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A suggested approach to effective water resource management using the Umgeni resource system as a test case

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Abstract A method of operating a water resources system effectively both during extreme conditions and during average conditions is to be desired. This may be achieved using the "control band" approach. When shortages occur there may need to be a policy for reducing long-term consumption by employing increasing restrictions on the amount of water that may be used. There may also be a need to reduce long-term consumption too, especially where resources appear to be becoming more limited. However, there is a need to prove the efficiency of the proposal. This may be achieved by developing a "credibility" index. Alternatives require the analysis of risk, reliability and vulnerability of the system under the proposed method of operation both initially and when the system is being used in the field. This would help to justify the method adopted.

Key words alternative approach; effective water resources management; "control bands"; credibility; reliability; sustainability; verification

INTRODUCTION

Alternative approaches to water resource management are being developed to meet changing objectives. There is now more awareness that the environment is in need of protection. There are also implications of "global warming" to be considered. In response there have been changes in legislation, which require different operating strategies. Also in many parts of the "Celtic World" the water industry has been either privatized or there is a public private partnership in operation. The result is that there are even more conflicting requirements. The private company requires the making of a profit, yet standards have become stricter, resulting in higher expenditure. No longer is it permissible to take all the water available for public water supply. Allowance also has to be made for other uses, including the environmental component. In addition both Water Quality and Quantity Standards everywhere are being reviewed.

There is now an even greater requirement to manage water resources efficiently. To that end many different mathematical models have been developed. However, most of them naturally concentrate on management during periods of scarcity and have neither been developed for, nor are applicable to, average conditions. The result may be an over cautious expensive operating policy, that keeps the reservoir full, or there may in contrast be an over optimistic approach of allowing the reservoir to draw down too much, with the result of too little water being available during a minor drought.

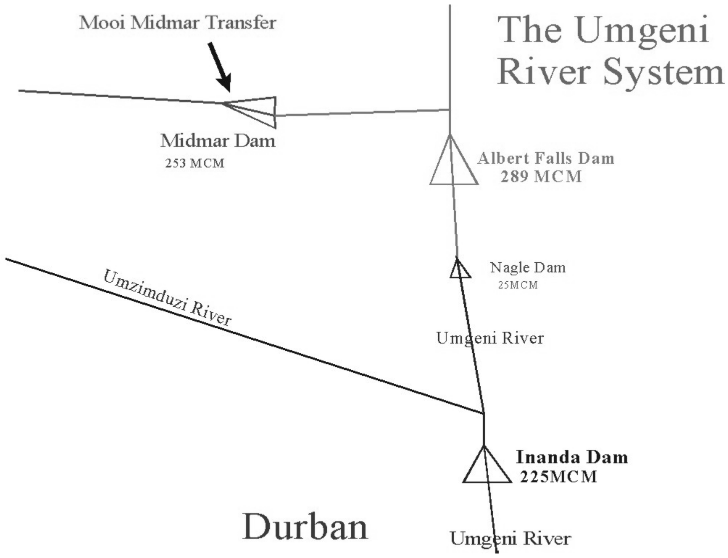

Fig. 1 The Umgeni System.

Many examples of both these scenarios have been documented in the local press throughout the "Celtic World" and beyond.

When developing any concept it is desirable to test the theory out on a real system. In this case the chosen system was the Umgeni Water System near Durban, South Africa (Fig. 1). The rainfall is around 1000 mm per year, which compares with many parts of the Celtic World. However, apart from the southern fringes, such as parts of Brittany and Portugal, the climate is generally warmer and in summer may be very humid. There is an inter-basin transfer then three reservoirs in series; Midmar (259 MCM), Albert Falls (289 MCM) and Inanda (225 MCM), respectively. These supply water to the two large conurbations of Pietermaritzburg and Durban.

Pietermaritzburg treated effluent finds its way via the river system into Inanda Dam. While in Durban some of the treated effluent (42 Mld) is retreated to potable quality and used for industry on the coastal area. Water demand is increasing mainly due to an increase in population. Water is supplied in bulk to the two major Municipalities by Umgeni Water. Most domestic users receive their water from the municipalities through a metered system. There are rising block tariff charges, which vary according to the Municipality. This penalises excessive use by punitive water charges. Most of the region is supplied by water using a gravity system. Pumping is kept to a minimum. There have been several major droughts and floods in the last 25 years. The most notable drought was that from 1980 to 1984, while the most severe flood (1 in 200 year return period) was in 1987. This latter flood occurred half way through the building of the Inanda Dam and resulted in flows in the Umgeni of over 7000 cumecs (Tollow, 1990).

Control Bands

The concept of the "control band" rather than a "control rule" was originally developed for two relatively small (25 MCM) reservoirs filled by pumping from relatively small river systems in East Anglia, the Stour and the Pant–Blackwater, UK. Although these were later augmented by inter-basin transfers from the Ely Ouse–Essex transfer system. The concept was further developed to facilitate the very efficient operation of the 137 MCM Rutland Water, which was again filled by pumping from two larger rivers, the Welland and the Nene. The prime objective was to ensure that as much water was pumped as was required to meet the expected demand at least cost (Tollow, 1989a).

These original approaches exclusively used historical data to derive the "control bands". The first approach used the classic drought sequence, but was also combined with sets of median flow data. This enabled a flexible approach to be developed, which was applicable to everyday operation when the system was not under stress. The concept was developed for the Umgeni system and was verified and refined using generated data and Linear Programming.

As an analogy the concept may be compared to the fuzzy logic approach to water pricing (Hall, 1991). The "control band" does not assume that there is one optimal solution but imparts a flexibility to the operating system. Thus, what may at first sight appear to be "sub-optimal" usually results in as near an optimal solution as is feasible. The reason for this is that the "control band" is not a single line but may cover a selected number of lines, depending on the conditions prevailing at the time. For example; in the extreme, a small width may result in there being only a few solutions while conversely a large band width results in a large range of acceptable solutions. However, when the actual operational line crosses any of the boundaries a series of constraints may be activated, depending on:

(a) whether the line is crossing the upper or lower boundary
(b) the constraints of the resources forming the system
(c) the future availability of the resource (incoming flow and quality)
(d) the forecasts of future demands
(e) the trends both of past and future operational requirements
(f) the acceptable risk of failure (is it necessary to meet demand?)

A typical "control band" is shown in Fig. 2, together with a simulated actual and projected demand scenario. The "control band" illustrated could be considered either as annual, or of any suitable seasonal duration.

When designing the "control band" it is advantageous to use simulated data sets made up of median, high and low flows, together with combinations. In the case of the Umgeni system five year data sets were appropriate, but for the earlier research three year sets were used to develop the appropriate "control bands". The Umgeni bands were tested using 100 year sets of data (Tollow, 1989b). Multiple data sets helped identify waeknesses in the proposed strategy (Tollow 1991a). As a result there were opportunities to:

(a) modify the "control band"
(b) modify the operating policy or
(c) more extremely, modify the infrastructure

The objective is to make the policy and thus the "control bands" more efficient. As well as Linear Programming an analysis employing Non-Linear Programming was tested, but no advantage was found (Tollow, 1993). However, an hypothesis employing Non-Linear Programming has been developed for the Durban segment of the

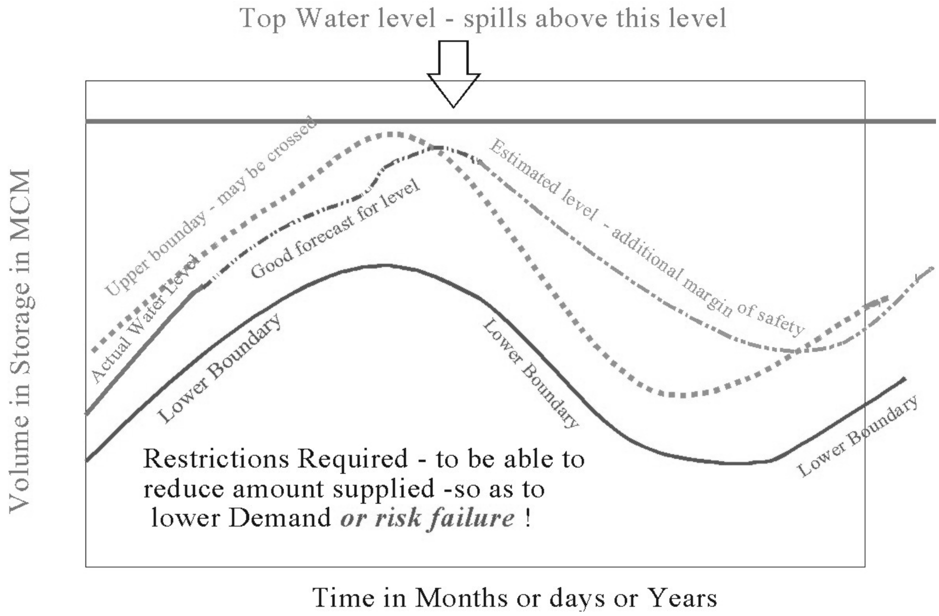

Fig. 2 A typical "control band" covering one operational period.

Umgeni system (Biscos *et al.*, 2003). It was relatively straightforward to generate the required data used in the analysis from existing data records. At least 10 sets of 100 years of data were generated, which together with a reconstruction of the original data formed the information required to generate and analyse the "control bands". Ten sets of synthetic data were considered the statistical minimum to give acceptable results. The initial derivation required sets of about five years of data to develop acceptable "control bands". Thus the process may in practice be summarized as a means of deriving of suitable "evolutionary algorithms", which subsequently need to be verified.

Verifying the results

In order to measure the effectiveness of the proposals it is necessary to be able to demonstrate their advantages. My initial approach developed a "credibility index" (Tollow, 1991b). The idea was to try and quantify, in some form of numerical terminology, a combination of the risk, reliability, resiliency and vulnerability of the system employing a unique index. This proved to work on the Umgeni system but there is still much scope for development. Other means have been formulated for the same catchment (Kjeldson & Rosbjerg, 2001). Their method also considered the "sustainability" of the resources (Kjeldson & Rosbjerg, 2002). However, the need for further development was indicated. One aspect that needs to be considered when operating the system is the management of consumption.

Managing the use of available water may be considered as the meeting or managing of the perceived requirement for water, including the environment as well as all other users, whether industrial, domestic or agriculture. A suggestion has been developed using the Umgeni system. This demonstrates the desirable constraints that may need to be applied to consumption (Tollow, 1995a). Although the cost of developing resources is increasing worldwide, in one instance selected sustainability criteria, as applied to the Umgeni River system, indicated that it would be better to develop new resources rather than practice a revised management policy using existing resources. However, this phenomenon was explained as being due to the choice of "selected users" as well as other shortcomings. An alternative approach was needed to see if this conclusion could be verified (Kjeldson & Rosbjerg, 2001). However, from research on the same catchment, using different criteria and data, a significantly different outcome, more in line with global trends, appeared to be more likely (Tollow, 1995b).

CONCLUSIONS

The advantage of the "control band" approach is that there is a pre-determined degree of flexibility. In addition, with the use of sophisticated control systems an automatic operating system could be developed, provided that there are sufficient "rules" embedded in the operating procedure. However, even if used as a guide when it is developed in conjunction with other management tools, it would aid the efficient use of water resources when operated under extreme conditions. Additional bands may be developed as required. An example would be a "band", which initiates constraints once demand has increased above a certain specified level. In the short term this may take the form of a forced reduction in pressure. In the past this took the form of inserting Orifice plate "washers" in the supply line to physically limit supply to that property (Tollow, 1994). Other aspects to be considered would be the development of separate management strategies for the requirements for industry (Tollow, 2000).

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