Sustainable Utilisation of Water Resources - *a non-equilibrium approach:* Informed by the Usangu Plains, Tanzania

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Abstract

This paper argues that six approaches to water management in river basins in Sub-Sahara Africa help ensure the sustainability of water resources utilisation. These are; threshold contingency planning, sectoral demand management, an integrated approach, proportional water sharing, core water provision and capping of the maximum abstraction volume. The latter three of these six are specific to the non-equilibrium hydrological conditions found in such river basins. These conditions arise because groundwater resources are absent due to basement parent rock, and because a highly dynamic climate, which exogenously supplies the river basin, opens and closes the river basin in wet and dry years respectively. For both proportional and core water allocation, steps can be identified that promote these in ways which are cost efficient, transparent and less resilient to subversion.

Introduction

In Sub-Saharan Africa, specific conditions underwrite the nature of sustainable utilisation of water resources. The climate drives the dynamic nature of water supply; the lack of groundwater increases reliance on surface water; and changing population densities, improved access to markets and a high ratio of land to water pushes potential future demand far beyond long term mean supply. The trend is towards closing and fully closed river basins that may be *seen* to be unsustainable (i.e. demand exceeding supply). Moreover, unlike other natural resources, surface water is not subject to the same kinds of factors that affect the 'underlying resource base'; rather it is renewed, exogenous, cyclical and variable in supply. In addition, it's availability for a given user is contingent on upstream use rather than on local activity.

Therefore this paper argues that in the Sub-Saharan context (as informed by the conditions found in the Ruaha River Basin, see Baur *et al*, 2000) sustainable utilisation of water translates into dividing variable surface water to users within defined, accepted but flexible limits. While it is acknowledged that an integrated approach is required to sustain effective water management services, a focussed emphasis on a few measures, such as proportional and core water rights with supporting technology, can backstop such agreements providing a platform for the more equitable and sustainable division of available supplies.

Definitions of sustainable water use

Sustainability is about the need to provide, over the longer term, a level of service, resource or benefit to ensure growth or protection of productivity. This maintenance or sustenance of provision has to occur in the face of gradual or sudden systemic and non-systemic disturbances. These disturbances, for example such as over-use, budget cuts, changing legislation and climate, can erode this provision leading to negative economic, environmental and livelihood impacts.

Precise definitions of sustainable use of water are not easy to find. One possible definition of sustainable utilisation of water is derived from definitions of other natural resources. An example is taken from Australia's Department of Agriculture, Fisheries and Forestry (AFFA, 2000): "The management of natural resources to ensure their continued capacity to be productive in both agricultural and environmental capacities". We can see that threshold processes underlie this

definition. Below a certain limit, the resource is unable to generate, renew or protect itself. Examples of this are; soil threatened by soil erosion, fish stocks threatened by over-fishing, and grassland unable to re-seed itself through overgrazing. The resource moves through thresholds from self-renewing to exhaustible to exhausted. This kind of sustainability might best be known as 'renewable sustainability', and it introduces the principle of threshold resource control - having to consider different strategies or responses contingent upon the state of the resource.

Demand management provides another definition of sustainability. Demand management means reducing levels of demand to meet levels of supply. This contrasts with supply management; providing supply to meet ever increasing demands. Demand management therefore introduces the concept that sustainability is about matching demand with supply, either at parity or some other managed ratio. Thus, the resource is sustainably used when supply meets or is greater than demand.

For groundwater, the notion of sustainability is therefore clear; groundwater is renewed by recharge but drawn down by use. For example, Grimble (1996: 98) is very clear of his meaning for the sustainable management of an aquifer, when he writes "maintain the aquifer by reducing abstraction and contamination to sustainable levels". He is suggesting that use rates be set to renewal rates or face mining of the resource which by definition 'degrades'. This trend is taken be operating on a time scale, so for example EC (1998:41) discusses "sustainability of the resource over the longer term." For groundwater, sustainability concerns abstraction at the long-term rate of recharge, unless if mining is expressly sanctioned. Groundwater is therefore a stored resource that is subject to calls for demand management at the level of the total resource in order to abstract a demand that meets the re-supply rate over the longer term.

For four reasons, these kinds of 'sustainability' definitions do not accurately apply to surface water resources in Sub-Saharan Africa. Firstly, at the river basin level, the source of the resource is exogenous to the system, so that over-use does not necessarily via a feedback loop undermine potential for re-supply. Surface water resources are exogenously supplied and 'renewed' rather than internally 'renewable'. In other words, a river basin that completely dries out due to drought can be in flood the next season.

Secondly, the supply volume is held within channel flow rather than within storage bodies such as aquifers. Crystalline basement rock underlies much of Sub-Sahara Africa with only small potential for groundwater storage. In other words, there is no substantial 'common access' storage body to run down. Instead surface water becomes available to the user at the point of abstraction, and if not abstracted, it is no longer available *to that user*.

Thirdly, supply for a downstream user is contingent upon control of upstream use. Because Sub-Saharan water resource systems are rarely pressurised, piped and reticulated (as they can be in Europe for example), water, by virtue of its flow downhill, becomes available to its common users in sequential downstream order. Added to this are transaction losses of seepage and evaporation, all of which reinforces the fact that at the river basin level, water is not an ideal common property. Management has to recognise this one-way system, requiring a balanced approach to the levels of abstraction. On the one hand, water might be abstracted to the detriment of downstream users. On the other hand, if upstream users do not take enough water (and provided environmental demands are accounted for) the maximisation of utility of water does not occur.

The points in the previous two paragraphs mean that demand management, whilst applicable to control over-use for any one sector, is not wholly applicable at the river basin scale. Demand is much more closely and immediately coupled to supply in surface water than in stored (ground or reservoir) water. This discussion is picked up in the next section, below.

Fourthly, water supply is subject to marked perturbations by global, regional and local climatic circulations. The movement of the inter-tropical convergence zone creates rain belts, which are in turn affected by ENSO events, which are in turn mediated by local topography. Importantly rainfall is distributed via convection cells giving rise to a range of macro and meso-scale changeable seasons in any given locality. These meteorological dynamics are the driving force of water supply and demand in Sub-Saharan African.

Sustainability of closed river basins

It is generally acknowledged (Keller *et al*, 1996) that, globally, most surface water resources are increasingly becoming utilised or committed. Closed and closing river basins are also becoming the norm in Sub-Saharan Africa. As an example, the increasing demand for water in the Usangu Plains of the River Ruaha typifies this situation. There are greater numbers of people settling in the area, many claiming irrigable plots of land for rice cultivation. These farmers view rice as popular crop, providing cash and rural livelihood needs. Rice is well established in the area with good access to an active national market. It is difficult to envisage how rice might be discouraged. With estimates of more than 55 000 ha of irrigable land - which includes the current maximum area irrigated of 42 000 ha - potential water demand is exceedingly high. Technological changes in intake design have also been responsible for increases in water abstraction, allowing low flows to be abstracted efficiently and high flows to be diverted without the danger of intakes being washed out. Lastly, there is growing local, national and international acknowledgement that the environment needs a water share. Together, the Usangu Swamp, other wetlands and riverine reaches in the Ruaha system establish important environmental water requirements.

In river basins moving towards a closed condition, a picture is commonly found where potential demand greatly exceeds supply. Given these pressures on supply, the question is 'should this be interpreted as unsustainable?' In the usual circumstances of say a grazed grassland or water extraction from an aquifer, demand greater than long term supply is deemed unsustainable. Yet because there is little storage (except in dams) at the river basin level, demand can never technically exceed supply. Importantly, therefore the emphasis switches from controlling overall levels of demand to dividing the variable supply among users. So, for surface water resources the term sustainability has to be redefined to consider this division of water between users.

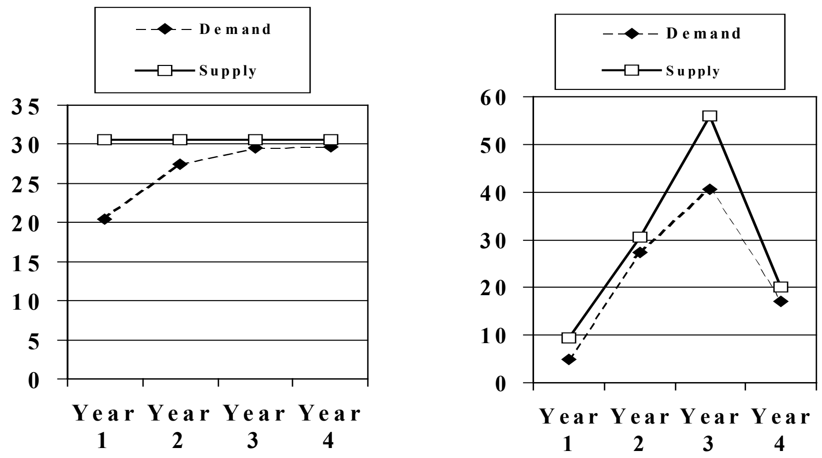
Water management under idealised conditions of supply and demand

Analysis of current abstraction licensing for the Usangu Plains indicates that water rights and abstraction designs are being provided for conditions where a set level of supply is believed to occur, or indeed where the expectations are that both supply and demand reach a predictable equilibrium. If this equilibrium occurs where demand equally matches supply, the river basin closes and remains closed. Clearly, managing the division of water to different sectors under these idealised conditions would not only be relatively simple, but it would also favour the sustainable, year-on-year, management of water to those sectors.

However, the situation in the Ruaha Basin is very different. Because of the variable climate, supply is very dynamic; alternating from dry to rainy seasons, and in the rainy seasons, from flood to drought. Demand moves with this level, increasing in a wet year as the rice area increases and decreasing in a dry year as the rice area shrinks. Significantly, the demand in wet year is unsustainable in dry year, but demand in a dry year would be too little in a wet year. For the latter condition, insufficient utilisation of the available water would occur, and economic utility would not be maximised. In effect, the river basin opens and closes for a wet and dry year respectively.

Figure 1 contrasts these two situations. The left-hand graph shows a trend over time towards a closed river basin at equilibrium with demand matching supply. In the right-hand graph both supply and demand rise and fall from year to year. On the left, supply ideally matches demand expectations. On the right, supply fluctuates as does demand (although demand expectations might remain constantly high) - neither are in equilibrium with each other.

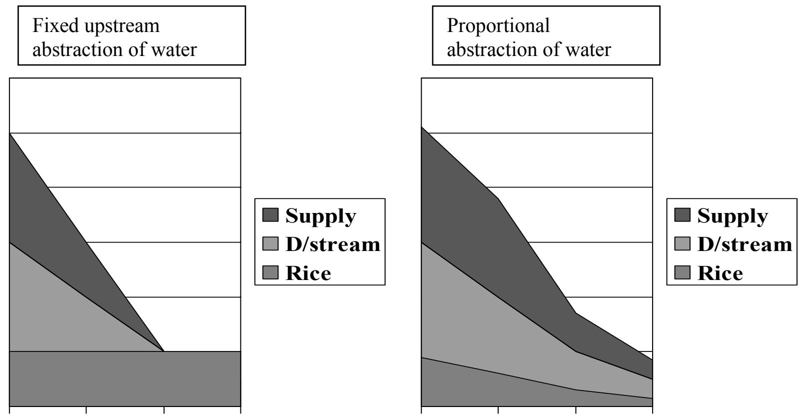
Figure 1. Depiction of equilibrium and non-equilibrium river basins in Sub-Saharan Africa



Notes: Y-axes are flow in cumecs at a given point in the river system. Source: Author.

It may be argued that fixed water rights apply to conditions of average or predicted stable supply rates. This is compounded by designed intakes and weirs that promote fixed maximum abstraction for rights awarded. With decreasing water, upstream users continue to take a fixed amount, leading to an abstraction that proportionally becomes larger and larger, eventually drying out the river. On the other hand a proportional approach follows the fluxes in supply, dividing water according to pre-arranged shares. Figure 2 contrasts these two approaches. On the left, upstream rice abstracts a fixed amount leading to zero supply for downstream users when upstream supply falls below the rice abstraction threshold. The right-hand graph depicts the shared reduction in water for both rice and downstream users as the supply falls.

Figure 2. Effects of fixed upstream abstraction with declining supply



In summary, the current approach to Usangu water management of fixed water rights appears to be appropriate for an open river basin (where 'spare' supply exceeds the upstream abstraction amount) or a stable supply (where a fixed upstream demand remains a fixed proportion of supply). However, this is misleading, appearing not to fully acknowledge the inter-dependent, non-equilibrium, zero-storage nature of the resource. In the dynamic environment of the Usangu, one can conclude that the current approach favours upstream abstractors. As hinted at, would a proportional approach be described as more sustainable?

Integrated approaches to sustainable utilisation of water

Before examining the proportional approach in more detail, it is acknowledged that recent initiatives supporting reform of water management reveals holistic or integrated approaches are required if sustainable utilisation is to be achieved (EC, 1998, World Bank 1993). Table 1 presents different dimensions of the key requirements of this catch-all approach, and demonstrates the high number of factors and processes that need to be in place for its success.

Demand and supply management

As discussed above, demand management represents one view of sustainable management of water resources. There are two levels at which demand management operate - one is at the level of the total basin, or part of the basin, and the other is at the level of the individual user or sector. The former is addressed below under the section below entitled "capping of maximum abstraction rate".

At the level of the individual user, demand management improves the productivity of water use. Efficiency of irrigation is an example of the benefits of demand management, providing the chance to re-distribute saved water to downstream users. User or sectoral demand management represents a very real part of a sustainable approach to water utilisation.

Supply management with the objective of increasing total storage should not necessarily be viewed negatively even though it is currently out of favour with respect to demand management. Adding extra storage provides an important buffer of supply to users, therefore increasing the sustainability of supply during low flow periods.

Non-equilibrium sustainable utilisation of water resources

Previous sections argued that if water resources are in dynamic flux, and that the balance between demand and supply is not at equilibrium, and that the analysis of sustainability regarding excess of demand over supply does not hold for surface water resources, then a refined definition of sustainability is required. This definition should acknowledge and expect variable climatic conditions, and explicitly provide for a safety net approach during the most severe of dry periods. A three-tier strategy arises out of this. Figure 3 shows how these approaches take precedence at different states of river discharge. The graph is a frequency distribution of low to high flows, and demonstrates that each approach activates at certain thresholds. A proportional approach to dividing water applies most flow conditions, whereas provision of core water needs is required for low flow periods, and a capping of maximum abstraction is needed during medium to high flow periods

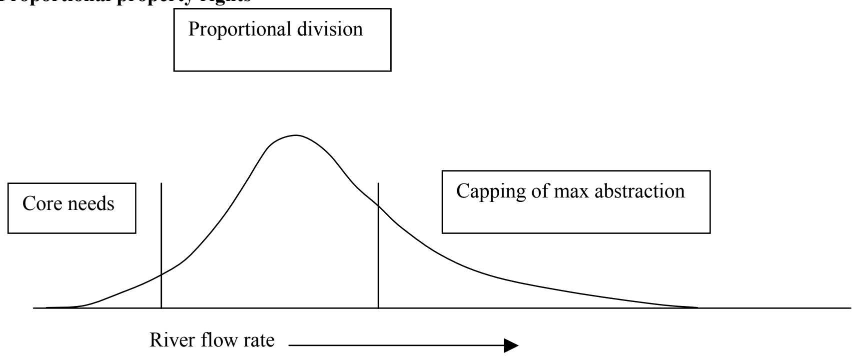
Table 1. Holistic approaches to sustainable utilisation of water

Means of water management • "Do nothing" strategies • Command and control systems (quota/regulation - how much, when, by whom, purpose) • Common property systems (users decide, usually small-scale, transferring systems to Water User Associations) • Economic instruments (actions involving pricing and market mechanisms, requires an organisation to aid marketing) • Supply and demand technical solutions • Education and information policies	**Contextual difficulties** • Natural (Climate, short/long term variability, poor aquifers, distance) • Technical ("correctness", appropriateness, choice, skills, capital) • Managerial (structures, responsibility, role of the individual, levels, organisation) • Socio-economic/political (Complexity of society, cultural attitudes, education, legal systems, leadership, distribution of authority) • Contextual international water policy (by example)
Principles of water policy development (World Bank, 1993) • An integrated approach (engineering should not dominate) • Co-operation (between different stakeholders) • Partnership, pluralism (informed, empowered, many interest groups) • Water: an economic good (costs of water management to be valued) • Health and environmental sustainability (e.g. basic needs considered and costed) • Public awareness and indigenous knowledge (promoted/utilised) • Gender sensitivity (women involved in domestic water) **Project sustainability principles (EC, 1998)** • Correspondence of policy support measures • Appropriate technology – fit with financial, technical, managerial and social capabilities and preferences of the operating agencies and final end users. • Environmental protection – env. impacts affect env. sustainability of the project itself • Socio-cultural and gender issues - appropriate ownership • Management capacity and commitment of the agencies, parties & project involved • Economic and financial analysis **Knowledge-based approach** • Resource assessment and monitoring • Understanding of hydrological processes • Determination of wants, needs and supply • River basin "situational analysis" • Communication in river systems • Linking data, knowledge and decision-making	**An integrated basin management framework (after Mitchell, 1990)** <u>Context</u> • State of the environment • Prevailing ideologies • Economic conditions • Legal, administrative and financial arrangements <u>Legitimisation</u> • Objectives of basin organisation • Responsibility, power, authority • Rules for intervention and conflict resolution <u>Functions</u> • Generic functions, e.g. date functions • Substantive functions e.g. pollution control • Structures • Centralised vs. dispersed • Accountability • Flexibility <u>Processes/mechanisms</u> • Councils, communities, task forces • Professional linkages, interdisciplinary action • Plans and planning process • Benefit-cost analysis • Environmental assessment • Public participation <u>Cultures/ attitudes</u> • Service to public • Bargaining/partnerships

Source: Various and author

Figure 3. Frequency distribution of flow rates requiring different control mechanisms

Proportional property rights



As analysed in the previous section, a proportional approach to dividing water between users might be more appropriate in dynamic hydrological environments. This approach reflects the expression "sharing water, sharing drought.” A proportional approach maintains the share of water to each user rather than a fixed amount. Therefore, as the total supply increases or decreases, the amount given to each riparian user fluctuates in accordance with the share.

Taking the Ruaha River as an example, a proportional approach could be reviewed, and if introduced, supported and legitimised via proportional water rights. For example, dividing the riverflow into 100 shares, 60 shares of the flow could be for upstream rice and domestic users, 20 shares for Mtera/Kidatu and 20 shares for the environment. (Note the downstream sectors of the environment and Mtera/Kidatu would be supplied with more water once the rivers flooded above the threshold of the proportional approach). The change to a proportional approach is likely to be contested by currently favoured upstream users, and so to be successful would need to be accepted by these river communities.

Core water needs

The proportional approach to water divides bulk surface supplies into pre-negotiated divisions. Although this application probably suffices in say 60-70% of flow conditions, very low flows may not provide for the water needed for vital livelihood and environmental functions. It is likely that at a contingent threshold, the approach needs to switch from proportional division to a different set of priority rights reflecting core needs for domestic, environmental and possibly agricultural purposes. These core rights need defining in ways that recognise minimum requirements for a given riverine and user context, recognising that they might be fixed or proportional depending on specific circumstances and agreements. In summary, core water needs require special attention; recognised, legitimised and designed for.

Capping maximum abstraction

Earlier in this paper, the opening and closing of river basins was mentioned as an artefact of a dynamic climate. While the ability to increase demand when supply allows maximises economic utility, this does not necessarily sanction the uncontrolled expansion of upstream user abstraction capacity ever upwards. While core water needs primarily addressed dry season and drought year periods, capping

maximum abstraction concerns a balanced approach to the high flows found during wet seasons and wet years.

Historical incremental increases in abstraction are exemplified by the situation in Usangu (SMUWC, 2000). The total number of offtakes increased from approximately 60 intakes in 1980 to 120 intakes in 2000. In addition, the design of offtakes has been changing. In the 60 years or so of rice development in the Usangu plains before 1990, only 13% of the total irrigated area of 42 000 ha was supplied by 14 concrete 'improved' intakes. However, in the ten years since 1990, 20 additional intakes have been upgraded supplying 32% (13 500 ha) of the total irrigated area. It is estimated that the maximum abstraction in Usangu now is about 46 cumecs, while 15 years ago in 1985, abstraction rates was probably about 25 cumecs (taking area as a proxy indicator of abstraction rate).

In a sense, capping maximum abstraction is a form of demand management at the river basin scale. The reason for capping the maximum (or 'total') abstraction lies in the need to allow substantial flows reach downstream users. High volumes replenish users that have storage facilities (e.g. HEP reservoirs) and floods perform useful environmental functions in flushing rivers and deltas of silt, salts and debris.

From a sustainability point of view, controlling the maximum total abstraction assists in the management of proportional division and core water provision. Expansion above the current 46 cumecs increases the marginal propensity for each intake to abstract small amounts of water during the dry season, cumulatively drying out the river system, and requiring disproportionately more control and policing to manage the system. In other words, a large total abstraction rate sensitises the whole river system to drying out during low flow periods.

Technological support

A move towards non-equilibrium management of water would involve many aspects to be considered including changes in river basin management, community management of water, open forum deliberative processes and legitimisation of proportional water rights.

Switching from fixed abstraction to proportional division of water entails a technological change at the intake. Without backstopping this changeover with a more appropriately designed intake, proportional division is unlikely to be successful by human operation alone. Proportional divisors and weirs are common technology used in irrigation schemes to split water flows into selected shares. There is no reason why this kind of technology might not be adapted to the riverine situation improving the 'automation' and transparency of division. Determinants underlying this design include drought and flood return periods and discharges, silt removal, proportions required for irrigation intakes and downstream needs, (including the evaporation losses associated with the latter) and the need to minimise or hinder upstream manipulation of intake/weir cross-sectional areas.

Technologically speaking, core needs for domestic and livestock provision can be met by installing piped systems or village boreholes. Analysis shows that in Usangu, point supplies might reduce gross water demands from approximately 5 cumecs across the whole plain down to less than one cumec - much closer to the net demand estimated at less than half a cumec.

Conclusion

Nicol (1996: 257) argues that water management reflects good governance; “articulation of regional needs within central bodies responsible for water policy development will be the litmus test of the Government's sensitivity to the efficient management of national water resources. This principle of 'fit' can be applied to principles underlying the sustainable utilisation of water resources; that it requires specific, flexible processes appropriate to the regional, hydrological and environmental conditions. In addition to the site-specificity of strategies employed, a flexible open-governance approach is required; one that respects information needs of the poorest sections of society.

This paper has argued that for sustainable utilisation of water resources to be applied in Sub-Saharan river basins, there are 6 principles to consider; three that are specific to the dynamic conditions found in those systems.

- Firstly, there is a need for holistic well-designed service management that is knowledge-based, aware of the fact that complex problems required appropriate integrated solutions. Service management should recognise riverine community needs for information to allow them to make appropriate short and long term contingency planning. An appropriate participative communication policy would seem to be a definitive feature of water management in a highly changeable hydrological environment.

- Secondly, threshold renewable sustainability, while not strongly at work in exogenously supplied surface water resources, reminds us that natural resources require different operating rules at different levels of supply or demand. Hence the principle of threshold contingency planning is important.

- Thirdly, a balanced approach of demand and supply management is required in order to raise the ratio of supply to demand decreasing the probability and severity of water shortages.

- Fourthly, a proportional approach to water rights might prove more suitable in apportioning water to riverine users, including the environment.

- Fifthly, switching to core needs provision during drought periods is a necessary response to provide vital safety nets to people, livestock and ecological systems. Such a switch requires the articulation of a different set of priority needs than that designed for proportional provision.

- Sixthly, capping the maximum total abstraction in a given part of a river system promotes sustainability by allowing more water to move downstream in times of high flow. It also reduces the propensity of the river to dry out during low flow periods from many small abstractions.

Finally, it has been suggested that changes in the approach to water management in situations such as the Ruaha River Basin require a range of interventions to ensure its success, not least modified designs of intakes and weirs that proportionately divide water between upstream and downstream users.

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