Drought management as an alternative to new water schemes - Theory

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Abstract

Instead of planning water resource projects to yield a constant maximum rate, it is advocated that reservoirs be operated on a variable draft basis. That is, when water levels drop to predefined levels the supply rate is decreased accordingly. This will increase the yield of the reservoirs and reduce the necessity to build additional dams.

The level of water restrictions during drought should be sensitive to the economic consequences. If possible the tariff should be adjusted to reduce consumption to the desirable level of supply. Other uses of water tariffs are presented, including for repayments of costs, subsidisation, tiered, punitive tariffs, maximum use of resources and conservation.

Introduction

In the urban areas of South Africa we have been accustomed to receiving all the water we require. Historically the cost has been relatively low by international standards due largely to bulk supplies. The quality has been good and the reliability acceptable. As the cost of tapping additional sources increases (Stephenson, 1995) due to greater distances and pumping lifts and increasing costs of purifying, we need to re-examine our standards. It may become more economical to suffer restrictions during drought because the yield of surface reservoirs can then be increased. The cost of suffering due to limited restriction can be less than the increased cost of new reliable sources (see e.g. Riley and Scherer, 1979).

Similarly in the future the quality we expect may not always be warranted. Herold (1980) indicated that over 75% of urban water is returned to water courses. Waste water is biologically and physically purified in municipal waste-water works before being discharged to streams although mineral concentrations increase during the cycle because they are more expensive to eradicate. Instead of tapping fresh surface water resources further away it may be economical to recycle and tolerate lower quality for the bulk of our supply. In the extreme, potable water (which accounts for only 10% of the supply by Rand Water) could be supplied in a separate system or in containers.

This paper concentrates on restricting water usage during drought as an alternative to providing high reliability in our surface water tapping projects.

The bulk of our water is supplied from rivers, which are notoriously erratic over seasons and cycles in South Africa. Therefore the cost of storage is high. Alternatively water must be piped from distant more abundant surface sources. The alternatives of groundwater have proved limited and recycled water is expensive to purify.

It was customary to ensure safety of supply during the worst recorded drought. Then the concept of recurrence interval, e.g. 50 years average between failure, became fashionable. More recently Basson et al. (1994) proposed risk methods. By analysing the stochastic nature of river flow records long-term simulations could be performed and the frequency of the necessity to reduce supply (ration) could be calculated. This varied depending on the target draft and level at which rationing commenced.

The optimum level at which rationing should commence and to what level to ration is addressed here, bearing in mind the economics. That is the cost of reliable supplies is balanced against the economic cost of rationing water. One way of rationing water is by means of water tariffs.

The use and basis of water tariffs

Organisations managing the supply of water have used and possibly misused water tariffs in many ways. There are alternative types of water tariffs and designations for different methods of charging for water have not always been consistent. A classification of tariffs is therefore given below.

In the past water tariffs have been imposed by the authorities responsible for supplying us with water. This is designated supply-managed tariffs as opposed to user-managed tariffs where the community is able to control to some extent the cost as well as the allocation of the cost of water. Whereas a supply-managed tariff results in a common standard being set by the supplier in the case of user-based schemes the standards may vary to suit the community. The funding and methods of funding may vary. Supply management is now regarded as autocratic although it is the simplest and perhaps most economic at face value. The scope and cost are, however, limited by the technocrats planning water schemes. It is also difficult to separate the supply organisation's objectives from the user's objectives. For example, the bureaucrats of a supply organisation will understandably have pride in the system and therefore may attempt to reach higher standards although this is not necessary in all cases. Also for simplifying work, major schemes may receive preference over minor schemes. For example, rural disconnected supply schemes may require a high professional input compared with the yield and capital cost.

The components which make up the supply cost of water include:

- Payment for capital or financial repayments for capital loans
- Operating costs including maintenance, power and management

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- Quality control including purification and pressure maintenance as well as back-up for droughts
- Funding of indirect projects such as redistribution of wealth or national improvement in health and economy
- Deterrents for conserving resources such as a premium to reduce usage of water
- Components to pay for environmental protection or reclamation
- Community funding including training
- Reserves for future expansion water and to ensure continuity of supply or jobs
- To cross-fund, e.g. other department's shortfalls, or redistribution of charges.

The redistribution of resources is not necessarily more expensive in total but may mean subsidisation by those that can afford for those who cannot afford basic necessities. The above-mentioned principle is therefore a philosophy which is turning into a sacred cow in South Africa regarding tiered water tariffs. Various euphemisms have been suggested such as lifeline tariffs (Triebel, 1994) for enabling the poorer sectors of the population to meet basic needs and even RDP (Reconstruction and Development Program) support.

Water tariffs may have technical components which are based on:

- The volume of water consumed in a certain time, e.g. per month
- The peak rate of flow which dictates the size of distribution system. This might be influenced by fire-fighting requirements, or on-site storage to reduce peaks
- The erf or stand size or number of stands as a measure of consumption
- The number of water connections
- The size of stand or some other measure of wealth or ability to pay.

The latter may also be indicated by the volume of water consumed, for instance there could be a sliding tariff charging increasingly higher rates for higher consumption per connection or per stand.

The cost of water

The basis on which tariffs are calculated is generally the cost of supplying the water (Stephenson, 1995). However, there is now talk of charging for water before it has been controlled or tapped by man. This is a form of funding as the real cost is zero seeing it is a renewable resource. If the resource is mined such as the use of groundwater at a rate greater than the natural replenishment rate, then there may be a long-term cost to the environment.

The historical cost has been the one most commonly used for establishing water tariffs (Palmer, 1994). Here the income from water tariffs is used to meet the costs of repaying loans, operation, maintenance, fuel, management and often a fund for future expansion. Based on average cost the water authority will charge a tariff which could be the total expenditure divided by the total sales of water.

A deviation from this method of costing is the marginal cost basis. Based on the fact that additional augmentation costs more than the original source of water, new users may have to pay more. Alternatively all users may have to meet the additional cost. An alternative marginal effect may be the reduced cost due to bulk supply since the cost per unit delivered from a source decreases the larger the pipeline or the supply system.

If the total income from tariffs is only to meet average costs then it is purely a financial calculation. However there are invariably economic components which makes the historical or average cost basis rather academic. For example, the non-technical components described above may be added onto the total cost.

The cost of water is not static even though historical costs may be constant until the loans are repaid. Invariably there is no reduction in average tariffs when costs are paid off, since expansion increases expenditure faster than the reduction in loan repayments over years, particularly in South Africa.

Costs increase because supplies have to be augmented and these augmentation schemes are invariably from more and more costly sources. There is also inflation of prices causing the unit cost to increase. Policy factors may also cause increasing cost to some of the consumers. For example, subsidisation or redistribution of resources may mean more acceptable costs to some but others will have to pay more to meet total costs. There may also be cost increases of a temporary nature due to limited sales, for example during drought, which means that the unit price must be increased to meet certain fixed costs.

When should water tariffs be determined?

There are 3 stages during which the tariff for water needs consideration:

During planning

Before a water scheme is constructed the capital cost of the project is likely to be the most serious economic consideration. Average running costs will be added to discounted capital cost of dams and conduits for alternative schemes in order to select the most economical alternative. If rationing is to be considered at this stage as an alternative to larger resource schemes, the true economic cost to the consumers due to shortfall also needs to be included. (This is not the same as the income to the water supplier which may even increase due to punitive tariffs during shortfall).

When new water schemes are being considered the cost of the scheme and consequently the average cost of water to consumers is the prime criterion. Alternative source and levels of assuredness will be compared. This paper is concerned with the reliability of supply during drought, and typically the more reliable the surface source the greater the cost will be (see Fig. 1).

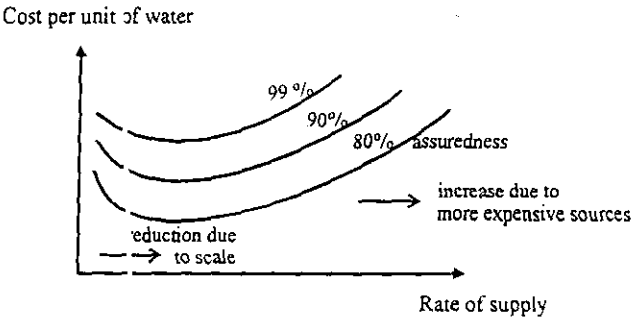

Figure 1
Effect of assuredness on cost of water

During normal operation

Once the scheme (e.g. dam and water works) is built, its cost does not feature in operational optimisation. The object of the new optimisation exercise is to minimise economic loss due to restrictions. This may mean shuffling the available water around to minimise total economic loss. The result will be an operating policy for a reservoir.

After a water scheme is commissioned, the perspective changes and day-to-day as well as annual supply rates change. Each year the tariff may be revised as supply rate increases and hence the tariff could be reduced if it were solely to meet fixed repayment costs. But funds for future more expensive schemes also have to be raised so it rarely happens that the tariff drops over the years. An operational policy for reservoirs may be designed to enable water to be conserved during drought. The control of usage could be by tariffs.

Crisis management

When there is a shortage at the source e.g. during a drought, then there could be restrictions on water usage but at the same time the authorities have to meet fixed costs. The tariff may have to be increased (see Fig. 2). This is not the same as the use of punitive tariffs to restrict water usage. During drought it may be necessary to reduce consumption by means of higher tariffs (see Fig. 3)

When a drought occurs, the most economical allocation of limited water resources needs to be decided. Also a tariff structure could be employed to ensure the correct consumption level. Individual consumers may be taxed on a separate basis to ensure that they comply with the necessary reduction in consumption. Alternatively the free market could reign and a uniform increase in tariff applied. The latter may necessitate a stepped tariff to ensure no personal hardship for poor consumers.

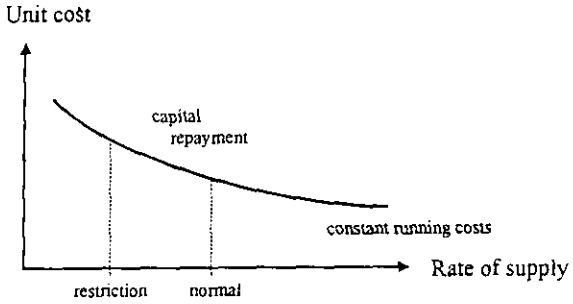

Figure 2
Effect of restrictions on cost of water to supplier

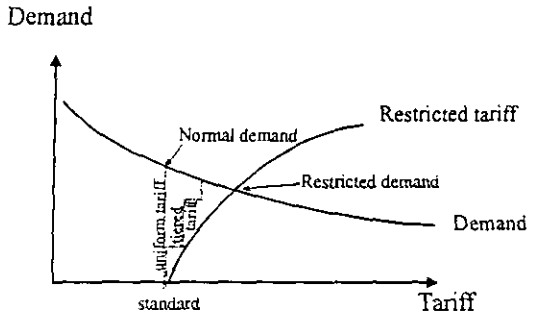

Figure 3
Effect of tariff on consumption

Types of water tariffs

Apart from meeting many (sometimes conflicting) objectives, water tariffs may differ depending on the stage at which they are established.

Long-term objectives

A water tariff which is set at the time of planning a project could be influenced by the following factors:

- **Cost**
  Water schemes already implemented have to be paid for as well as operating costs. The tariff based on cost could be the historical cost repayment.

- **Marginal cost**
  To control additional usage the marginal or incremental cost of new water could be charged (Hirschleifer et al., 1960).

- **Opportunity cost**
  There may be an alternative use for water so that the charge could be based on the alternative use and not on the actual cost of obtaining the water. If the alternative use is more profitable it would push up the price to all.

- **Time-of-use or peak-load basis**
  To reduce peak drawoff rates and thereby pipeline distribution costs (Lumgair, 1994) off-peak tariffs could be lower than average. The time-of-use basis is an optional method of paying for electricity supplied by Eskom (1994).

- **Investment**
  Some organisations such as Eskom (Electricity Supply Commission of SA) in the past, built reserves for funding future schemes. Authorities have been accused of empire building if they have an autocratic control and over-charge. This has also been called an equalisation fund.

- **Conservation**
  A charge could be levied to reduce water usage, but the figure which would be derived would not be based on the cost of raw water which is free but on a figure estimated to reduce consumption.

- **Environmental**
  A cost may be levied for investing in environmental preservation.

- **Foundation consumers**
  It used to be true that original investors in water boards (e.g. Rand Water) would receive preferential tariffs since they had invested many years before and therefore had a foot in the door in managing or controlling the water authority.

- **Insurance**
  It may be that some consumers are prepared to pay more for water to minimise the impact of drought i.e. to ensure continuity of supply. In fact they are paying for additional storage or alternative standby sources. This type of charging is one which will be described further.

- **Capacity allocation**
  It could be that certain volumes in storage are allocated to different consumers and they may use it as they wish (Dudley, 1990). The cost of the storage plus the distribution system is then allocated to that consumer. This puts management in the hands of the consumer. However, in practice it is difficult to enforce since inflow and evaporation must also be allocated and different water qualities may occur.

- **Tiered**
  Different consumers may be charged at different rates. This could be done by setting a low (lifeline) tariff for initial amounts, with increasing tariffs for higher consumption. This is based on the premise that richer consumers use more water. Alternatively different classes of consumers may be charged differently e.g. industrial, domestic or agricultural.

- **Subsidisation**
  In South Africa in particular the use of basic or lifeline tariffs for poor people with a sliding scale for those who can afford has received serious consideration. This is an affirmative action type of charging or could be justified from a national economic or health point of view.

A water authority would more logically have differential tariffs based on location of the consumer as that would affect the cost of distribution as well as scale i.e. rate of supply, since the larger the bulk supply the cheaper the unit cost, as well as marginal new consumption since it has been argued that newer consumers must pay for the newer water which costs more. The latter fact is justified by the fact that it may be more economical for a newer consumer to locate in areas of water abundance if it is economically sensible.

Operational basis or crisis management

South Africa has for a long time used the basis of critical droughts for planning water supplies and reservoir sizing. That is a selected recurrence interval of failure is used to calculate storage volume and therefore the cost of the dam. An alternative to this is the variable draft (e.g. Midgley and Pitman, 1967). Variable draft principles can be taken further and changing the draft as a function of reservoir level and probability of inflow (Stephenson, 1970) in the future as an alternative to this system is discussed below.

However, assuming that an emergency has arisen in the way of drought or some other reason for inability to supply water then the method of restricting water consumption could be based on an economic system as follows:

- **Penalties or punitive tariffs**
  Higher tariffs could be charged for total consumption if consumption is above a set figure (Davis, 1995). Alternatively a marginal penalty could be applied for consumption above a certain figure. This method is not guaranteed to reduce consumption correctly because the supplier has not necessarily estimated the value of water to the consumer.

- **Purchase system**
  If there were a free market then consumers could bargain amongst themselves to purchase different allocations of water.

- **Insurance**
  Some consumers may elect to pay a higher tariff when the supply is initiated to ensure that the drought effects are minimised. They, therefore, pay for reserve storage or alternative supplies in advance. This is actually a long-term pricing basis but affects the rationing when the time arises.

- **Capacity allocation**
  If certain volumes in the reservoir and certain proportions of the current inflow have been pre-allocated then it is up to the consumer when he uses that water, provided he has paid his share of costs involved.

- **Shortfall surcharge**
  Due to lower sales figures by the water authority they may have to increase tariffs in some way to meet their costs which cannot all be reduced in proportion to the amount supplied.

- **Funding**
  The supply authority may during shortfalls increase tariffs more than strictly necessary to build reserves and to capitalise on the crisis. South Africa must take care not to cry wolf like this. In particular the use of increased tariffs for drought management must not be confused with the use of tariffs for redistribution of wealth.

Non-tariff management methods

The capacity allocation method is actually not a tariff-based method of controlling water usage provided there is some other way of controlling the volumes used. There are a number of other methods for controlling water use during periods of shortfall or crisis. For example, public appeal has been resorted to with limited success. There are also methods of physically restricting supply of water by control valves, orifices and pressure reduction. The latter have been employed with roof tanks so that consumers can draw at peak rates while inflow is restricted.

It may also be that the consumer could find alternatives to being restricted in water usage or paying higher tariffs. He may seek alternative sources such as groundwater. These sources may have a higher operating cost but as they are intermittent it may be not be as severe as long-term usage. This is efficient conjunctive use of alternative resources.

Consumers may also elect to reuse water and if necessary purify the effluent reused. Again this may be a higher operating cost alternative but owing to the limited duration the effect could be ameliorated.

Drought management by use of water tariffs

If the true value of water to consumers could be assessed there is likely to be a wide range of charges which could be recovered. Again one must be careful of applying long-term criteria during crisis. Some consumers may locate their organisation based on indicated water tariffs but the use of variable tariffs to manage water during drought must be explained and incorporated within the overall tariff system.

The level of rationing can be decided at planning stage if the cost of assured water is balanced against the cost to the economy of rationing. However, the operational basis during drought will be from a different perspective.

A drought would be identified if the water level in the reservoir is at a low level and the probability of refilling the reservoir during

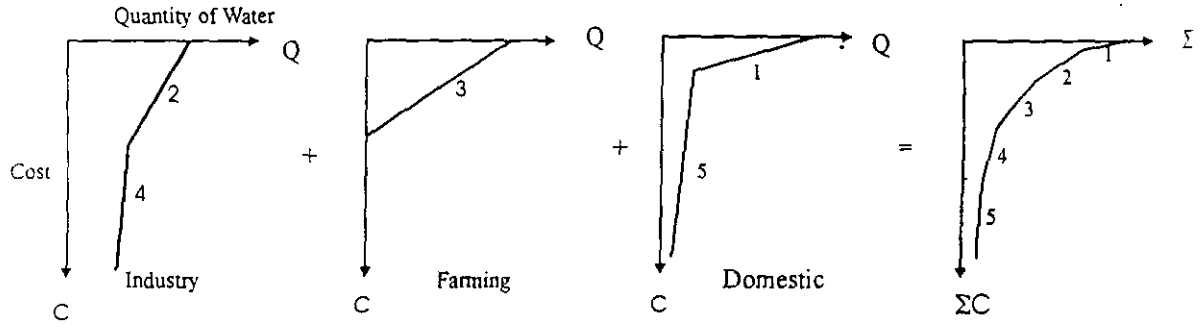

Figure 4
Economic loss due to water shortage

the current operational season is remote. The objective is to minimise the probable economic damage by applying water restrictions. The fact that water restrictions may be implemented by use of tariffs is incidental, but it has the advantage that the tariff can be more easily decided if the level at which the tariff will influence the consumption is known, i.e. the economic value of water to the consumer is known. Unfortunately this may result in recuperation of excess income or possibly under-recovery of income by the water supply authority and therefore a balancing fund would have to be built up by the water supply authority to ensure he does not make a profit or loss if it is an autonomous non-profit-making organisation. It is on this basis that the operating rule for the Min-Der reservoir would be derived, i.e. after ranking all consumers, a relationship between minimum damage and level of restriction will be established. Then the objective would be to minimise the probable damage or economic loss due to restrictions. In order to apply the restrictions, the cost of water must be increased to its perceived economic value.

Unfortunately a uniform tariff cannot be applied in this way to restrict the use of water, for the poorest sectors of the economy may not afford to meet the tariffs which would be imposed on industry in order to force them to restrict water. Therefore a percentage reduction, or a differential tariff or shadow value may have to be incorporated. The shadow value may not be paid by the poorer sectors but it should be added onto the cost of water. The alternative would be to charge a tiered tariff, i.e. the first volume would be at the original tariff and above an estimated lifeline supply rate the tariff would be successively increased as a function of the percent of the lifeline supply rate. In this way poorer consumers will only pay marginally more if they use above the minimum requirement whereas richer industrial consumers would pay considerably more. The tariffs would have to be based on the economic value to all consumers.

Case study

A joint research project on water supply policy during drought has been embarked upon by the Water Systems Research Group at the University of the Witwatersrand in South Africa and the Department of River and Harbour Engineering at the National Taiwan Ocean University of Keelung, Taiwan. The objective is to ensure equitable and rational conservation of water resources during drought.

The Min-Der reservoir, South of Taipei, is used for the case study. Taiwan is particularly prone to drought. The majority of river flow occurs during typhoons frequently followed by lengthy periods of drought. Rivers are steep so storage is limited and reservoirs fill with sediment (large boulders). Average storage is

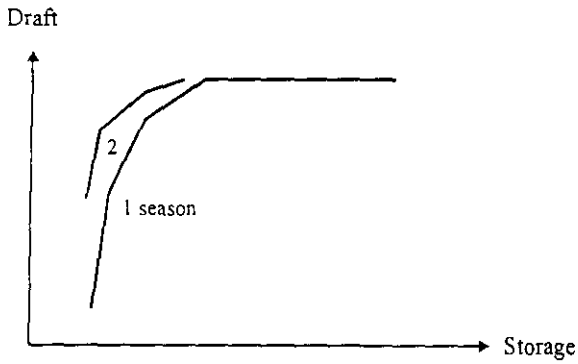

Figure 5
Operating rule

therefore limited and new storage is expensive. Drought management is therefore a viable and economic alternative to new supply schemes.

Methodology

The procedure in deciding on an operating rule for the reservoir is as follows:

- **Hydrology**
  Long-term time series of monthly inflows into the reservoir were prepared. River flow records are only available since 1970 and were therefore of limited use in obtaining 100 year or other extreme flows. Time series could be generated synthetically by stochastic means or deterministically. A physically based module RAFLER (Stephenson and Paling, 1992) was used with monthly rain data for surrounding rain gauges. Acceptable agreement was obtained with the existing streamflow records giving confidence in the longer term projections.

  The monthly streamflow series was analysed to obtain risk of running the reservoir dam to different levels with various combinations of starting storage and draft, over the winter and summer seasons respectively.

- **Probability**
  A matrix relating probable end to starting storage and draft was then set up for solution by linear programming. Each draft was associated with a cost coefficient for the optimisation exercise.

- **Economics**
  The economic costs of various levels of water restriction were

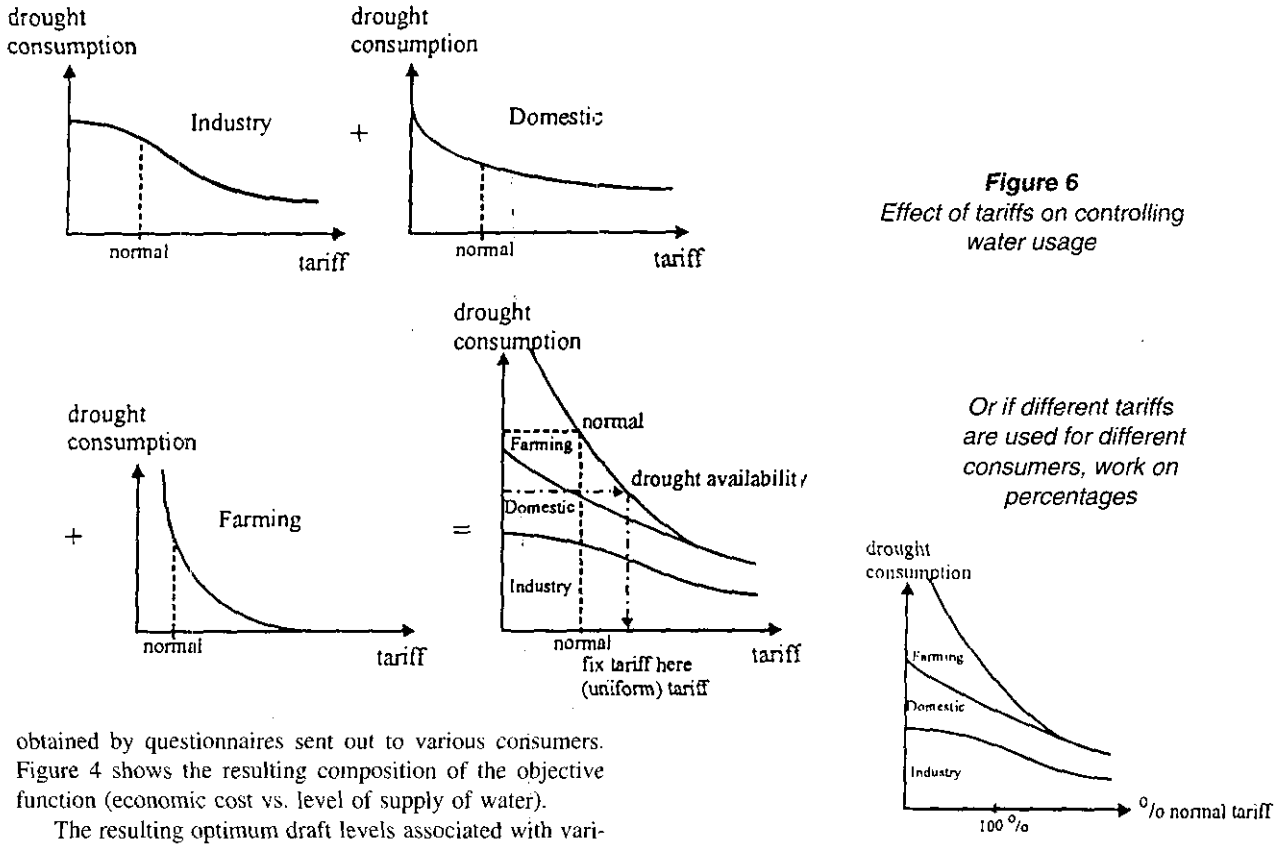

Figure 6
Effect of tariffs on controlling water usage

obtained by questionnaires sent out to various consumers. Figure 4 shows the resulting composition of the objective function (economic cost vs. level of supply of water).

The resulting optimum draft levels associated with various reservoir levels and seasons are graphed in Fig. 5. Once the desirable level of supply had been established, a method of controlling water usage to the desired supply level was developed. This was based on use of tariffs to control water use. The water consumption can be controlled at the desired supply level by imposing high water tariffs. Hopefully the consumer will balance water payments against economic loss due to restriction so that the tariff can be established from Fig. 4, but if the consumer is unaware of his water consumption/economic production relationship, use of questionnaires or past experience may be necessary to set tariffs.

Conclusions

Drought management of reservoirs is an alternative to new water schemes in some cases, and can increase the yield of reservoirs as well as conserve water. The economic consequences of restricting water use need to be considered and used in selecting the degree of water restrictions as well as at what storage level restriction should commence. An operating rule indicating draft vs. reservoir storage and season can be prepared using optimisation techniques.

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