

Business Models for Water Resources Planning, Licensing, Management and Associated Decision Support

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Abstract

The institutional arrangements, which develop in response to the 1998 South African Water Act (NWA), are likely to have a significant impact on how productively water is used. Arrangements which provide positive incentives to use water more effectively will be key to the successful uptake and implementation of, for example, Best Irrigation Management Practices. Since the irrigated agricultural sector uses the major portion of available water resources, facilitating gains in efficiency in this sector is a vital strategic issue in South Africa. In this paper, it is contended that volumetric / time water allocations, issued at some estimated level of assurance and managed using priority-based reservoir and river operating rules have significant disadvantages in terms of: ease of management, equitability, and potential for fomenting conflicts. They also provide little incentive and opportunity for stakeholders to manage their water supply status and so use water efficiently. In contrast, fractional allocation and capacity sharing (FWACS), which has been successfully implemented in the Mazowe catchment in Zimbabwe, enables more efficient, equitable and productive water use and management. FWACS is also reported to be a feasible and transparent management option for managing the Reserve. Simulation models in use and proposed as decision support tools for Catchment Management Agencies are discussed. Existing models need to be refined and developed to support scenario analyses under a FWACS water management system. The use of long rainfall records or spatially coordinated stochastic rainfall sequences as input to appropriately representative agrohydrological simulation models is proposed and defended as a decision support approach which is scientifically and practically sound and achievable.

Keywords: Water allocation, hydrological modeling, capacity sharing, water use efficiency, irrigation

Introduction

The institutional arrangements for water management which develop in response to the new South African National Water Act of 1998 (NWA) are likely to have a significant impact on how productively water is used. This is especially so in the irrigated agricultural sector. With the ongoing implementation of the NWA, South African stakeholders have been provided the opportunity and responsibility to develop water allocation and management mechanisms which are fair, transparent, easy to manage, and which *provide positive incentives to efficient and sustainable water use and water resource development*. Since the irrigated agricultural sector uses the major portion of the available water resources, facilitating gains in efficiency in this sector is a vital strategic issue in South Africa.

Institutional arrangements which provide positive incentives to use water more effectively are likely to be key to the successful uptake and implementation of best water management practices which, in turn, will lead to higher productivity, increased and sustained profits, and a healthy environment both now and in the future. Institutional arrangements also need to be developed to cope with the increased *interdependency* of upstream and downstream users, and the associated potential for conflicts.

In order to institute positive incentives to efficient water use and reduce the potential for conflicts, traditional water resources planning and management philosophies may need to undergo a paradigm change. If a change is desirable, it will need to be supported and reflected in relevant Decision Support Tools (DST). In the context of the NWA, the aims of this communication are:

- (i) to contrast two potential water allocation/licensing and management options in terms of their potential advantages or problems, and
- (ii) to discuss associated planning and management decision support tools (DSTs).

Water Allocation Options

The NWA requires that every Catchment Management Agency (CMA) develop a Catchment Management Strategy (CMS). The CMS must, amongst other things, set principles for allocating water. The CMS should be in harmony with the National Water Resource Strategy (NWRS) and needs to be developed with stakeholder participation / approval. Within a CMS, there are at least two contrasting options by which water allocations can be instituted by the CMA, *viz* :

- (i) volume per unit time water allocations, issued at an estimated level of assurance, or
- (ii) fractional water allocations and capacity sharing (FWACS).

(a) Volumetric Water Allocations and Priority-based Reservoir and River Operating Rules (VWA-PRROR)

Traditionally, water in South Africa has been allocated in terms of a volume per unit time (often based on land areas) at some assumed level of assurance. For example, an irrigation water allocation of 10000m³/ha/annum expected to be available, say, eight years out of ten. In times of shortages, priority-based reservoir and river operating rules (PRROR) are used by the water management authority to determine who has priority of access to the water and who should yield, and by how much. PRROR are what most water users, consultants and administrators are familiar with. Also, most of the water planning and allocation decision support tools, for example, the Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) are based on PRROR (Görgens *et al.*, 2002). Apart from the potential for recurrent conflicts, the major problem with PRROR, is that there is *little, if any, incentive for individual water use sectors to implement effective water conservation and demand management strategies*.

With PRROR individual users have very limited or no control as to when in the future their water abstractions may be curtailed. Therefore whilst water is available, the motivation is for users to abstract it. If water is stored in a shared multi-purpose reservoir, users carry the risk that any water savings made by an individual and left or stored in the reservoir, may, at a future date, be given to some other higher priority or less efficient user. To illustrate the issue, consider a user who believes a drought is imminent and so saves water. Under VWA-PRROR, the water this user has saved and maybe even paid for, could be reallocated to another, higher priority and/or less efficient user in the following season. The opportunity to implement optimal irrigation strategies,

such as deficit irrigation (English, 1990; Lecler, 1999) is, therefore, seriously hampered. With the diminished incentive to save water, the number and duration of water shortage periods will likely increase and overall water use productivity will likely decrease.

An example of the potentially catastrophic results such an allocation and licensing option has had, happened in the Runde river catchment in Zimbabwe. Between 1980 and 1992 the available water reserves in the Runde catchment were severely depleted culminating, *inter alia*, in the near collapse of the country's sugar industry. The PROR institutional arrangements and water allocation system which, during the 12 years preceding 1992, led many users to take as much water as they could, when it was available, played a major role in this catastrophe (in the authors opinion and based on personal communication with stakeholders in the catchment).

An additional problem with VWA-PROR is that conflicts are likely to arise. Reasons for potential conflicts include:

- (i) the determination of water use priorities will likely be contested. For example, is electricity generation more important than food production? In the context of an African continent where millions of people are food insecure and a global situation where irrigated agriculture will be called upon to produce up to two thirds of the increased food supply needed by an expanding world population (English *et al.*, 2002), the answer to this question is not straight forward;
- (ii) a license entitlement based on a volume of water available at some estimated level of assurance, potentially allows upstream users to extract water up to their entitlement even although this may leave very little water in the river for downstream users, who will no doubt become aggrieved.

(b) Fractional water allocations and capacity sharing (FWACS)

FWACS although:

- (i) having been successfully implemented in, for example, the Mazowe catchment in Zimbabwe (Darby Doertenbach, 1998a and 1998b),
- (ii) assessed in terms of equity and efficiency by Natsa *et al.* (2000), and
- (iii) assessed in terms of environmental water releases by Symphorian *et al.*, (2002),

represents a significant paradigm shift to many seasoned water planners and professionals in South Africa. FWACS could, nevertheless, lead to far simpler water allocation, licensing and management, with fewer conflicts and significant gains in water use productivity. The principles underlying FWACS have also been reported on in an Australian context by Dudley and Musgrave (1988) and Dudley (1990).

With FWACS, the water allocations/licenses will not reflect a volume, but rather entitlement to a percentage or fraction of the total available flow. The rate at which water can be abstracted by any given user is then dependent on the flow in the river at any given time multiplied by the licensed allocation fraction. The weekly or monthly volumes available for potential abstraction will vary significantly with the climate of the season. If necessary, the initial licensed allocation fraction could be linked to calendar months, i.e. the license of user 'x' may allow for 0.2 or 20 percent of the available flow to be abstracted during January, 0 percent in June and July and 10 percent of the flow to be abstracted in all other months. Computer-based information systems together with flow monitoring networks would be needed along defined river reaches to facilitate maintaining and reconciling records of inflows, abstractions and outflows. The practical challenge

of measuring and monitoring flows and water abstractions, was successfully overcome in practice, in the Mazowe catchment in Zimbabwe (Darby Doertenbach, 1998a and 1998b).

If there are storage works, the total potential storage capacity would be divided and portions of the total available storage made available for rental or purchase by individual stakeholders. In existing, government owned reservoirs, the amount of storage space offered to stakeholders for rental or purchase should be dependent, *inter alia*, on the CMS. Over time, stakeholders may, however, decide to purchase or rent a smaller or larger capacities, dependent on individual risk aversions and the willingness of other users to trade storage space. Such a system may also encourage private sector investment in storage works. For example, the insurance industry may, as an alternative to investing in shopping Malls, invest in the development and associated letting of space in water storage reservoirs (Natsa, 1999). Repayment schedules for such storage development would be relatively simple to administer, based on the capital and operating costs being apportioned according to allocated/requested storage capacity, independent of water inflows and similar to renting office space in a building. To manage water availability, computer-based accounting exercises similar to what is needed for the river reaches, with additional rules to apportion evaporation and overflows from individual storage spaces would be necessary. Evaporation could be apportioned in proportion to stored water and overflows in proportion to the potential (and available) storage space rented by different users (Darby Doertenbach, 1998a and 1998b).

The main advantages of FWACS include:

- (i) it will be relatively easy to audit and regulate water use because the rate (and hence weekly / monthly / annual volume) which individual users are allowed to abstract at any given time can be determined from actual flow measurements and reconciliation. Whilst presenting some practical implementation challenges, flow measurement and monitoring is a non-negotiable requirement if water is to be managed equitably - under any system;
- (ii) the license conditions allow upstream and downstream users to be managed in an integrated fashion, as opposed to a license based on a volume entitlement which may result in upstream users pumping a river dry in low flow periods, even though the amount pumped may be less than their license entitlements, thereby causing serious conflicts and problems for downstream users and the CMA;
- (iii) it is a more equitable option. Periods of high or low flows affect all users in a predictable, equal fashion;
- (iv) most importantly, users are empowered to manage their water supply status/security, and can receive direct benefits from any water savings they make. There is, therefore, a positive incentive to institute water conservation and demand management strategies and there is also a framework to facilitate 'win-win' water trades. The associated transfer of water to more productive users, can therefore, take place transparently and with minimal administrative complications. In addition, optimizing strategies, such as deficit irrigation will be facilitated. The overall result should be a significant improvement in the productive use of water and few conflicts. Individual stakeholders will be confident that water savings resulting from investments can be stored and saved for use (or trade) at a later stage, for example, during droughts, rather than taken and possibly wasted in high rainfall seasons. This is a key aspect of FWACS, the significance of which should not be underestimated.

Decision Support Tools: Comment and Discussion

In South Africa, guidelines to provide Water Management Institutions with a framework to guide and control modeling applications and procedures have been developed (DWAF, 2001; Görgens, *et al.*, 2002). Comment and discussion on these guideline documents, with particular emphasis on modifications or refinements necessary in order to institute FWACS, is given here.

Reserve Determination

The determination the Reserve, needs to be done in the context of either FWACS or PROR because the adopted licensing and management system will have a direct effect on the methodology and results of reserve determination studies. In a study by Symphorian *et al.* (2002), the FWACS concept was shown to be a feasible and transparent management option for implementing environmental (reserve) flow requirements. The reserve determination methods and models being developed for application in South Africa, need, therefore, to take cognisance of the FWACS water allocation licensing and management option.

Operating rules

The derivation of river-reservoir operating rules (RROR) in the context of FWACS is fundamentally different to what is relevant under VWA-PROR. Under the FWACS, operating rules would be constrained within user sectors rather than applied across user sectors. Operating rules could be derived by individual users in order to guide them in managing their own licensed flow fractions and reservoir portions, i.e. an irrigation stakeholder may decide to pro-actively modify an irrigation application schedule or irrigation area when the volume of water supplies *in his portion* of a dam reaches a certain level. This is in contrast to catchment-based global operating rules where the decision to modify an irrigation schedule or feasible irrigation area may be imposed on all irrigation stakeholders, probably at a less opportune time.

Water resource planning and management models

The assumption that in South Africa and internationally, any number of models are currently available that would be appropriate for water resource planning and management needs (DWAF, 2001), may not be correct in the context of FWACS. For example, the primary planning models used in South Africa, viz. the Water Resources Yield Model (WRYM) and the Water Resources Planning Model, are structured to represent VWA-PROR *not* FWACS. However, under FWACS such or similar systems analysis models could still play a significant role in guiding individual stakeholders, especially large stakeholders, on how to best manage their own supply and demand interactions *within their fraction* or portion of the available flow and storage network.

If there is consensus within a catchment that the advantages of FWACS are significant and stakeholders are successful in lobbying for its adoption, models which do not adequately represent FWACS should only be promoted and supported in terms of the roles they could potentially play in the FWACS context. Most models in their present form do not adequately represent FWACS and so would be unsuitable for use in guiding integrated whole catchment planning without modification / refinement. Funding and research effort should take cognizance that the traditional water allocation, licensing and management approaches may not be the desired option in the future, and DSTs need to be investigated and developed to support other potential options such as FWACS.

Under FWACS the need for:

“system optimization models for the assessment of reservoir and system yields and operating rules under various scenarios of catchment / system development, water use and water quality impacts” (DWAF, 2001),

is no longer relevant because there will be no global curtailment operating rules. Rather scenarios of system performance, given assigned fractional allocations and storage capacities will be required by the CMA and individual stakeholders in order to provide guidelines for the determination of initial fractional allocations and to determine impacts of various demand / use / trading options. Examples of “what if” scenarios include:

- (i) land and/or water use developments,
- (ii) consequences of developing or modifying storage facilities both on and off-channel,
- (iii) implications of changes to licensed water allocation and storage fractions, as may occur, for example, through trading, storage development /curtailment, re-allocations to cater for new entrants,
- (iv) stakeholder management strategies in relation to licensed fractions of flows and storage works with associated risks of shortages,
- (v) impacts of management practices and irrigation systems on the timing, location and quality of irrigation return flows and how these may affect the environmental reserve fraction needed at various times of the year,
- (vi) pro-active drought mitigation strategies, tailored to suit individual users, for example, an industry may want a more risk averse strategy than an irrigator.

It is likely that these scenarios would be required for both strategic and operational planning by individual stakeholders, and by the CMA. In order to determine initial fractional allocations, the CMA could (simplified here to illustrate broad principles):

- (i) ask to receive all license applications, in terms of a well justified (according to acceptable standards / references) average annual water requirement, for example, irrigation crop water requirements could be referenced against the World Standard Food and Agricultural Organisation Guidelines (Allen *et al.*, 1998)
- (ii) total the average annual volumes of all the legitimate license applications, and then
- (iii) issue licenses in terms of a proportion equal to the requested average annual volume divided by the total average annual volume of all the legitimate license requests.

It will then be up to individual stakeholders to determine how the allocated proportion relates to actual volumes of water and at what risk, and plan and/or trade accordingly.

When new users apply for licenses with legitimate proposals / needs, the total annual requirement and associated proportions could be adjusted accordingly. However, these adjustments would have to be limited so that investments are protected, i.e. new license applications would be approved, *inter alia*, only if existing proportions are affected by, say, less than 2 % per annum, accumulated since the license inception. A proportion of the available streamflow and storage works could be set aside for Black Economic Empowerment. Initially, these portions may be rented out to existing stakeholders, thereby raising funds for appropriate development schemes and ensuring that in the interim, opportunities for productive water use by existing users are realised in a ‘win-win’ scenario.

The CMA could require scenario planning tools in order to:

- (i) assess the potential externalities of all water trades before granting permission for the trade to take place, and

- (ii) help facilitate the trading process, by suggesting the best/most feasible potential trading partners (¹Pott, 2003), and
- (iii) ensure that the Reserve and other strategic national interests are adequately protected.

Operational system accounting models together with associated flow monitoring will be needed to keep track of inflows, abstractions and the stored water levels of individual users. These need not be overly complex. Practical spreadsheet-based tools with pragmatic rules have stood the test of time in an application in the Mazowe catchment in Zimbabwe (Darby Doertenbach, 1998a and 1998b), but with developments in Information Technology, could likely be improved.

As a result of, *inter alia*:

- (i) complex agrohydrological feedbacks,
- (ii) historical and potential future land use changes,
- (iii) associated difficulties in “naturalizing” streamflows, *viz.* historical land use changes are often not recorded accurately and resultant impacts “mis”-represented, for example, by using modeling parameters which have limited physical meaning, and
- (iv) poor representation of the interactions between stakeholders, their water demand patterns, abstraction points, available storage and the climate,

planning based on stochastic extrapolation of stream flow sequences is likely to be flawed with many of the assumptions inherent in such stochastic methodologies, not valid. A more representative approach is to use appropriately representative (in terms of what is actually happening in a catchment) agrohydrological simulation models for planning and scenario analysis. Long rainfall records or, where necessary, techniques to generate spatially coordinated stochastic rainfall sequences, which could potentially be modified according to likely climate change scenarios could be used as input to these agrohydrological models. Such an approach is likely to be more valid and representative of real-world scenarios than water resources planning based on stochastic stream flow extrapolations coupled with simplified agrohydrological assumptions in complex mathematical optimization routines. The technology and methods to generate spatially coordinated rainfall sequences are on the horizon (²Smithers, 2003).

It is vital that the science and the assumptions inherent in any modeling methodologies are valid for the intended applications. The description of models given in any CMA inventory needs to be comprehensive. When the capabilities of models are given, some information / comment on the algorithms and their scientific standing should be included. For example, where, a model is said to be able to simulate / account for “irrigation and other abstractions”, information on the basis of these simulations should be given, i.e. are the algorithms based on the World Standard Food and Agricultural Organisation Guidelines (Allen *et al.*, 1998) or equivalent? More importantly in the context of land uses, especially irrigation, the algorithms should be able to account for different and representative management practices and irrigation systems, all of which can have significant effects on catchment hydrology (Schulze *et al.*, 1999; Lumsden *et al.*, 2003) and, therefore, the resultant planning/operational guidelines. In addition, various models are said to be able to simulate stream flow reductions due to afforestation (DWAf, 2001) – do all these models use the same assumptions / algorithms / methodology? Or what are the fundamental differences / advantages / disadvantages? Reviewing models to this level of detail may be an arduous task, however, such a review will be necessary, at some stage, to guide the CMAs. Aggrieved

¹ Personal communication with Andrew Pott, ‘CPH Water’, Pietermaritzburg, South Africa.

² Personal communication with Professor Jeff Smithers, School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, South Africa

stakeholders are also likely to require such detailed transparency, either upfront, or in the water tribunal - a less desirable option.

Conclusions

Experiences with various institutional arrangements and underlying philosophies for water licensing and management has lead to the conclusion that volume / time water allocations given at some estimated level of assurance, combined with priority-based reservoir and river operating rules (PRROR) have inherent disadvantages. The primary disadvantages are:

- (i) they provide little, if any incentives for users to implement effective water conservation and demand management strategies,
- (ii) in times of shortages they result in almost ongoing conflicts between users and or management agencies,
- (iii) they are very difficult to regulate and audit, and
- (iv) it is difficult to formulate rules that are equitable at all times.

The fractional allocation and capacity sharing (FWACS) model of water allocation, licensing and management could be key in facilitating increased overall water productivity and less water wastage. The primary advantages of FWACS are:

- (i) FWACS gives incentive to users to adopt water demand management strategies because individuals have opportunity and responsibility to manage their own water supply and demand interactions,
- (ii) FWACS is relatively easy to audit and regulate, and
- (iii) FWACS is more equitable and hence offers less opportunity for conflicts.

Most water resources practitioners, who learned and practiced their trade under the old riparian rights and prior date system of water allocation, developed and used decision support tools and management philosophies based on a system of priority-based river and reservoir operating rules (PRROR) – understandably. However, it should not be taken for granted that decision support tools and planning procedures used in the past will be applicable now and /or in the future, especially of the FWACS system of water licensing and management is adopted by Catchment Management Agencies. The National Water Act of 1998 facilitates stakeholder empowerment, therefore, the opinions of stakeholders, need to be taken into serious consideration in determining water licensing, allocation and management guidelines. The choice and future development/refinement of appropriate models needs to take into consideration stakeholder requirements and, therefore, should not be limited to the opinions of select academics, DWAF staff and water resources consultants who are comfortable and relatively ‘well-tooled’, in the old, but maybe less appropriate paradigm of water resources planning and management.

In terms of appropriate water resources models and decision support tools to support the NWA and also FWACS, planning based on stochastic extrapolation of stream flow is likely to be problematic. Many of the assumptions inherent in such stochastic methodologies will be invalid or not relevant. Taken together with the need for realistic scenario analysis / insights, these issues are likely to render modeling tools based on the generation of stochastic stream flow sequences inappropriate, in many cases.

A case has been made to base integrated water resources planning and decision support on long rainfall records where available, and/or the development of systems to generate spatially

coordinated stochastic rainfall sequences. With the overwhelming evidence for climate change, it may also be important to manipulate these sequences accordingly (how could streamflow be manipulated for climate change scenarios?). The observed / generated / 'climate change manipulated' rainfall sequences could be used as input to appropriately representative (in terms of what is actually happening in a catchment) agrohydrological simulation models for scenario analysis. It is contended that such an approach is scientifically and practically sound and achievable. Whilst the initial development and configuration of appropriate simulation models may be relatively complex and time consuming, alternatives which are not: adequately representative of important agrohydrological processes, tailored to stakeholder needs and representative of optimal water allocation and management systems and business models, may be expedient short cuts which a water stressed nation like South Africa, can ill-afford.

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References

- Allen RG, Pereira LS, Raes D and Smith M (1998). Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56, Food and Agriculture Organisation of the United Nations, Rome, Italy.
- Darby Doertenbach, B., 1998a. Practical experiences with capacity sharing in the Mazowe river catchment, Zimbabwe. Mazowe Valley Catchment Development, Unpublished paper.
- Darby Doertenbach, B., 1998b. Fractional allocation in the Mazowe Catchment, Zimbabwe and feasibility for national replication under the new Water Act. Mazowe Valley Catchment Development, Unpublished paper.
- Dudley, N., 1990. Urban capacity sharing – an innovative property right for maturing water economies. *Natural Resources Journal* 30: 381 - 402
- Dudley, N. and Musgrave, F., 1988. Capacity sharing of water reservoirs. *Water Resources Research* 24: 649-658
- DWAF, 2001. Guide for the advisory committee for water resources modeling (Edition 1, Draft 4). Department of Water Affairs and Forestry, Pretoria, South Africa
- English, M.J., 1990. Deficit irrigation: I analytical framework. *Journal of irrigation and Drainage Engineering* 116(3): 399-412
- English, M. J., Solomon, K.H. and Hoffman, G.J., 2002. A paradigm shift in irrigation management. *Journal of Irrigation and Drainage Engineering*, 5(1): 267 - 276

- Görgens, A., Tanner, A., Viljoen, J., Sami, K., Dennis, I. and Nel, J., 2002. Guidelines for Models to be used for Water Resources Evaluation. Department of Water Affairs and Forestry, Pretoria, South Africa
- Natsa, T.F., 1999. *From priority date to fractional allocation; towards equitable distribution of surface water resources in Zimbabwe*. Unpublished MSc WREM dissertation, University of Zimbabwe, Harare, Zimbabwe
- Natsa, T.F., Nyagwambo, N, L, and van der Zaag, P., 2000. Comparing alternative surface water allocation scenarios for Zimbabwe. Paper presented at the 4th Biennial Congress of the Africa Division of the Intl. Ass. Of Hydraulic Engineering and Research on 'Conserving and sharing water resources in a water scarce environment', Windhoek.
- Lecler, N.L., 1999. Deficit irrigation of sugarcane: From theory to practice. In *WMO / UNESCO Workshop on Water Use and Demand Management*, Harare. Environment Agency, National Water Demand Management Centre, West Sussex, UK
- Lumsden, T.G., Jewitt, G.P.W. and Schulze, R.E., 2003. Modelling the Impacts of Land Cover and Land Management Practices on Runoff Responses. WRC Project No. 1015/1/03. Water Research Commission, Pretoria, South Africa
- Schulze, R.E., Lumsden, T.G., Horan, M.J.C. and Maharaj, M., 1999. Regional simulation analysis of hydrological and yield responses of sugarcane under dryland and irrigated conditions. *ACRUcons* Report 28. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, South Africa
- Symphorian, G.R., Madamombe, E. and van der Zaag, P., 2002. Dam operation for environmental water releases; the case of Osbourne dam, Save Catchment, Zimbabwe. Paper presented at the 3rd WARFSA/WaterNet Symposium on 'Intergrating Water Supply and Water Demand for Sustainable Use of Water Resources', Dar es Salaam.