)	P^o	(P'-Po)	P^o	(P'-Po)	P^o	(P'-Po)	
1	1200	39.2%	0.00	4.9%	0.00	34.3%	0.00	19.6%	0.00	2.0%	0.00	0.00
2	1100	39.2%	0.00	4.9%	0.00	34.3%	0.00	19.6%	0.00	2.0%	0.00	0.00
3	1000	40.0%	0.00	5.0%	0.00	35.0%	0.00	20.0%	0.00	0.0%	-0.02	0.02
4	900	44.4%	0.00	5.6%	0.00	38.9%	0.00	11.1%	-0.08	0.0%	-0.02	0.10
5	800	50.0%	0.00	6.3%	0.00	43.8%	0.00	0.0%	-0.20	0.0%	-0.02	0.22
6	700	57.1%	0.00	7.1%	0.00	35.7%	0.00	0.0%	-0.20	0.0%	-0.02	0.22
7	600	66.7%	0.00	8.3%	0.00	25.0%	-0.09	0.0%	-0.20	0.0%	-0.02	0.31
8	500	80.0%	0.00	10.0%	0.00	10.0%	-0.24	0.0%	-0.20	0.0%	-0.02	0.46
9	450	88.9%	0.00	11.1%	0.00	0.0%	-0.34	0.0%	-0.20	0.0%	-0.02	0.56
10	420	95.2%	0.00	4.8%	0.00	0.0%	-0.34	0.0%	-0.20	0.0%	-0.02	0.56
11	410	97.6%	0.00	2.4%	-0.02	0.0%	-0.34	0.0%	-0.20	0.0%	-0.02	0.58
12	400	100.0%	0.00	0.0%	-0.05	0.0%	-0.34	0.0%	-0.20	0.0%	-0.02	0.61
											Average WAI	0.30

Figure 3. Graph of relationships between WAI and increasing aridity and supply variability

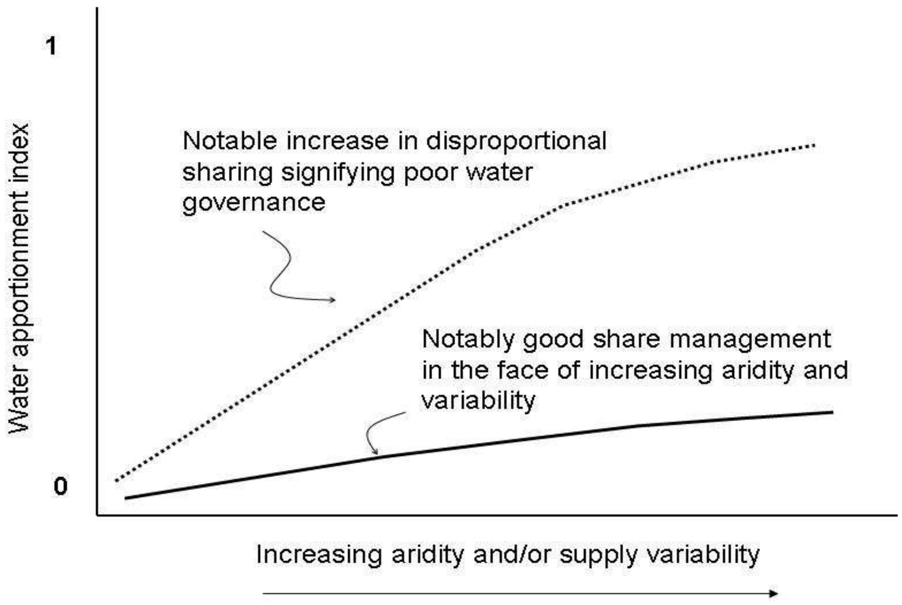


Figure 4. Graph of Table 3 showing varying proportions of abstraction with a declining supply

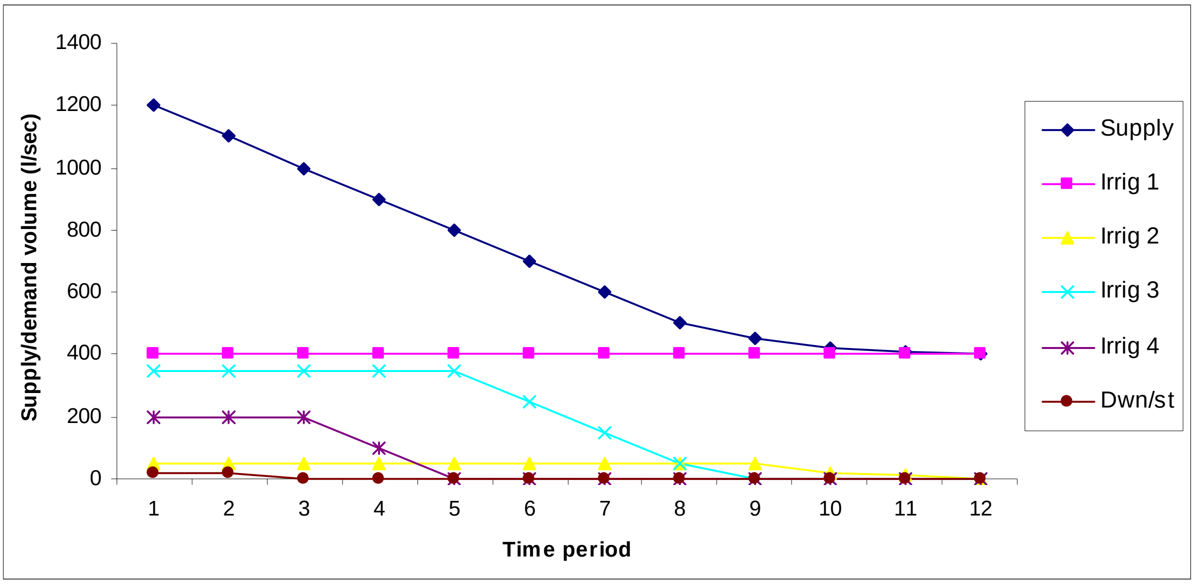


Table 3 reveals a Water Apportionment Index of 0.30 for the worked example of four irrigation intakes in sequence taking 400, 50, 350 and 200 litres/second, plus a downstream need of 20 litres/second. If the supply can meet all these needs, for the sake of argument, these requirements can be taken as the ideal 'shares' of the total requirement of 1020 l/sec, in other words as 39%, 5%, 34%, 20%, and 2% respectively. The top of Table 3 and Figure 4, reveals that if water is taken in sequence, the first intake takes its absolute amount of 400 litres/second. With a declining river supply from 1200 l/sec (in time slot 1) to 400 litres/second (in slot 12), this absolute abstraction progressively magnifies the reduction in flow for the remaining downstream intakes. Thus the apportionment of water between the four intakes changes disproportionately with each declining flow, which can be calculated as a deficit from the ideal share. This change in the share deficit is given in the lower part of Table 3, giving the WAI for each time slot and average WAI for all 12 time slots. The WAI of 0.3 expresses that about the basin users are experiencing 30% water shortages below their requirements as a result of poor apportionment. The index can therefore be used intuitively alongside the volumetric Water Stress Index to reveal total stress and the distribution of stress within a basin or catchment.

This example explains how the apportionment of water via modification occurs, and demonstrates how modification is an instantaneous phenomenon, mediating apportionment between users on an on-going basis, leading to disproportionate scarcity imparted upon users already facing a declining supply. Modification can be seen in the lower half of Table 3 by looking at the P^o columns, particularly the column for irrigation intake 1 where P^o increases from an ideal of 39% to taking 100% of the available flow leaving other intakes with far less than their ideal proportion of the declining supply.

A conceptual framework of scarcity logics

Expanding beyond the volumetric mission for balancing supply and demand opens up space for considering how inter-user shares can be managed, particularly dividing water to users contemporaneously in the face of a variable supply. Figure 5 schematically expresses a single-axis concept of these contrasting responses to scarcity. The left hand side of Figure 5 tends towards a primary logic, tackling scarcity volumetrically, while the right side proposes that a share response that recognises the allocative dimensions of scarcity and moreover facilitates, for competing users, transitions in and out of scarcity. The territory in the middle suggests both a mixed multi-layered approach that selects from both volumetric and share perspectives.

Additional dimensions of these responses are given in Figure 5. Thus supply and demand management are associated with a quantity-balance logic, while share management characterises the facilitative model. The water property most associated with the balancing emphasis is volume (cubic metres) or discharge (litres/second), while the composite approach accommodates evaporation, which ratio of flow-to-area supplied can be expressed as the hydromodule (litres/second/hectare). A facilitative approach is inherently concerned with managing existing shares as proportions and specific flows working continuously or within smaller periods of time and recognising the paramount importance of timing and scheduling in ecological functioning.

When water scarcity is primarily held to be a problem of direct volumetric scarcity arising out of an imbalance of supply and demand linked to an elementary application of supply and demand solutions under conditions of perceived average ‘equilibria’, analysts tend towards a direct and primary managerial logic when addressing water scarcity. ‘Quantity-balance’ logic in water thinking while effective is not necessarily complete or accurate enough in other types of semi-arid environments – an environment marked by both scarcity and variability. How society *shares* a variable supply between different sectors rather than attempts to climate proof such an environment by boosting supply is a fundamental, systemic question. The discussion in the previous section regarding translation and modification forms of sharing of reveals that if a reservoir is constructed as a supply solution for a semi-arid environment, the manner in which that water *volume* helps equilibrate the locality becomes significant, with implications for allocation (water shared for domestic, productive or environmental purposes during an extended dry period), translation (user proportions changed through the presence of the dam) and modification (the interference of other infrastructure on the intended allocation of reservoir releases) would have to be critically addressed.

Figure 5. Conceptual framework of scarcity response logics

Response	**Volumetric/quantity logic**	↔	**Composite 'facilitative' logic**
Order of response	**'Primary'; solving water balance**	↔	**Layered, composite, addressing architecture**
Hydrological predictability & stability	**Humid, temperate, stable**	↔	**Seasonal, semi-arid, dynamic**
Climate ecological 'fit'	**Equilibrium**	↔	**Non-equilibrium**
Approach	Supply mgt Demand mgt Share mgt (allocation)	↔	Share mgt (modification)
Managerial intention	Alter volume balance within a sufficiency phase	↔	Alter share balance when moving between phases
Water unit of measurement	Volume/Discharge/Depth	↔	% Proportion or intensity/specific
Means of water measurement	Metering	↔	Non-metering solutions
Water rights	Volumetrically specified	↔	Locally, temporally, or proportionally specified

Case study example of the framework

The differences between volumetric and facilitative approaches to scarcity are now briefly explored, exemplified by work conducted by the author in Tanzania during the period 1999-2005[7].

[7] Much of this work also provided the inspiration to non-equilibrium and facilitative approaches to water apportionment. A number of publications can be referred to as background reading (Lankford et al 2007; McCartney et al, 2007; Lankford et al, 2004; Lankford, 2004).

A World Bank project 'River Basin Management and Smallholder Irrigation Improvement Project', funded in Tanzania to support river basin management (World Bank 1996), undertook to manage the allocation of scarce water via the implementation of a formal regulatory approach. This utilised new water rights sold in litres per second, combined with changes to intake design where 'improvement' from traditional designs was deemed necessary (Lankford, 2004). The rationale for introducing water rights were attached to water fees ("enhancement of water fees... as an incentive for water conservation... and as a source of funds for water regulation activities, catchment conservation and water resources monitoring"…"economic instruments include water pricing, charges, penalties and incentives to be used to stimulate marketing mechanisms and serve as an incentive to conserve water..")

Recent research (van Koppen et al., 2004) demonstrates that the new volumetric water rights were very poorly matched to the problems encountered in these sub-catchments. The water rights did not recognise existing customary water rights; they failed to accommodate swings in water supply due to rainfall and seasonality and could not be tied to actual water taken because no measuring structures are in place and in many cases were not related to actual discharge capacities of the new intakes or to the demand of irrigation systems[8]. Furthermore, the rights were not, when cumulatively added to other water rights, related to the overall supply in the river systems (which varied by several orders of magnitude) and were difficult to update in the light of constantly changing situation.

The design of irrigation rights and intakes by RBMSIIP influenced water allocation materially and in ways not intended by the rights given on paper. Downstream users were subjected to extreme low flows in the dry season as a result of upstream 'blocking weirs' taking all the water. These conventional types of intake aggravated a delicate situation where dry season flows of only 100-200 l/sec have to be shared between intakes and in-stream users. Thus a volumetric solution of water rights and intake 'improvements' based on normative water thinking exacerbated downstream water scarcity in ways similar to the worked example given in Table 3.

A facilitative alternative is provided in the legal-infrastructure framework of Lankford and Mwaruvanda (2005) for managing formal and informal rights and river basin infrastructure. It rationalizes the interface between formal volumetric water rights (that cap abstraction and determine allocation between users in the wet season) and customary agreements (that relate to negotiations over shares of in-stream water during the dry season). The framework demonstrates how, if strengthened and supported, local customary negotiations combined with formal water management interventions, apportion water during both wet and dry seasons. Furthermore, the framework argues that the current design of irrigation intakes, in terms of maximum capacity, adjustability and any proportional capability, needs to be re-thought so that the intakes fit and help support their associated sharing arrangements.

With a volumetric bias, water measurement using flow gauges becomes the logical tool to compare how supply and demand match and to charge users for the amount of water used (an economic incentive for demand management). Therefore, the logic runs, water discharges should be volumetrically measured[9]. Yet, water can be 'measured' in two other ways; by transparent proportional division and by modular gate technology, both of which establish ergonomic, user-friendly means of satisfying managerial gaps in apportionment of water.

[8] An exploration of why this was the case is given in Lankford, 2004b

[9] I refer here to a set of email discussions in November 2003 with World Bank on long-term aims of the RBMSIIP project to support water measurement so that fees could be set volumetrically.

Thus, contemporary water rights issuance in Tanzania can be seen as a volumetric response to scarcity. RBMSIIP hoped that these volumetric rights would ensure demand management and therefore bring about reduced upstream demand thereby effecting inter-sectoral allocation from upstream irrigation to downstream hydropower. The framework proposed by Lankford and Mwaruvanda suggests a need to distinguish between the wet and dry season sharing of water, between paper 'rights' and concrete structures, and between proportional as well as volumetric division of water.

Table 4. Comparing approaches for managing dynamic supply in sub-catchments

Water governance dimension	**RBMSIIP approach**	**Alternative 'facilitative' approach**
Seasonal change embedded in intake	Weir and orifice intake which has to be manually adjusted in dry season to reduce inflows	Proportional flume design for the intake embeds sharing of water during dry season
Part of intake design most closely associated with this	Advised to rely on Q max rather than on throttling. Gate is usually opened to maximum setting Focus = [litres/second]	Either design allows adjustability of gated intake flows or allows passive proportional abstraction of available river flow. Focus = [% of division]
Type of rights most closely associated with this season	Formal water permit (volumetric) with no recognition of informal shares or rights	Formal water permit (volumetric) also added to customary agreements and rights (proportional, or time schedule basis)
Payment structure	Fixed payment for water right	Fixed payment can continue for water right but at the sub-catchment level, not individual intake level. No payment for proportional share
Water measurement	If to support volumetric rights, then a measuring structure is necessary (yet open channel variable flow measurement is highly problematic)	No measurement necessary, volumetric cap designed into the intake, and proportional rights aided by proportional intake design
Role of intake improvement from traditional to 'improved'.	To improve irrigation efficiency via regulation	To help share water between users intra- and inter-sectorally.

Finally, the role of the irrigation intake in irrigation efficiency is revealed through the two different approaches. The RBMSIIP case is indicative of a problem-solution response built on an erroneous conception of demand management as applied to irrigation efficiency. The RBMSIIP project believed that their project activities would raise efficiency from 15% to 30% allowing substantial reallocation of water downstream, as the following quote from the Appraisal Report explains, and that this would be effected by improving intakes and training farmers. Yet detailed modelling and measurement by others including the author indicated that effective efficiency was probably in the region of 45% to 65% because of re-use of drain water by tail-enders (Machibya, 2003; SMUWC, 2001). The errors shown in the quote are that a) the efficiency was very low and b) the losses were localised and depleted from the basin, and c) improving intakes would reduce losses. In addition, the RBMSIIP approach to irrigation efficiencies did not account for the theoretical frame in which efficiency in river basins is situated; efficiency was higher because of reuse and because of the very many interacting activities within farmer fields and channels.

> *"In order to illustrate this effect, the "savings" in water which result from the improvement of some 7,000 ha of traditional irrigated area under the project (this includes both basins) are valued using their capacity to generate electricity in the*

downstream turbines. An average "in the field" requirement of 8,000 m^3 of water, for one ha of rice production, implies withdrawal of 53,300 m^3 from the river, with an irrigation efficiency of 15 percent. Following improvements in irrigation infrastructure, and an increase in irrigation efficiency to 30 percent, the withdrawal requirement from the river drops to 26,700 m^3 per ha. This releases some 26,700 m^3 for every ha of improved irrigation, to be used for hydropower generation downstream. For this exercise, the water is valued at 5 US cents per m3, the valuation for residential electricity use (34 percent of all electricity use, and intermediate point between the two alternate values)". World Bank RBMSIIP Appraisal Report page 42.

In summary, RBMSIIP focused on direct logic of reducing volumetric losses through intake improvements (but without explaining how this connection functions), whilst an alternative approach starts with facilitative principles to intake design combined an exploration of the many drivers of efficiency both at the technical and institutional level.

Conclusions

In presenting a wider framework of supply, demand and share management responses to scarcity, I propose a number of conclusions. First, with regards to scarcity responses, clarity is required, not simply in definitional terms but terms of intentions and material outcomes; what can boost supply can increase demand; what can seem to be demand management may not affect total demand; what might be demand or supply management might adjust how water is apportioned between users and thus not alleviate scarcity for some users. Within highly politicised debates about water scarcity, particularly in the face of policies to address scarcity under climate change, the need to define meanings, causalities, data needs and intentions is paramount.

Second, I argue that a supply-and-demand 'volumetric' logic runs the risk of being a superficially response to water scarcity. This approach can occlude dimensions of water management that address the management, scheduling and sharing of limited and varying water supplies. A composite framework that examines the supply, demand and sharing of water was proposed, emphasising in particular modification and translation dimensions of sharing water during transitions between states of high and low sufficiency of water. Pursued to outputs, this approach might nevertheless require additional storage or water saving solutions – but they will be encapsulated within a prioritised set of ideas regarding apportionment carefully contrasted against 'self-evident' volumetric notions proposed by experts immersed in dominant scarcity narratives.

A further contention of my argument is that responses to water scarcity are either implied from the use of models or indices, or solved by bringing physical quantities of water. Drawing from political ecology theory, crises and technical responses are framed by those who have an ability to shape current narratives intending to shape further influence and finance associated with that. Thus, orthodoxies that appear to have a *straightforward* and *sensible* technical basis should be thoroughly contested. One example of this is that irrigation efficiency can be addressed by shifts to micro-irrigation or with canal lining. While this is technically generalisable, it omits a definition of the boundaries that define whether the savings actually result in a reduction of the gross cap of irrigation abstraction.

Third, the paper elevates irrigation abstraction technology (previously neutral in the demand and supply management debate, or being potentially mistaken as a technology to improve efficiency within irrigation systems) to being critical for considering how share management functions and behaves in the face of a varying supply.

Fourth, the selection of supply, demand and share management responses represents issues that forthcoming theories of water governance must reflect and comment upon. Share and demand management requires an effort of governance, more so than the capital and infrastructural requirements of storage. Governance theory must be in a position to comment on the inter-linkages between, and respective relevance of, supply, demand and share management.

Fifth, the framework has critical implications for equilibrium and non-equilibrium theories of water apportionment between users and sectors. Under equilibrium conditions, where water is perceived to be predictable and knowable in terms of supply and amount, 'allocation' of averaged volumes via IWRM may be the most appropriate response to water sharing. The regulatory result is that water rights can be allocated in terms of quanta (litres per second). However in semi-arid conditions where water supply is unpredictable and highly variable over short time scales, 'translation', 'scheduling' and particularly 'modification' gains in significance as a mediating mechanism for water sharing between sectors. In addition, under such conditions, water rights are better expressed as proportions (%) of the available supply.

Concluding, solutions to scarcity underestimate the interplay between demand, supply and share management in different types of landscapes and environments. Put simply, if water, water management and the systems in which management sits are held to be manifold, composite and complex, then approaches to water shift from being direct and volumetric to being composite and 'para-volumetric'. Share management with demand and supply management describes a tripartite view of scarcity management, underpinning an objective of facilitating a water-using society in shifting to different states of water sufficiency during wet and dry periods by organising resources at a locally and temporally relevant scale. It is about adaptive guises – experts tend to discern volumetric responses as adaptations to shortages rather than other kinds of adaptation to shortages that accommodate the nature of water management (high variability, continuous flows, poor transparency). This returns to the notion of an underlying adaptive or 'knowledge scarcity' which suggests that many water specialists do not critically unpack scarcity dimensions, a scarcity reinforced politically as governments and donors seek specific types of programmes that meet their criteria such as high levels of capital expenditure in relatively short time horizons.

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