Demand management theory

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Abstract

Demand management is an alternative to increased water supply to meet growing demand. Control of water usage can be effected by the supplier or the consumer. The supplier can use physical methods to limit supply or economic, and the consumer can adjust his way of living either voluntarily or under pressure by the supplier. The classical supply-and-demand curves are applied to water supply, considering also the effects of metering, and marginal vs. average costing.

Introduction

South Africa is a water-scarce country and as a result unit water consumption is expected to be less than in water-rich countries. Although there are water resources in the region sufficient to meet present requirements, the distances required to pump water, and the storage required to meet droughts, make the cost of obtaining new sources higher and higher. The cost of additional water is therefore likely to increase exponentially. In addition, the expected increasing living standard of many of the population will mean that greater volumes of water are needed, even though consumption will be at a minimal level. A balance will therefore have to be achieved between consumption and new supplies (see e.g. Rademeyer et al., 1997). This cannot be achieved except by considering marginal costs and variable tariffs. The occasions when water tariffs need to be considered will also effect the instrument used to control usage. During crises (e.g. drought) short-term tariff increases may be applied, whereas in the long-term the average tariff will depend on the marginal cost of new sources.

Water consumption management

Water consumption can be limited by physical, sociological or economic means (instruments). Physical means include cutoffs or pressure control by reduced pumping or constrictions in pipes, e.g. orifices or washers. The latter costs money in waste of energy and cost of installations. On the other hand, it may even out the water drawoff variations by making consumers take water over more hours per day and provide in-house storage to meet peak consumption. The former (curtailing supply over periods of hours), could result in higher peaks when supply is resumed, but this will in turn reduce pressure and therefore peak drawoff. Demand control by pressure reduction could result in different drawoff patterns. Roof tanks could be filled at night. This will save distribution pipe costs but not necessarily reduce total volume of use. It may also be possible to reduce supplies to uneconomical, no longer valued consumers with compensation, in preference to newer consumers. In the long term, water-saving plumbing devices could be installed. These include small and double action cisterns, low-volume showers, and automatic tap closers.

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Sociological methods include appeals, way of living or legal action. Appeals, through the media or on accounts rarely last long before consumers forget the urgency. Long-term changes in ways of life to reduce water consumption will generally be caused by increasing water costs, together with public relations campaigns. Legal enforcement of water restrictions, if associated with fines, can be effective but costly to apply. It may mean inspectors checking on consumers, or relying on spying neighbours. Then fines would have to be imposed by courts unless incorporated in water accounts. Such methods include prohibiting use of water on gardens on specified days, banning filling of swimming pools or use of hosepipes or flushing of drives, etc. Consumer awareness can encourage local reuse of grey water, e.g. wash-water for gardening.

Economic methods include water tariffs, metering or charges on discharges. Theoretically the best system would be to charge prices which reduce the usage to meet availability. This is, however, an unknown equation since the true value of water may not be known to the supplier or even the consumer. It may also involve tiered tariffs. That is, successively increasing consumption will be charged at higher rates so that the basic requirements of consumers, particularly domestic consumers, are met and more luxurious uses are charged at higher rates. This assumes there will be no trading between consumers (Moore, 1989). It may also encourage consumers to seek alternative sources which, although they may be more costly in total supply, may be cheaper to individual consumers.

Apart from the socio-economic objectives of providing water, there is a long-term value of water. If the world population and standards of living continue to increase, water will become scarcer. It may also occur that climatic change requires more careful use of water owing to reduced availability or greater variability in rainfall.

The traditional approach to supply management is to meet demands with successively more expensive schemes until the demand balances the supply. However, unless marginal pricing is applied, the average supply cost will always be less than the marginal additional cost of water, so that the demand will continue to increase asymptotically.

Theory of supply and demand

A fundamental concept in economics is the law of supply and demand. Figure 1 shows theoretical supply and demand for water. At higher prices, producers would be willing to supply more but consumer demand would decrease; at lower prices,

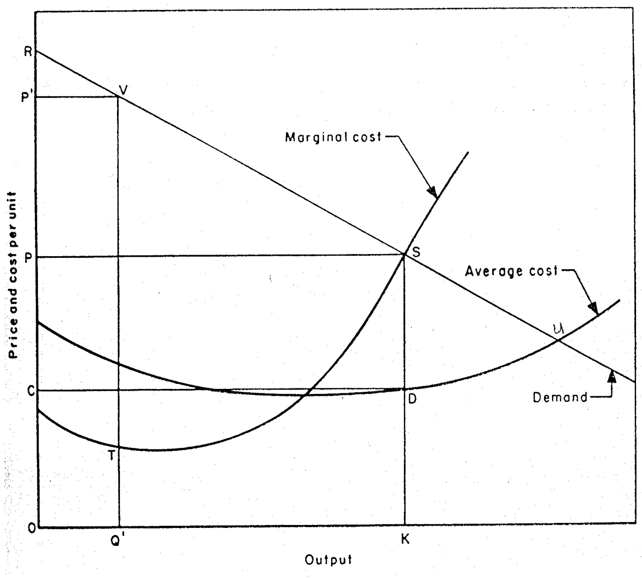

Figure 1
Supply and demand with different price structures

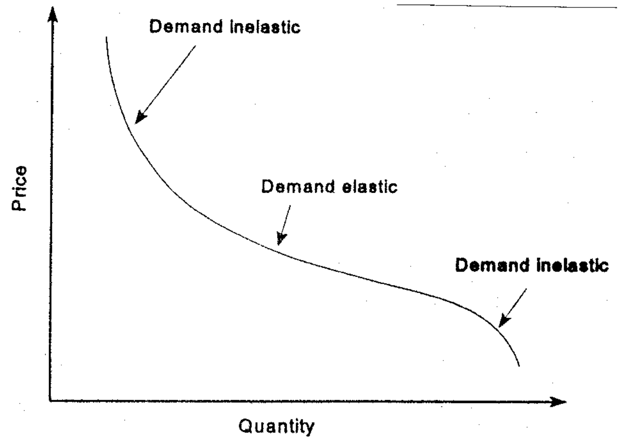

Figure 2
Showing how elasticity changes at different points along the water demand curve

consumers would demand more but producers would cut back on supply. Figure 1 shows the theoretical equilibrium condition between the price and the quantity supplied and demanded for average costing and marginal costing (Hirschleifer, 1960).

With increasing price, the reduction decreases because further reductions may require changes in behaviour that are inconvenient or contrary to personal or social norms. And at even higher prices, there will be no reduction at all if it means cutting into essential uses like cooking and waste disposal. On Fig. 2, this relationship is shown by an increasingly steep demand curve as prices increase on the left side of the graph. At low prices people will buy and use more water, but there is a limit on how much water anyone can use, even if it is free. So again as price falls, demand eventually drops off as well.

The rate at which demand changes as price changes is called the *price elasticity of demand*. (Similarly, there is a *price elasticity of supply*.) Conceptually, when demand changes a great deal for a given change in price demand is said to be *elastic*. When demand does not change very much compared to the change in price, demand is said to be *inelastic*. Economists calculate the elasticity of demand *e* as:

$$e = \frac{dQ / Q}{dP / P}$$

where P is price and Q is quantity.

As new water schemes are commissioned, the average cost per unit (long-run average cost or LRAC) is likely to increase due to more expensive projects succeeding cheaper projects. On the other hand, over the life-span of each project the short-run average costs (SRAC) may reduce as consumption increases and more efficient use of facilities occurs (Fig. 3).

Effects of metering

Those consumers who pay average cost will tend to use more than those paying higher marginal cost. If the water is metered, it is the (long range) marginal cost to the consumer which influences

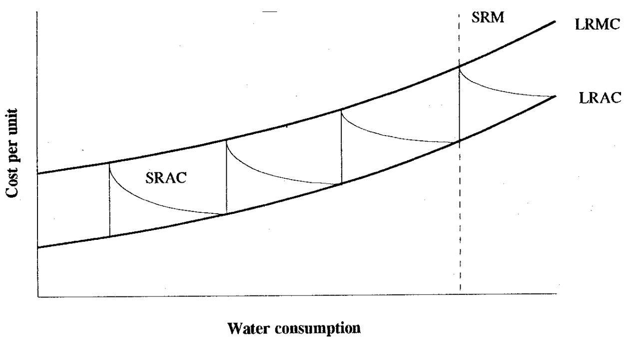

Figure 3
Short-run average costs of water supply

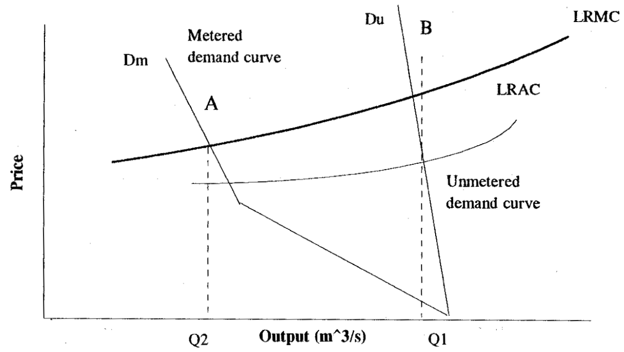

Figure 4
Demand curves with and without metering

the consumption (Fig. 4). If it is unmetered, public responsibility, which is related to LRAC, influences consumption (Q_1).

The marginal cost of not metering is area ABQ_1Q_2. This may be compared with the cost of metering.

Actually the marginal cost varies slightly with metering, so the comparison is a bit more complicated (see Henderson Sellers, 1979).

Management by use of water tariffs

If the true value of water to consumers could be assessed, it may be possible to charge a limiting tariff. This method could be applied on a long-term basis or less effectively for short-term (crisis) demand reduction. However, one must be careful of applying crisis criteria persistently. Some consumers may locate their organisation based on indicated water tariffs but the use of variable tariffs to manage water during drought, for example, must be explained and incorporated within the overall tariff system.

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

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 be able 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 for excess consumption, whereas richer or industrial consumers would pay considerably more. The tariffs would have to be based on the economic value to all consumers. Dandy and Connarty (1994) indicate increased tariffs reduce consumption but to a limit.

Hong Kong's experience with tiered tariffs (Chan, 1997) is that the resulting demand management is limited. But they were limited by having to keep charge levels within inflation. Their most successful experiment in saving water was to use sea-water for flushing. Tucson's experiments with block rates also failed due to the politicians' control on maxima (Agthe and Billings, 1997), but their summer rate differential reduced consumption. Australia is also experimenting with demand management (Duncan, 1991). Locally, Hermanus is experimenting with water saving plumbing devices.

In fact water pricing experiences throughout the world (Dinar and Subramanian, 1997) show that external objectives of politicians or administrators can destroy the efficiency of water use control through tariffs. Increasing prices can instead be intended for many purposes, e.g. financing new schemes, becoming financially self-sufficient or cross-subsidisation.

In the long run, 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 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.

The effectiveness of economic methods to control use will vary with the consumer. Industry may be most sensitive to price increase, whereas poor people will hardly be able to adjust their consumption even though they may find it difficult to pay. The richer domestic consumer is likely to have most elasticity in demand, but this is likely to constitute a decreasing proportion of the total.

In order to put objectiveness into water tariffs, Bahl and Linn (1992) suggest a five-part tariff based on:

Variable costs:	Consumption
	Maintenance
Fixed costs:	Connection
	Development
	Upgrading

The above basis is, however, not sufficiently detailed to control use or obtain a method of cost allocation. There are other factors which affect water tariffs, e.g.

- Capital and operating costs
- Opportunity cost
- Time-of-use or peak-load basis (Eskom, 1994)
- Size of property (e.g. Lumgair, 1994)
- Size of connection
- Zoning of district or purpose of use
- Timing of application
- Investment reserve
- Conservation
- Environmental
- Foundation consumers
- Insurance to ensure continuity during shortfalls
- Capacity allocation (Dudley, 1990)
- Tiered
- Cross-subsidisation of income groups
- Location

Timing of water tariff establishment

There are three stages during which the tariff for water needs consideration (Table 1 summarises which methods of demand management are applicable to which occasion).

• Long-term (planning and design)

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 sources and levels of assuredness will be compared. This section 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. 5) (Berthouex, 1971).

TABLE 1 DEMAND MANAGEMENT METHODS AND THEIR USE			
Method	**Crisis management (Drought, non-payment)**	**Operational time-frame**	**Long-term (Planning and design)**
Technical	Pressure reduction Scheduled use Valve closure	Flow control Orifices	Metering Loss control Plumbing devices
Social	Appeal Social persuasion Advertisements	Legislation	Consumer education
Economic	Fines Punitive measures	Differential tariffs Trade	Supply-and-demand economics Marginal prices

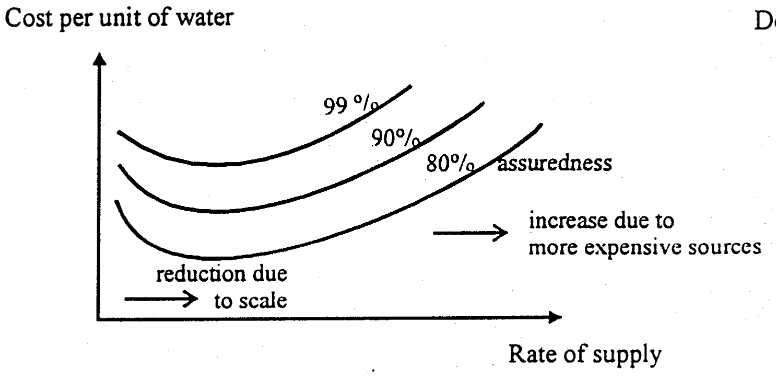

Figure 5
Effect of assuredness on cost of water

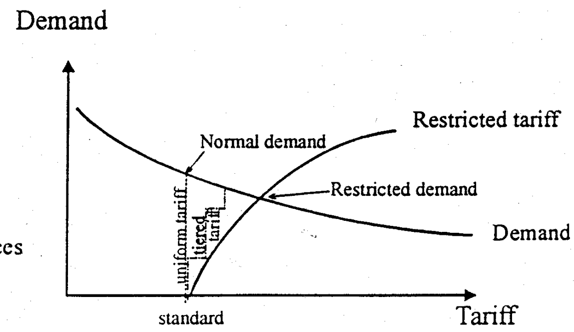

Figure 7
Effect of restrictions on cost of water to supplier

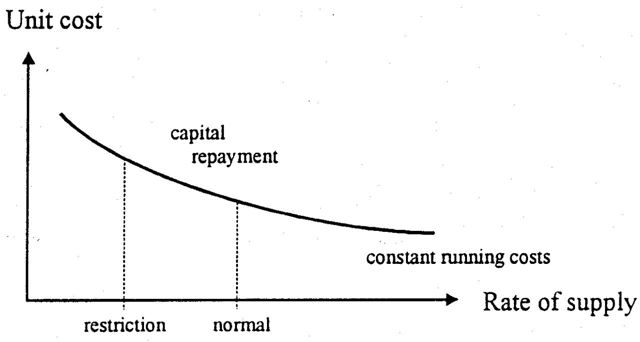

Figure 6
Effect of tariff on consumption

• Operational time-frame

Once the scheme (e.g. dam and waterworks) 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 the supply rate increases and hence the tariff could be reduced if it were solely to meet fixed repayment costs. However, 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. The tariff may be consumer orientated or tiered (Fig. 6 shows the resulting effect).

• Crisis management

When there is a shortage at the source, e.g. during a drought, then there could be rationing of water but at the same time the authorities have to meet fixed costs. The tariff may have to be increased (see Fig. 7).

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.

- ***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.

The problem of time lag arises with crisis management by means of tariffs. Following the establishment and promulgation of punitive tiered tariffs to meet a certain requirement, it may be months before the tariff is charged, detected and evaluated by a consumer. He will then change his consumption, but possibly not by the amount desired by the biller. So the process may be iterative.

The cost of water

To control use of water by means of tariffs requires estimating the marginal value of water as well as the marginal cost. The components which make up the supply cost of water include (see also Table 2):

- Capital costs
- Operating costs
- Quality control, purification, pressure maintenance, supply rate including 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 and to ensure continuity of supply or jobs.
- To cross-fund, e.g. other department's shortfalls, or redistribution of charges.

The historical basis on which tariffs are calculated is generally the cost of supplying the water (Stephenson, 1995). However, there is the possibility 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 Development Group, 1994). 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 alternating 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 make 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.

Historical water costs vary enormously throughout the world, and it is difficult to compare them internationally. They depend on the cost of installations at the time, inflation since then, the standards of supply and the ability of the consumer and government or authority to meet costs.

The cost of municipal water in Europe is of the order of R5/m^3 (US 80c) and more in Germany. In South Africa it is less than R3/m^3 (US 50c), and elsewhere in Africa it is sometimes free. An affordability of 1 to 2% of income is a yardstick in developed countries, but in some developing communities they may pay up to 10% of their income.

The methods developed for justifying water resource projects, particularly in the United States in the mid-20th century, were based on comparing benefits and costs of projects before ranking them or deciding on the scale or priority of development. Whether these techniques can be applied to water supply is doubtful. In particular the evaluation of benefits which cannot be cashed in on could distort the market. It could result in over-expenditure or power-building in government centres which fund water supply projects. At the most for water supply, it should be used for ranking projects but the social impact needs to be evaluated for inclusion in the decision-making process.

When trying to assess the value of water to a user with regard to curtailing supply, the true long-term value may not be the applicable figure. The user will only consider his operating benefits minus costs, since capital expenses cannot be avoided. He will also consider primarily cash benefits, since intangible benefits, e.g. education, are long-term. So it is important to distnguish between long-term and short-term benefits as well as tariffs.

The principles of economics, however, should be used for comparing projects and optimising supplies. Thus the possibility of alternative sources or intercatchment transfers may have to be compared in some fashion.

TABLE 2
WATER PRICING CAN BE BASED ON ANY OR ALL OF THE FOLLOWING

Supply costs	Charges	Controls
DIRECT		
Dams	Sale of natural resource for income	Differential tariffs
Pumping	Prevention of over-exploitation	Subsidisation
Pipelines	Cost of alternative sources	- communities
Reservoirs	Cost of depletion	- localities
Purification	Fines	- relocation
Administration	Pollution - cost of purification	- use type
Repairs and maintenance	Environmental restitution	- higher marginal cost
Upgrading	Control of usage	Drought rationing
Land	Economic benefits	
INDIRECT	- health	
Financing	- time	
Risk minimisation	- education	
Standby equipment	- commercial	
Monitoring	Taxes	
Future more expensive sources	Affordability	
Commissions	Permits	
Mismanagement	Willingness	
Inefficiency	Bearability	
HIDDEN (NOT CHARGED)		
Labour disruption during construction		
Rerouting communications		
Loss of land surface		
Loss of future potential		
Alternative uses of water		
Environmental impact		
Wastewater disposal		
Siltation		

Benefits
Income
Health
Improved quality of life
Time - education
- leisure
- economically productive
Commercial and industrial development
Agricultural
Power generation
Environmental

The benefits and costs of water supply are not easy to evaluate (see Gibson, 1987). Table 2 lists some of these. The costs can vary not only for the direct installation costs but also the social impact costs. These could be as obscure as changing social customs due to different methods of water collection. There are also changing population demographics which are difficult to evaluate, and the interruption of the economy by providing temporary construction employment. The river patterns may change if the water is dammed. This may affect agriculture. The environment is affected whether it is due to burying pipelines or construction of structures. More particularly, it is affected by the change in hydrology if the demand is surface water. Ground-water is also obviously affected and the effects are not as readily seen in the short term, but in the long term it could have severe environmental implications.

There are also opportunities lost as the water cannot be used for other purposes and also future planning will change owing to the lesser availability of water. Costs of planning also need to be considered in the total system cost and if all direct, indirect and hidden costs were included, it is likely that the level of water supply would be reduced in many countries. On the other hand, the benefits of providing water are many. Not only are they those listed below but also they have a multiplying effect in parallel with many services. That is, money is injected into the economy, the level of development increases, the standards of living increase, expectations increase and therefore the entire economy is provided with an injection. Of course, there is also the effect of increasing price leading to lower consumption (Postel, 1985).

The human rights issue means that if water is to be provided to all, then it must be marketed at affordable rates, which vary considerably. It therefore appears that some form of differential tariff system would be required whereby the richer subsidised the poor. This could be disguised in various ways. For example, incremental water consumption would be charged at a higher and higher tariff. This assumes that the full cost is to be recovered by the water supplier. Subsidisation by the government could further complicate the issue. This in fact may be necessary if the policy is set by the government.

An alternative to the cost recovery pricing system would be the production cost pricing system. This would imply that prices were pushed up to reflect the value of water to the consumer, whereas the price may not be pushed to the limit of affordability, it would reflect some value to the consumer (see Mirrelees et al., 1994).

The third alternative is the water scarcity pricing system whereby the price of water is increased to reflect its value (see Berk, 1981). This may be on a permanent basis or temporarily during drought. Unless a thorough understanding of the affordability of water is obtained then the price to limit consumption during scarcity maybe a matter of trial and error.

The problems of setting affordable tariffs, particularly to poorer communities, will draw in the following considerations:

- Adequate quality of service, that is pressure and flow.
- The possibility of upgrading the system as living standards or affordability improve.
- Labour-orientated construction to inject money into the community.
- Flexibility to ensure that various levels of demand are satisfied to their standard.
- Charging for services to recover what is possible, but also to instill a sense of value.
- This may involve prepayment systems or flat rate systems to simplify collection of rates.
- Speed of delivery which is a function of financial resources and technical resources.

The problem of non-payment for water complicates the issues - the cost must be borne by others until pressure is sufficient to right the problems causing non-payment.

Methods of subsidising water costs vary. If the subsidiser does not want to become involved in the politics, he may subsidise the water supplier and this could be by means of direct payments or reducing taxes or cost of raw water. The alternative of payment to the consumer is complicated not only by administration or the need to appear equitable and just, but also in the method of payment. It would appear more logical to subsidise indirectly, that is by reducing taxes or providing other services to reduce expenditure. Donors often subsidise the capital cost of the system, particularly rural water supply schemes. It is also not easy to decide how to discriminate between recipients subject to different levels of subsidisation. In many cases abuse of the system needs consideration (misappropriation or resale).

Risk

The value of water to a consumer is influenced by risk (Cotruvo, 1989). If there are frequent interruptions (due to breakdowns) or lengthy rationing (drought) or pressure drops or pollution, or high tariff increases, the value is diminished. Unfortunately, supply authorities generally give no indication of these or the associated probability of occurrence. Some are catered for, e.g. emergency storage, and others may be completely unknown, e.g. future price increases.

Conclusions

The future is likely to see increasing water costs in SA. This will automatically reduce consumption. The theoretical correct way to control consumption would be to charge marginal costs on the top consumption, but the administration and lifeline requirements make this difficult.

Conflicting objectives make economic methods impractical for accurate day-to-day control, but economics can be used in the longer term.

Physical ways of limiting consumption (pressure reduction, cutoff) are only applicable in periods of crisis, and long-term education of consumers is seen as a necessity.

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Evolving from the Decision Theory School, the Mathematical School gives a quantitative basis for decision-making and considers management as a system of mathematical models and processes. This school is also sometimes called, â€˜ Operations Researchâ€ or â€œManagement Science Schoolâ€™. The main feature of this school is the use of mixed teams of scientists from several disciplines.