The challenge of Water Conservation and Water Demand Management for Irrigated Agriculture in South Africa.

Andrew Pott[1], Jason Hallowes[1], Gerhard Backeberg[2] and Max Döckel[3]

[1] Clear Pure Water, www.cphwater.com, South Africa
[2] Water Research Commission, www.wrc.org.za, South Africa
[3] Private consultant, Stilbaai, South Africa

Abstract

South Africa has reached a stage where many of its catchments are considered to be over-allocated. This was partially caused by the movement to a new National Water Act, which recognizes the importance of formally allocating water required for ecological flows, which was not the case with the former Water Act. South Africa also faces the challenge of addressing imbalances in the distribution and use of water use entitlements, due to racially discriminatory legislation in the past.

Although some water augmentation options exist to increase the supply of water in South Africa, many of these options are very expensive, and ecologically undesirable. Water resource managers are thus challenged to redistribute water use entitlements to be fairer (i.e. more equitable), more sustainable, and also more efficient. This reallocation process may see some entitlements moving away from existing users to new users.

There will be an initial challenge for the curtailed existing users to use water more efficiently, as they will have few choices other than to make do with the same or less. The longer term challenge for all water users (other than water for Basic Human Needs and Ecological flows) will be to continually find ways to use water more efficiently, thereby liberating water (at no to little loss in production), which can then be reallocated to other water users. Water Conservation and Water Demand Management is a set of approaches to bring about the more efficient use of water. This paper focuses on WC & WDM options pertinent to irrigated agriculture, as this sector is currently responsible for roughly 60% of South Africa's surface water use.

Introduction

Over the past 10 years there have been a number of reforms taking place in South Africa, which have had a bearing on how water is to be managed. There are two key legislative reforms that have taken place which have had, and will continue to have, a significant impact on how water is managed, controlled, protected and developed in South Africa. These two legislative reforms are supported by a number of policy and strategy documents. The first and most over-arching constitutional reform followed the abolition of the racially discriminatory Apartheid regime (which reigned from 1948 – 1994). A new democratic Constitution (Republic of South Africa (RSA), 1996) was gazetted, which states that "everyone has the right to have access to sufficient food and water". The second legislative reform, which has a significant bearing on the management of water, was the promulgation of a new National Water Act in 1998 (RSA, 1998). The 1998 Water Act is founded on 28 Water Law Principles (Department of Water Affairs and Forestry, 1996) developed via an open consultative process with the citizens of South Africa.

The previous Water Act was based on a Riparian Rights system. There appear to be three major short-comings of the riparian rights system to address the needs of the post-Apartheid South Africa, requiring the need to adopt a new water act. The first relates to the fact that the Riparian Rights system is more suited to wetter countries, and is not suitable for application in a relatively dry country like South Africa, which is characterized by rainfall and runoff that is unevenly distributed in both time and space in South Africa (DWAF, 2004a). The second short-coming relates to the fact that it would have been difficult to address equity imbalances. This is caused by land possession in the Apartheid era and water rights linked to land rights in the Riparian Rights framework. The third short-coming relates to the fact that the Riparian Rights system did not make a formal provision for flows required to sustainably meet ecological water requirements. The movement to a "licensing" principle in the Act has provided water resource managers with more control over the allocation, protection and development of water resources, which has provided an enabling environment to address the equity and sustainability imbalances existing in the country, and can also be used to promote efficiency.

The focus of this paper is to highlight the importance of Water Conservation and Water Demand Management in the context of South Africa. Various WC & WDM related to irrigated agriculture in particular will be explored, and new options which are not yet being practiced but which are being debated, will be introduced. The paper starts with an over-view of the water related policy, legislation and current state of implementation, as this forms a backdrop to the WC & WDM options that are currently possible, and those that will be possible in the future.

Water policy, Legislation, Strategy and Implementation

In the 1998 Water Act, only two forms of water-use have a right to use water, including a daily allowance of 25 liters of water per person per day (for Basic Human Needs - BHN), and the quantity and quality water required to sustainably meet ecological water requirements. Water required to meet ecological requirements has thus been elevated from not being formally recognized in the Riparian Rights system, to the most elevated position possible (on the same standing as Basic Human Needs). Calculating the quantity and quality of water for ecological water requirements is complicated, and will not be explored in this document. A draft National Water Resource Classification policy document detailing how water resources are to be classified in terms of the level of protection that will be afforded to them, which will influence the quantity and quality of water that will be set aside for ecological water requirements has been published (DWAF, 2006).

According to the 1998 National Water Act, eleven categories (types) of water use are discerned, with these uses potentially having a significant impact on the quantity or quality of water in catchments, or on safety aspects. Authorisations to use water, in the form of water use-entitlements (sometimes referred to as water use licenses), are required by water users wishing to legally undertake one or more of the eleven water uses. The use-entitlements include, amongst others, water abstraction licenses, storage licenses (i.e. licenses to build dams), commercial forestry licenses, and various forms of discharge licenses (which may influence the quality of water resources). The water use entitlements are temporary in nature (generally ranging up to forty years in duration). As water use licenses are temporary in nature, water users need to apply for their licenses to be renewed periodically before they expire.

Water use licenses are to be allocated by water resource managers to water users on the grounds of equity, efficiency and sustainability, guided by the Water Law Principles, provisions in the 1998 National Water Act, as well as other supporting policies and strategies. Catchment Management Strategies (CMS) will be drawn up for each of the 19 Water Management Areas in the country, with the CMSs being consistent with principles and objectives laid down in the NWRS.

Water resource managers are required by the 1998 Water Act to continually review all the water use entitlements in issue within a 5 year period. The water resource managers are able to add or modify conditions that may be attached to the licenses, if there is a justifiable need to do so. The finite duration of licenses, coupled by the ability of water resource managers to add extra conditions attached to licenses in issue, provides water resource managers with powers to control the nature and number of licenses that are issued, to whom the licenses are issued, and various conditions that may be attached to the licenses. This power promotes “adaptive management”, i.e. the ability of water resource managers to adapt to changes that may occur, be these natural (e.g. climate change), or legislative (e.g. changes to the NWRS and/or CMS). It will be argued in the later parts of this document, that this power at the hands of water managers well may threaten the adoption of water saving technologies due to lowered investor confidence.

There are two major challenges facing water users and water managers in South Africa.

The first relates to addressing equity considerations and ecological sustainability. This challenge is immediate, but relatively temporary in nature, and aims to level the playing-field to ensure that water is allocated fairly (i.e. equitably, thereby addressing the skewed water use patterns caused by Apartheid), as well to determine the quantity and quality of water use required for ecological water requirements. The move to a water use entitlement system (away from a Riparian Rights system), can be seen as the first step, which enables water resource managers to address the equity and ecological sustainability shortcomings that exist in South Africa. A Water Allocation Reform policy document has been drafted, which describes principles that will be adopted to ensure that water entitlements are allocated to those races discriminated and prejudiced by the Apartheid regime.

The 1998 National Water Act (chapter 4, part 8) makes provision for a process referred to as “Compulsory Licensing” to address equity and sustainability shortcomings that may exist in catchments (RSA, 1998). Compulsory Licensing can also be used to address efficiency considerations, but in general it will be used to address equity and ecological sustainability imbalances. The Compulsory Licensing process is a socio-political process. The outcome of a Compulsory Licensing is that all water users, be they registered existing lawful users or new users with licenses, will need to formally apply for water use licenses. Although consideration will be given to verified registered existing lawful use, it is probable that some water use entitlements will need to be taken away (i.e. reduced) from the existing lawful users in particular in order to reallocate to previously disadvantaged persons and to ensure that the ecological water requirements are met. Existing lawful water users will be challenged to improve the efficiency with which they use water so they can get by with lower water use entitlements.

The second challenge, which is the focus of this paper, is to improve the efficiency with which water is used. This challenge will exist in both the pre-Compulsory Licensing and post-Compulsory Licensing periods, and is important to enable South Africa to sustainably grow its economy in the face of water scarcity. Water is a key factor of production for many economic goods and services. Water supply options are often either very expensive and/or ecologically undesirable, there will be increasing pressure to find ways to optimally use the limited supplies of water available. Two related steps are required to facilitate the optimal use of water, seen from the South African society’s point of view.

- The first step is for all licensed water users and managers to continually explore and adopt methods to use water more efficiently, thereby liberating water for expansion or re-allocation. In this context, an increase in water use efficiency ideally implies that less water is used to produce the same quantity and quality of economic good or service. From a socio-economic point of view it is desirable for patterns of water use not to change dramatically. The preferred option is thus for the existing water users to become more efficient, thereby liberating water.
- The second step, which follows from the first, is for the liberated water to be reallocated to the most appropriate new or existing water users, to ensure optimal economic growth. The 1998 National Water Act makes provision for water to be used more efficiently via the adoption of 3 types of water use charges, and also makes provision in Section 25 of the act for water use entitlements to be traded (which can take the form of a sale or lease arrangement).

Instruments and policies which are efficient at promoting water use efficiency, as well as the efficient reallocation of entitlements associated with the saved water should are ideally required. These will be discussed in the sections that follow.

Water Conservation and Water Demand Management (WC & WDM)

Water Conservation is defined as "The minimization of loss or waste, the care and protection of water resources and the efficient and effective use of water" (DWAF, 2004b).

Water Demand Management is defined as "The adaptation and implementation of a strategy by a water organizations or consumer to influence the demand and usage of water in order to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection, sustainability of water supply and services and political acceptability" (DWAF, 2004b).

The DWAF WC & WDM strategy document (DWAF, 2004b) acknowledges that although there are differences between WC & WDM objectives, it is not practical to separate their interlinking components. The strategy document states that in order to achieve a balance between social equity, economic efficiency and environmental sustainability, the WC/WDM strategies are grounded on three fundamental principles, which include:

1. Water institutions should endeavour to supply water in an efficient and effective manner by minimizing losses and promoting WC / WDM to their consumers,
2. Water users should endeavour to use water efficiently, and
3. Water Conservation and Water Demand Management should be considered as part of the planning processes for water resources, water supply and water services.

WC & WDM options for application to irrigated agriculture in South Africa

The three WC & WDM principles above provide a useful framework with which to discuss WC & WDM initiatives currently being undertaken in South Africa, as well as initiatives that are being debated, and may be applied in future.

<u>Principle 1. Improving the effectiveness and efficiency of water management by water organisations</u>

The total runoff in South Africa is estimated to be 49 000 million cubic meters of water (DWAF, 2004a). Due to highly variable rainfall, in terms of both time (e.g. within and between years) and geographical distribution, a number of large dams (exceeding supply capacities of 1 million cubic meters) have been built in South Africa over the past century. The total storage capacity of large dams in the country is estimated at 32 000 million cubic meters (DWAF, 2004a), which is approximately 66% of the mean annual runoff. The storage / MAR ratio is very high by international standards, and reflects the importance of dams to increase the sustainable yield (supply of water) in South Africa.

Many water users rely on water releases from the large dams across the country. The dam releases are managed by water control officers, who need to carefully respond to water orders by downstream water users. There are many challenges to release the optimal (right) amount of water from the dams, to meet the user demands, which relate to channel transmission losses, lags and attenuation of flows from the time of release at the dam to the various points where the water will be abstracted by various water users, to potential inflows from tributaries downstream of the dam, which could be used to fulfill some if not all of the water demand of downstream water users. The lags may range from hours to weeks, i.e. from the time of release, to the time the water reaches the abstraction point of a respective water user. Inefficiencies occur in the form of too much water being released and times, and too little water being released at other times. When too little water is released, the dam level may benefit, however the production of economic goods and services by downstream users may compromised.

The DWAF is currently pilot testing four Near Real Time Systems (NRTS) around the country, with promising results (Mwaka, 2008). The NRTS offer a dynamic solution which has great potential to integrate /link/update with the progress and activities of various departments in the DWAF, such as water allocation, the Reserve, updating hydrology, ground water studies and water quality (Cai, 2008). The DSS can also serve as an information system for various levels stakeholders and also a decision support tool to help stakeholders analyse water distribution scenarios at requested risk levels and options (Cai, 2008).

The NRTS generally have the following components:

- Metering of dam levels – telemetry enabled where possible,
- Metering of flows (below the dams, as well as above the dams) – telemetry enabled where possible,
- Measurement of rainfall (via automatic rain-gauges) both upstream and downstream of the dam – telemetry enabled where possible,
- A water order module, which helps capture downstream users water order in a systematic manner. The downstream users need to specify the flow rate they require over 6 or 12 hour increments.
- A water release module, where use is made of a hydraulic model or module, to calculate how much water must be released to meet the downstream users flow requirements. Consideration needs to be given to potential losses, lags, attenuation and gains from tributaries.
- As downstream tributaries may provide the flows required by downstream users, use is made of rainfall-runoff models, in combination with short term rainfall forecasts. This helps the water control officer determine the probability and magnitude of contributions by tributaries. Although the rainfall forecasts currently have relatively low levels of skill (accuracy), and are also not provided at fine spatial scales, it is anticipated that over time these limitations will be improved upon

The real time systems are thus used to generate a recommended flow release pattern, which can be used by the water control officer. The actual flows moving down the river are measured, and fed into the real time system, which are then compared to the flows that are anticipated at the flow measurement sites. If deviations between simulated and observed flows exist, the NRTS raises a flag, and re-calculates the flows to be released.

The DWAF has also recognized the importance of abstraction metering (Chunda, 2008). They are in the process of developing strategies and guidelines related to the roll-out of water meters throughout the water-stressed catchments parts in the country. There are a number of logistical questions that need to be carefully thought through, including, amongst others; which water meters should be used, who will pay for the meters, who will own the meters and who will install and service the meters.

Poor metering and monitoring results in significant uncertainties regarding the physical water-related processes taking place in catchments. The improved metering, monitoring and modeling of catchments will also enable scientists to better research and understand the potential impact of global climate change on water supplies within various catchments as we step into the future.

Principle 2. Improved water use efficiency

The focus of this section is to review the steps that are possible to improve the water demand of users. In effect, the desire to for water user to become more water use efficient, thereby requiring less water to produce the same quantity and quality of economic goods and services as before (if not even better). The National Water Act (1998) makes provision for the use of water use charges (tariffs), as well as for water use entitlements to be traded, both of which are considered to promote water use efficiency.

Water use charges

Currently water use charges are based on the full water use entitlement per scheduled irrigable land area held by water users, and not on the actual water use. Basing water use charges on the full entitlement does not promote water use efficiency to the extent that it could if the charge were to be levied on actual use. There are two possible reasons for the adoption of a non-variable water use charge presently; Firstly, water meters will be required to meter the actual use of users. As is pointed out in the sections above, the DWAF have recognised the importance of water meters, and are initiating steps to start implementing water metering in over-allocated catchments around South Africa (Chunda, 2008). The second reason for a non-variable user charge is that this provides water managers with a steady and reliable source of income. By basing user charges on actual use, the flow of funds will become more variable. The recommendation has been put forward for a dual charge system to be adopted, with a non-variable component (allowing some assurance regarding the flow of funds), as well as a variable component.

The variable component of the user charge may well influence the irrigation decisions of farmers. It was mentioned in the section above that there are two key steps required for water to be used more efficiently (from society's point of view). The first was for all water users to use water more efficiently, and the second was for the liberated water to be reallocated to the most appropriate water users (be they new water users, or existing water users who require more water to expand their operations). Increasing the user charge may result in less water being used by water users, but this may also come at a reduction in the level of production. Irrespective if there is or is not a reduction in production, there is still the challenge to reallocate the liberated water to the most appropriate water user/s. Literature indicates that beaurocratic allocation is often not optimal in this regard. One option may be use auction the liberated water in an open market, after allocating water to possibly meet equity and sustainability needs.

Water Market

A water market is the only effective way to establish the opportunity cost of water. The price of water use entitlements that is established will provide the incentive to use water efficiently and cause the water to be (re)allocated to highest value uses. The challenge therefore is to create the conditions that will lead to the efficient functioning of such a water market.

Section 25 of the National Water Act makes provision for the transfer of water use entitlements. The transfers can take the form of the permanent transfer of use entitlement ownership (or part thereof) from a licensed water user to another person, or can take the form of a temporary lease arrangement, where the ownership does not change, but the rights to use the water are temporarily leased from a licensed water user to another. Currently the temporary transfer of entitlements are quite limited, in that they are limited to a lease duration of one year, with the option for extension for another year, and can only be undertaken for irrigation either on the same property for a different use, or to another property for the same or similar use. Thus inter-sectoral leasing is not permitted currently, which is a significant limitation. Permanent transfers must be approved by the responsible water management authority, and the authority may attach different conditions to the traded water use entitlement.

Although the 1998 NWA by implication makes provision for the trade of water use entitlements in water markets, in the form of temporary and permanent transfers, the number of trades in the Pre-Compulsory Licensing period is quite low. There are a number of reasons for this, largely related to the amounts of water required for the Reserve, as well as uncertainty as to the outcome of the Compulsory Licensing process (i.e. how over-allocated are catchments, and how will the over-allocation be addressed). Water resource managers are also highly cautious, due to sensitivities that exist around water and land reform in the country (Backeberg, 2007). The number of water market transactions is anticipated to increase dramatically after the completion of the Compulsory Licensing process, as there will be more confidence attached to the water use licenses, and many users may receive less water entitlements required to address the over-allocation in stressed catchments.

Water markets are most effective when water use entitlements are well defined and well managed, are transferable, are divisible (so that parts of a water use license can be traded). Defining water use entitlements is not as straight forward as one may initially imagine, as water accrues from a number of sources in catchment, and is variable in space and in time. Literature suggests that the definition system adopted should result in the entitlements being explicit (i.e. very clear, from which can accurately determine how much water a user is entitled to, and where the water exists in the catchment) and exclusive (Paterson, 1989). The definition system adopted currently in South Africa can be described as a "Priority-based River and Reservoir Operation Rule" (PRROR) system. It will be argued in the sections below that this may not be the most appropriate definition option for South African conditions, as it may not promote water use efficiency by water users as well as other possible options. An alternative water apportionment option, referred to as a Fractional Water Allocation and Capacity Sharing (FWA-CS) option will be introduced in the sections below.

Given the potential value of water markets to promote water use efficiency (i.e. the adoption of more water use efficient practices, as well as the efficient reallocation of the liberated water to other users), there is scope for the Department of Water Affairs to do more to support water trades. For example, the limiting clauses pertaining to water lease arrangements could be relaxed to allow for inter-sectoral leases to take place. The 1 year lease duration limitation can also be reviewed. The DWAF can also set up web-sites where willing traders can post their bids and offers, and the resultant transaction price should also be captured for all to see. This will enable all water users to gain an insight into the opportunity cost they face with respect to water, by allowing them to compare the value they expect to realize from the direct use of the water themselves, or the value they could achieve if they sold or leased their entitlements. It will also be argued in the section below that the PRROR system results in different categories of water use entitlements, i.e. high, medium and low assurance-of-water supply entitlements. This complicates the transfer of entitlements between different types of water users (i.e. between low and high assurance-of-water-supply users).

The Near Real Time Systems being developed by DWAF, combined with the installation of water meters, will help promote the confidence attached to water use licenses, and will hence increase the price people are willing to pay for water trades (permanent or temporary), as there is a higher confidence of actually receiving the water attached to the licenses.

<u>Principle 3. Water Conservation and Water Demand Management should be considered as part of the planning processes for water resources, water supply and water services.</u>

The sections above have dealt with finding ways for water resource managers to improve the efficiency and effectiveness of managing, in particular, releases from dams and/or inter-basin transfers (as these can be controlled), as well as introducing instruments such as water use charges and / or water markets to improve the demands of water user. Progress is being made in these regards, largely supported by the installation of water meters and Near Real Time Systems, which help improve water resource management. This section relates to the manner in which water use entitlements are defined in South Africa, and how water resources are operationally managed. This discussion is relevant under the third WC & WDM as it relates to manner with which water resources are planned and operated. It was pointed out above the water use licenses should be defined in a manner that is explicit, enforceable, exclusive and transferable. The word "explicit" infers that at any point in time, or time range, it must be possible for water managers knowing the volumes of water available in catchments for the point in time or time range, to accurately calculate how the water is to be allocated amongst the competing licensed water users.

It will be argued that although present water apportionment (and related planning and operational methods) are physically capable of explicitly determining water use rights, there are a few short-comings of the current water apportionment system being adopted, which reduce incentives for water users to use water more efficiently, by virtue of the mechanism with which the apportionment rules work.

The two water apportionment options will be introduced and contrasted. The first, which is the option currently adopted in South Africa is referred to as a Priority-based River and Reservoir Operating Rule (PRROR) approach (Lecler, 2004a & 2004b). A second water apportionment option will be introduced, referred to as a Fractional Water Allocation and Capacity Sharing (FWA-CS) approach (Pott *et al*, 2005).

<u>The PRROR water apportionment system</u>
The current water management methods being applied at the DWAF were developed in the mid 1980's as a response to a severe drought which required the department to improve its resource management measures (reference). The modelling systems developed to assist water resources planning was the Water Resources Yield Model (WRYM) and the Water Resources Planning Model (WRPM). The models are capable of simulating a wide range of operating policies governing the allocation of water in a multi-

purpose multi-reservoir system (McKenzie and Van Rooyen, 1999). The models are based on a modular system and assume that a water resources system can be represented by a flow network. The model uses a least cost routing approach using a linear programming network solver to replicate water resource operating policies by specifying penalty structures associated with storage and flow channels on the system (McKenzie and Van Rooyen, 1999). The systems have been designed in order to handle a specific method of water management which is a water apportionment system for the purposes of this document referred to as the Priority-based River and Reservoir Operating Rule (PRROR) system. As the name suggests, the system discerns between priorities given to different types of authorised water use, while reservoir and river operating rules govern the water restrictions faced by the water users under different conditions of water availability.

In the PRROR system, the catchment is managed as a single system, and licenses are issued against the system. The system is primarily designed to manage the supply facilities on developed (large amounts of storage infrastructure) water resource systems. The Water Managers or DWAF are responsible for the allocation, apportionment and restriction of the various water users on the system.

The FWA-CS water apportionment system

Fractional Water Allocation (FWA) refers to entitlements issued against run-of-river flows (where no storage exists), while Capacity Sharing (CS) refers to entitlements issued against shares of the storage capacity of large government dams, which are leased. Water users will thus have the option to hold a basked of discretely defined water user entitlements which cover both stocks (i.e. stored water) and flow (unregulated run-of-river flows),(Dudley & Musgrave, 1998). It will be argued that defining water use entitlements in terms of FWACS acts as an enabling environment to encourage the development of a water market thus improving water use efficiency while accounting for undesirable externalities associated with water quality, the environment and equity considerations in South Africa.

Paterson (1989) argues that the four necessary conditions for water licenses (transferable, exclusive, explicit and enforceable) can only be met if the instrument of entitlement permits an exhaustive portioning of the resource among titleholders. FWACS represents a methodology of partitioning a water user entitlement at source, which better meets the requirements of transferability, exclusivity, explicitness and enforceability.

With respect to flows in tributaries where no storage facilities exist, water users can hold fractional entitlements to the flows in the respective tributaries (i.e. shares of the flow in the tributaries), after allocating water to for Basic Human Needs and Ecological Water Requirements on the various tributaries. By measuring or simulating the flow at the various tributaries, and then deducting the flows for Basic Human Needs and Ecological Water Requirements, one can determine the volume of water that the fractional allocations translate into for a given point in time, or time range.

With respect to storage facilities (e.g. dams), and the flows into the storage facilities, water users can hold entitlements to both the storage capacity of the dams, as well as the flow into the dams. A water use may for example hold entitlements to 20% of a given dams storage capacity, and say 15% of the inflow into the dam.

The definition of water entitlements in terms of FWACS thus meets the requirements for; (i) an exhaustive and unique partitioning of the resource and (ii) a legal basis for a consistent system of non-attenuated entitlements.

3 levels of partitioning are required on the system, namely: the partitioning of runoff (Fractional Water Allocation), the partitioning of storage capacity on the system (Capacity sharing) and finally the partitioning of losses. While the partitioning concept is relatively simple its application in reality is more complicated.

The first level of partitioning is that of runoff, this is partitioned according to the overall runoff on the system. By way of an example consider the conceptual configuration shown in figure 1. To begin the full runoff from catchments A, B, C, D and E need to be partitioned as shares of flow amongst the various licensed users on the system. There are four normal users on the system (these could be agricultural, industrial or domestic) and a single user representing the environmental requirement at the base of the system. In the case of the example in figure 1 for arguments sake say that the entire system produces 100,000,000 m^3 runoff per annum and Catchments A, B, and D produce 25% of that runoff each while catchment C produces 15% of the runoff and catchment E produces 10% of the runoff from the system. Let us also say that the environment requires 20% of the runoff and that this amount of water is partitioned to be delivered from each of the catchments proportionally. Thus catchments A, B and D each contribute 5% to the environment while catchment C contributes 3% and catchment E contributes 2%. Users 1 – 4 can now obtain a proportion of the remaining runoff.

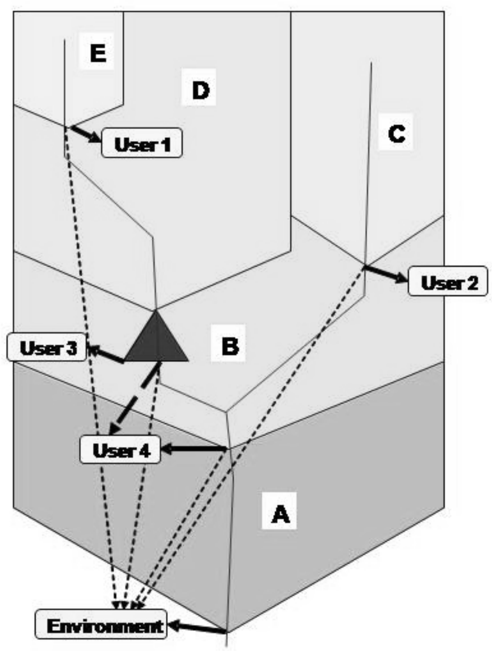

Figure 1: An illustration of water use entitlements expressed as Fractional Water Allocations of flows in unregulated tributaries.

This proportion could be determined in many different ways either by converting the price paid for their existing water (use) entitlements, a system based on conversion of priority of supply and various other schemes which could be discussed through stakeholder participation. Each user can then be given a proportion of the total runoff on the system, a strict rule however is that a water user cannot be given a higher proportion than they have access to at a specific point, for instance user 1 at catchment E can only have access to 8% of the runoff (10% - 2% environmental requirement). Once the runoff has been partitioned on a global basis it must also be translated to a meaningful level at the distribution point. Let us say that user 1 has access to 4% of the overall runoff on the system, this means that this user can only access 40% (10% flows past the point, user has 4% of total allocation that is 4/10 which equals 40% of flow going past the point) of the runoff flowing past his abstraction point at any stage. The fractional allocation of the flow at that point is thus 0.4 of the total flow going past. A user such as user 4 who has access to water from multiple catchments will need to get this water in certain ratios from all the catchments. Lets say for the sake of argument that User 4 has been allocated 40% of the overall runoff of the system the user may get 8% of the water from Catchment C, 20% of the water from Catchment B and 10% of the water from catchment D and 2% of the water from catchment E. Some of this water will be run of river and other pieces could be stored in the dam.

The advantage of the FWA system of proportioning runoff is that the allocations are relatively transparent and it is easy to trade the fractions of overall runoff between different users (the provisos being that it is physically possible for the trading party to gain access to the water, and the trade does not bear with it unacceptable third party effects). The environment or dilution requirements in the system can also be easily handled in this type of allocation structure.

The second level of proportional allocation is the capacity sharing where the capacity of the dam is divided between the users. In the scenario shown in Figure 1 Users 3, 4 and the Environment requirement have access to the storage facility or dam. In this case User 3 has access to 12% of the overall runoff, while User 4 has access to 40% of the overall runoff and the Environment has access to 20% of the total runoff. In the scenario catchment D and E contribute 35% of the overall runoff that flows into the dam. User 1 takes 4% of this runoff leaving the other 31% to flow into the dam. Of the 31% the environment has access to 7%, User 3 has access to 12% and User 4 has access to 12% making up the entire 31% flowing into the dam. Thus, User 3 and 4 each have access to 38.7 % of the inflow into the dam while the environment has access to 22.6 % of the flow into the dam. This represents their local allocation of the dam inflow. The dam however acts as a storage structure for the water users who are thus able to secure an allocation to a piece of the storage on the system, the capacity share. This is conceptually shown in Figure 2 with the dam being capacity being split into 3 pieces, with user 4 holding 60% of the storage, user 3 holding 30% of the storage and the environment holding 10% of the storage (when we refer to storage we are referring to the live storage capacity on the system, between flood control level and dead storage level on a reservoir). Again these proportions can be allocated according to price paid, priority of user allocation etc. It is possible to control assurance of supply (reliability) by manipulating the ratios of inflow, dam size and water use.

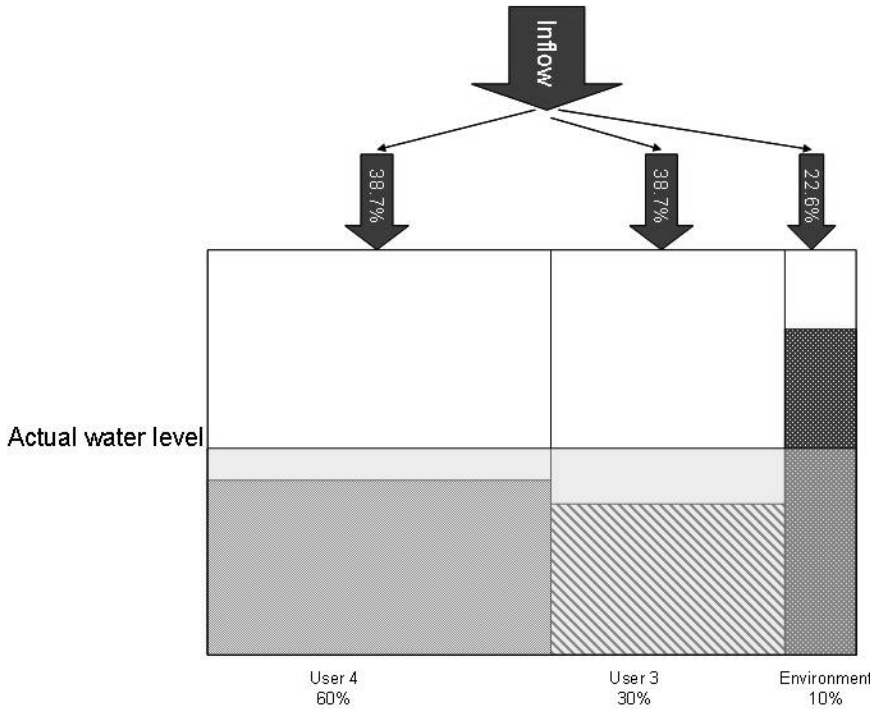

Figure 2: An illustration of water use entitlements expressed as Capacity Shares (CS)

In figure 2 it can be seen that the water held in the dam will be at a different level compared to the individual compartments (individual dam levels) in the dam. In the example User 3 and 4 have used more water than the average and thus their compartments are less full than the environment which has used less water than the average and thus has a fuller individual dam level. The users thus maintain their own dam levels and decide when they wish to use the water. The users would order water from the dam resource and this would be deducted from their compartment, likewise inflows would recharge the compartment. Water in one compartment can also easily be transferred and thus traded with and individual owning a compartment or released downstream for users requiring water downstream of the dam. Rules can be set up where if a compartment overflows it is either distributed pro-rata with other users on the system or alternatively traded to fill another user's individual compartment. The capacity sharing system is thus transparent and flexible and it fulfils the requirements of non-attenuated property rights.

Considering water user 4 on the system, it can be seen that the water user and his/her water entitlement at a specific time will be a function of the amount of run of river flow from catchments B and C which the user receives a proportion of according to the FWA rule, and also a function of the amount of water that the user has requested be released from the dam resource. The complexity associated with these rules and interactions place a much higher emphasis on the management of the resource compared to currently used system as the water entitlement needs to be communicated to the individual users on a continuous basis.

The last element on the system is the proportioning of losses on the system. Losses will be a result of evaporation and seepage in both the river and dam resources. In the capacity share system losses are calculated then distributed pro rata according to the amount of water held in an individual's component of the dam. In run of river systems the losses calculation could be done differently and could be a function of the position in the catchment or also factored as an overall loss which is distributed to the individual users pro rata according to the amount of water they have access too as a function of the overall runoff.

FWACS is thus a highly flexible system that fulfils the requirements for non-attenuated property rights (Viljoen et al, 2004). It is conceptually easy to understand and the water is allocated from source not just distribution point. In order to understand the true benefits of this system it is useful to compare it to the current water management methods applied in South Africa.

The arguments being put forward in favour of the FWA-CS approach are:

1. This apportionment model will promote water use efficiency by water users to a far greater extent to that of the PRROR apportionment model. Capacity Sharing (CS) is in effect another name for water banking. It will be argued that enabling water users to bank their water (in large dams), will provide an additional and significant incentive for water users to become more water use efficient,
2. Computer models exist that are capable of supporting the FWA-CS apportionment approach, both at an operational (i.e. sub-daily, daily or weekly level) as well as on a planning level (where the model is run on a monthly or annual time-step). There will thus be vertical consistency between the planning and operational approach, and
3. The FWA-CS approach promotes far greater participation by water users, who can plan for their own water use requirements. The methods currently used by water resources planners in DWAF can be made available to the water users (which could be groups of users, in the form of Water User Associations).
4. In the FWA-CS approach the water users know where their entitlements accrue from, and can thus self-police to a far greater extent than can be done in the PRROR approach (where the source of water is determined by the water availability in the various sub-catchments).
5. In the FWA-CS system the water use entitlements are homogenous, whereas the PRROR system results in differentiated entitlements due to differences in priority. With the entitlements being homogenous, and clearly specified where the source of the water is from, water trading is far less complicated than with the PRROR system. This is a serious consideration if water trading is seen to be an important vehicle through which water use efficiency can be attained in South Africa's future.

Re-visiting the PRROR system

Under the PRROR system water is allocated to users with four different level of assurance of supply (Table 1). Water user groups are then allocated a certain proportion of their allocation at each of the different levels of assurance. For instance, irrigators only get 10% of their water at the highest level of assurance (1 in 200 year level of failure) while domestic users get 60% of their allocation at this level of assurance. The system is iteratively run with various scenarios with stochastically generated hydrology and different operating rules to determine the amount of water that can be allocated at different levels of assurance using the WRYM.

Once users have been allocated their quotas short-term yield curves are developed using the WRPM, which determine the level of restriction which will be applied to each user group at various levels of the reservoir. Restrictions are then placed on various users according to the level of the various resources in the system. These restrictions are decided by the water manager and applied to the users typically on an annual or biannual basis.

Table 1 : An example of how water is allocated at different priority levels in the PRROR water apportionment system.

Priority Classification & Assurance of Supply					
User Category	Low	Medium Low	Medium High	High	Total
	1:10 year	1:50 year	1:100 year	1 in 200 year	
Domestic % of Domestic allocation	0.5 10%	0.5 10%	1 20%	3 60%	5 100%
Mining and Industrial % of Mining and Industrial allocation	0 0%	0 0%	0 0%	0 0%	0 0%
International % of International allocation	0.73 10%	0.73 10%	1.46 20%	4.38 60%	7.3 100%
Irrigation % of Irrigation allocation	4.58 40%	3.44 30%	2.29 20%	1.15 10%	11.46 100%
Total per class	5.81	4.67	4.75	8.53	23.76
% of Total Demand	24	20	20	36	
Cumulative	23.76	17.95	13.28	8.53	

It can be seen that the PRROR system is fundamentally different to the proposed FWACS system. It should be noted that the PRROR system was developed in the era of the old national water act (1956) when water resource systems were not as heavily developed, and equity, efficiency and sustainability were not major concerns, participatory management was not an objective and efficient management was not a key issue. Key differences between the two methodologies are; (i) Transparency (explicit, exclusive water entitlements): In the PRROR system the water entitlements are not well defined. The linear programming structures used by the WRYM and WRPM models make it difficult to track where water is coming from thus water is not allocated from the source but rather at distribution point. While assurance of supply is implied in the license it is not guaranteed. In the FWACS system the entitlements are explicitly defined and water is allocated at both source and distribution point. The users can also manipulate their own management to ensure their assurance of supply, (ii) Participatory management: In the PRROR system operating rules and water restrictions are determined by the water manager or DWAF. In the FWACS system the water users are able to manage the resource themselves, with advice from the water manager, (iii) Transferability: In the PRROR system it is difficult to transfer water use entitlements between different sectors (with different levels of assurance). This introduces uncertainty in a trade process as the buyers are not sure what they will receive. This is not the case in the FWACS as the method of defining the entitlement is the same for all individuals in the system, and (iv) Transaction cost: In the PRROR system an expert has to be involved to perform a trade or to consider a different scenario as it is not intuitive. The transaction cost for both temporary and permanent trades are therefore high compared the FWACS system.

Given the criteria required for a water market to operate efficiently it can be seen that the PRROR system does not fulfill many of the criteria. It would thus be difficult to use the market as a mechanism to improve efficiency. The PRROR system provides little or no incentive for efficiency gain as, a use-it-or-lose-it principle is applied, i.e. if water users adopt more efficient water use technologies, or don't use their water, the entitlement to this water is lost. Thus the only measures that could be used to improve efficiency in this scenario would be punitive, legislative measures that do not encourage allocation, or economic efficiency (see section 3).

Conclusion

South Africa finds itself in the unenviable position of becomingly increasingly water scarce, with demands for water (at given assurance of supply levels) exceeding the ability of catchments to supply the required assurance of supply levels. In addition, there are currently equity imbalances with respect to the allocation and use of water that need to be addressed. Furthermore, although the new Water Act makes provision for water to be allocated to sustainably meet ecological water requirements, the challenge will be to operationally manage systems to ensure that the flows (in terms of quantity and quality) are indeed being met.

The only viable solution for South Africa to prosper sustainably is for the management of water resources to be improved. Water supply augmentation options will have their place (DWAF, 2004A), however there is a shift in focus towards the improved management and control of existing water resources, with the aim to become more efficient and effective. Water Conservation and Water Demand Management options, which aim to see water being used and managed more efficiently and effectively, will continue to gain importance in South Africa.

In this paper a number of WC & WDM initiatives currently taking place in South Africa, for application to irrigated agriculture in particular, have been introduced. The logical starting point to improved management and control is improved measurement of flows in catchments, as well as improved metering of abstraction by water users in combination with the adoption of computerized systems which are able to provide water resource managers and water users with vital information, with which the management and use of water can be improved. The DWAF is currently setting up computerized systems which operate on a Near Real Time basis, which can help water control officers and water users with the water order, water release and water use decisions. The functionality of these systems is anticipated to grow, which will help quantify water use efficiency in catchments, and help with water audits to ensure that users are complying with the conditions attached to their water use entitlements.

The installation of water meters provides water managers with the opportunity to levy water use charges on actual water use (as opposed to a flat fee on the full entitlement, which will not promote water use efficiency as effectively as a user charge based on actual use). The water meters will also provide water users with better information regarding the amounts of water being used, and the timing of such use. This information may be valuable to irrigators to help them become more water use efficient, as it will help them quantitatively track their water use and crop yield obtained for different irrigation system or management practice options. The water market, in the form of permanent and temporary transfers of water use entitlements was shown to be a very important mechanism through which water use efficiency can be promoted. Water trading usually involves a financial transaction between buyer and seller (or lessor and lessee). The finance paid by the buyer or lessor may provide the seller or lessee with finance required to fund the adoption of more water use efficient technologies or management, without reductions to the current level of economic output. Permanent trades in particular will still need to be regulated by water resource managers, due to possible third part effects that may result from the trades.

The final point raised was that the currently adopted water apportionment rule, referred to as a Priority-based River and Reservoir Operating Rule (PRROR) may not enable water use efficiency by water users as well as the Fractional Water Allocation and Capacity Sharing (FWA-CS) apportionment rule. There is currently some debate taking place regarding the merits and demerits of this statement. The FWA-CS system becomes increasingly viable with improved monitoring and metering and associated computerized information management systems. As DWAF is introducing the roll-out of metering, as well as the adoption of Near Real Time Systems to aid water management, the FWA-CS water apportionment option becomes increasingly viable.

The FWA-CS system directly and indirectly promotes water users to become more water use efficient. The Capacity Sharing system enables water users to bank their water in large Government Dams, which is not possible under the current PRROR system. Thus water users who access water from large dams (which is the general rule for irrigators in South Africa) have a direct incentive to use their water more efficiently, as they can use it, or keep it banked in the dam (subject to losses from evaporation). Water use efficiency is promoted indirectly due to the fact that water trading in a FWA-CS water apportionment system is far simpler and clearer than in the PRROR system.

References

Backeberg, G. R., (2007). Allocation of water use rights in irrigated agriculture: experience with designing institutions and facilitating market processes in South Africa. United States Committee on Irrigation and Drainage (USCID) : 4th International Conference on Irrigation and Drainage; California, USA

Cai, R. (2008). Personal Communication. Department of Water Affairs and Forestry. Sub-Directorate : Systems Operations. Tel +27 (12) 336 8480, dce@dwaf.gov.za

Chunda, C. (2008). Personal Communication. Department of Water Affairs and Forestry. Directorate: Water Use Efficiency. Tel +27 (12) 336 8174, qtv@dwaf.gov.za

Department of Water Affairs and Forestry (DWAF). (1996). Water Law Principles. Discussion document. Pretoria.

Department of Water Affairs and Forestry (DWAF). (2004a). National Water Resources Strategy. First Edition. http://www.dwaf.gov.za/Documents/Default.asp.

Department of Water Affairs and Forestry (DWAF). (2004b). The W100 Secondary Catchment (Mhlathuze, Mtunzini and Matikulu rivers) : Provision of general modeling and water resource evaluation services for allocable water quantification and to support integrated water resource planning. Pretoria.

Department of Water Affairs and Forestry (DWAF). (2005). A draft position paper for water allocation reform in South Africa. Towards a framework for water allocation planning. Pretoria.

Department of Water Affairs and Forestry (DWAF). (2005). National Water Conservation and Water Demand Management Strategy. Pretoria.

Department of Water Affairs and Forestry (DWAF). (2006). A draft position paper on the development of National Water Resource Classification System (NWRCS). Discussion document.

Dudley, N. and Musgrave, F., 1988. Capacity sharing of water reservoirs. Water Resources Research 24: 649-658

Lecler, N.L. (2004a). Fractional water allocation and capacity sharing/water banking. Proc S Afr Sug Technol Ass, 78, pp 245-250

Lecler, N.L. (2004b). Methods, tools and institutional arrangements for water conservation and demand management in irrigated sugarcane. Proc of the 13th International Soil Conservation Organization conference: ‘Conserving soil and water for society: sharing solutions’, Brisbane, Australia

Republic of South Africa. (1996). The Constitution of South Africa (Act No. 108 of 1996), Cape Town.

Mwaka, B. (2008), Personal Communication. Department of Water Affairs and Forestry. Sub-directorate : Systems Operations. Tel +27 (12) 336-8188, qda@dwaf.gov.za

Republic of South Africa. (1998). The National Water Act (1998) Act No 36 of 1998. Government Gazette.

Paterson, J. (1991). Rationalised Law and Well Defined Water Rights for Improved Water Resources Management. In Renewable Natural Resources Economic Incentives for Improved Management. Chapter 3. pp 43 – 64. Organisation for Economic Co-operation and Development. Paris, France.

Pott, A.J., Hallowes, J.S., Mtshali, S.S., Mbokazi, S., van Rooyen, M., Clulow, A. and Everson, C. (2005). The Development of a Computerised System for Auditing Real Time or Historical Water Use From Large Reservoirs in Order to Promote the Efficiency of Water Use. Water Research Commission report No. 1300/1/05. Water Research Commission. Pretoria, South Africa.

Viljoen, M.F., Dudley, N.J., Gakpo, E.F.Y. and Mahlaha, J.M. (2004). Effective Local Management of Water Resources with Reference to the Middle Orange River. Water Research Commission Report No. 1134/1/04. Water Research Commission, Pretoria, South Africa.