Factors affecting the cost of water supply to Gauteng

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Abstract

The cost of water to Gauteng has continued to increase over time owing to new sources being more remote and due to cost inflation. The savings due to increased scale of supply and improved technology have been dwarfed. Methods of minimising the cost of water conveyance and distribution are discussed. Factors affecting the cost are documented and guides for supply engineers are given. The possibility of lower marginal costs being exploited for poorer sectors of the population is mentioned but demand management and pricing policy are not covered.

Introduction

Considerable research and discussion have taken place on the subject of water costs in South Africa in recent years. This is largely because of the policy set out in the Reconstruction and Development Programme (1994) to supply the bulk of the population with potable water. This paper attempts to establish the basic costs of water using Gauteng as an example. The different components of cost and how they effect prices are indicated. Costs may therefore be minimised so that, based on the law of supply and demand, the supply can be maximised.

Water supply could also be extended to those previously excluded especially if costs could be re-distributed by a suitable tariff structure.

One of the aims of the RDP is to supply everyone in South Africa with 25 ℓ of potable water per day within a radius of 200 m of their residence. The cost of supplying the 12 m. people in South Africa who at present do not have clean drinking water is estimated to be between R1 bn. and R10 bn. Cost minimisation and optimisation are therefore important.

Some aspects of different water tariffs

The "cost" here is taken to be the cost to the supply authority. This may not be the same in total or what could be incrementally charged to consumers.

The tariff charged for water can influence the cost (consumer management effect), since it can influence the amount of water consumed.

There has been discussion on alternative tariffs to make water affordable to everyone. These include lifeline tariffs for the poor and progressive block tariffs with cross-subsidies for increasing consumption. In rural areas it may only be possible to charge the costs of operating and maintenance while capital recovery could be by cross-subsidy from urban areas. The financial implications are great.

It has been implicit in some discussions that the marginal cost of additional water could be lower than the average cost. The Palmer Development Group (1994) replace marginal cost by average incremental cost (AIC). It is shown that it is not always necessary that increased scale of supply reduces the cost nor that the incremental cost is much less than the average cost. At present most authorities charge average historic costs (AHC) which is, as the name implies, averaged over consumers to meet the costs incurred by the supply authorities.

Exactly what the marginal cost is, is subject to debate. On a new pipeline it is the extra cost of providing extra water, which (see **Appendix**) is 80% of the average cost per litre. In the case of an existing infrastructure it may be the cost of tapping new sources including all the associated engineering works. Then the marginal cost is likely to be more than the average historic cost.

The conflict between reducing costs due to increased scale and increasing costs due to sources further afield is discussed. For instance, whereas the average cost of raw water to the Gauteng area is about 39c/kℓ, the Lesotho Highlands Water Authority suggests that the marginal cost of raw water is R1.50/kℓ, based on the furthest source for obtaining additional water.

Triebel (1994) indicated that because water supplies in South Africa are by monopolistic authorities, they have no inducement to charge marginal costs. He assumes that the marginal cost is less than the average total cost. However, he suggests that tariffs could range from subsidised lifeline tariffs through to full cost recovery at market worth by consumers who can afford it. The different tariffs suggested by Asmal (1994) are broken down into a stepped tariff ranging from 50c/kℓ to 350c/kℓ. Triebel (1994) suggests a social tariff for consumption of less than 30 ℓ/capita·d with the normal tariff applying up to 250 ℓ/capita·d and an excess tariff above this figure. The costs to industry would be more difficult to determine.

The use of stepped tariffs for cross-subsidisation is a relatively new idea whereas the use of increasing tariffs for minimising the use of limited resources has been applied in Gauteng when droughts forced the restrictions on the use of water.

Water tariffs in South Africa are generally based on one or more of the following (Lumgair, 1994):

Per kℓ of consumption
Per erf
Erf area
Connection size
Per connection
Function of zone

Figure 1 shows the influence of the three major technical factors on the cost of a water scheme. For example, the cost of water is a function of the volume delivered as well as the peak rate of flow.

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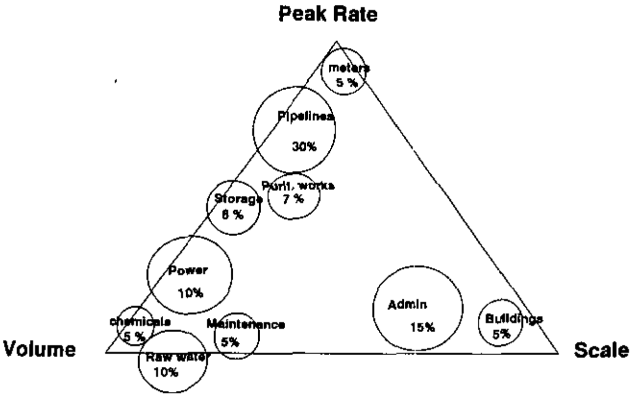


Figure 1
Influence of three technical factors on cost of water scheme

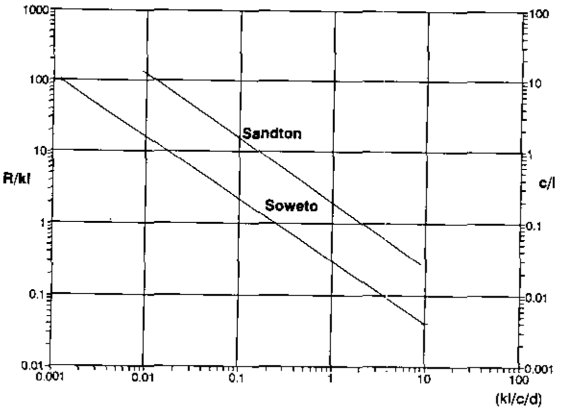


Figure 2
Effect of price on water demand

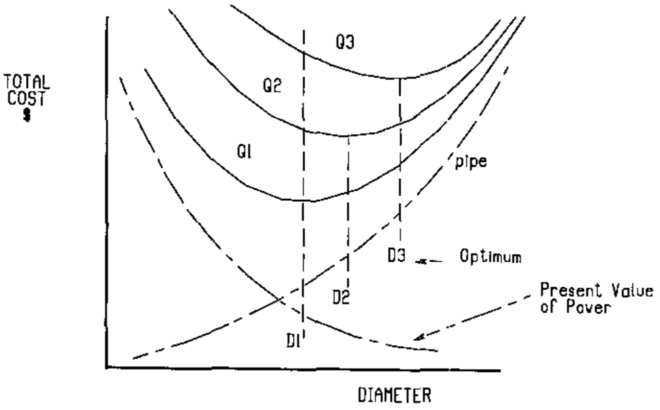


Figure 3
Optimisation of diameter of a pumping pipeline

It is also affected by the scale (magnitude) of supply. The larger the rate of supply generally the lower the unit cost. The relative value of the three technical components on the costs of different components of the system is indicated by the position of the diagram. The diagram does not cover non-technical factors such as financing, i.e. interest rate and period of redemption of loans. It does not consider the cost of risk which can be an important factor and must be allowed for in the cost of the supply, i.e. if consumption is not up to the estimate, the cost of water will be higher.

Berthoux (1971) considered that risk could be accounted for by increasing the effective discount rate in the financial analysis. The rate of increase in demand will also affect the cost of the water to the consumer since the load factor (ratio of average supply rate to capacity of the system) increases as the capacity of a scheme is used up. Other factors affecting the cost of water to the consumer include losses, i.e. leakage and unaccounted-for water. The quality of the raw water and the supplied product also affect the cost.

Bahl and Linn (1992) suggest a five-part tariff based on:

Variable costs:
Consumption
Maintenance

Fixed costs:
Connection
Development
Upgrading

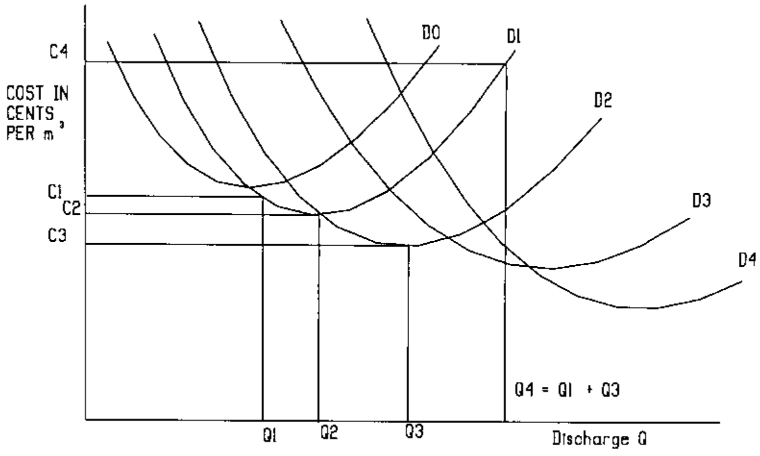
The above basis is, however, not sufficiently detailed to control use or to obtain a method of cost allocation. Bahl and Linn (1992) further indicate that resources are most efficiently allocated when the price is set equal to the marginal cost. On the other hand Dandy and Connerty (1994) indicate increasing consumption with reducing price (See Fig. 2 where the author has attempted to illustrate the marginal value of water to different income classes in Gauteng, by guessing how much each would be prepared to pay, based on usage in different locations in SA).

There is an interaction between supply and demand which is more complicated than suggested by Dandy and Connerty (1994). Whereas this paper presents the picture from the supply management point of view, the demand can equally influence costs. Increased demand on any installation could reduce costs (Fig. 4 is explained later) or it could be accommodated by price increase to reduce demand. The latter should be considered as an interim measure until other possibilities (new supplies or recycling) are evaluated and compared with the economic cost of rationing water.

System optimisation

Costs of supply should be minimised by selecting the optimum pipe dia., reservoir size and pumping rates. The bulk of the cost of water to Gauteng lies in the pipeline costs (Fig. 5). A pumping main dia. should be selected by minimising the total capital plus operating costs brought to a common time basis. Figure 3 shows how the minimum cost system is selected by adding the pipeline cost, which increases with size, to the operating (mainly power) cost which decreases with increasing pipe dia. owing to decreasing friction losses. Other factors which have to be considered in the optimisation are the relative pipeline capacity and storage volume at the end of the pumping line. With no storage it is necessary to pump at the instantaneous peak rate which maximises the pipe cost, whereas with increasing storage and therefore reservoir costs the pipeline operating factor (ratio of average pumping rate to peak) can be increased and therefore the pipe dia. minimised. Another factor which has to be optimised is the time horizon for which the system is planned (Stephenson, 1989). It is not worthwhile planning too far into the future because the system will operate at a low load factor initially pushing up the unit cost of water. On the other hand too short a time-span between successive increments in the system

Figure 4
Optimisation of throughput for certain diameters



capacity means that the advantage of scale is not achieved.

The economic minimum may be obtained as in Fig. 3. After a pipeline is constructed, the decision on whether to and when to increase the capacity of the system is more complex. The data in Fig. 3 are re-plotted in Fig. 4 as a cost in c/kℓ of water supplied vs. flow rate. The optimum dia. D1 from Fig. 3 for a flow rate of Q1 will be the lowest curve at point Q1 in Fig. 4. However, that cost in c/m^3 can be reduced even further by increasing the capacity of the pipeline. It could thus pay to boost through a pipeline rather than to install a second pipeline, and this situation could continue until some flow rate Q4 when it becomes more economical to install a duplicate pipeline. It can be shown that the cost per unit delivered for any pipeline is a minimum when the pipeline cost expressed as an annual basis is twice the annual cost of power used in overcoming friction (Stephenson 1989).

The components making up the cost of a pipeline vary widely from situation to situation but for water pipelines in open country and typical conditions could be as follows:

Supply of pipe	-	55%
Excavation	-	20%
Laying and jointing	-	5%
Fittings and specials	-	5%
Coating	-	2%
Structures (valve chambers, anchors)	-	2%
Water hammer protection	-	1%
Land access, security	-	1%
Engineering and surveys	-	5%
Administrative costs	-	1%
Interest during construction	-	3%

For water pumping mains the flow velocity at the optimum dia. varies from 0.6 m/s to 2 m/s, depending on flow and working pressure. It is about 1 m/s for low pressure heads and a flow of 100 ℓ/s increasing to 2 m/s for a flow of 1 000 ℓ/s and pressure heads about 400 m of water, and may be even higher for higher pressures. The capacity factor (ratio of actual average discharge to design capacity) and power cost structure (Lotz et al., 1992) also influence the optimum flow velocity or conversely the dia. for any particular flow.

In planning a pipeline system it should be borne in mind that the scale of operation of a pipeline has a considerable effect on the cost. If the head remains constant and the dia. is doubled, the capacity increases sixfold. On the other hand the cost approximately doubles so that the cost per unit delivered decreases to 1/3 of the original. Whether it is in fact most economical to install a large dia. main at the outset depends on the following factors as well as scale:

- Rate of growth in demand (it may be uneconomical to operate at low capacity factors during initial years).
- Operating factor which can be improved by installing storage at the consumer end.
- Reduced power costs due to low friction losses while the pipeline is not operating at full capacity.
- Certainty of future demands.
- Varying costs with time (both capital and operating).
- Rate of interest.
- Physical difficulties in the construction of subsequent pipelines.

In waterworks practice it has been found economical, i.e. to minimise costs, to size pipelines for demands up to 10 to 30 years hence. For large throughput and high growth rates, technical capabilities may limit the size of the pipeline, so that duplication may be required earlier. Longer planning stages are normally justified for small bores and low pressures.

It may not always be most economic to lay a uniform bore pipeline: where pressures are high the dia. can be reduced and consequently the wall thickness. Hence the dia. could vary over the length of the line.

The capacity of the pipeline may often be increased by installing booster pumps at a later stage although it should be realised that this is not always economical, i.e. minimising costs. The friction losses along a pipeline increase approximately with the square of the flow, consequently power losses increase considerably for higher flows.

If at some stage it is desired to increase the throughput of a pumping system, it is convenient to replot data from Fig. 3 in the form of Fig. 4. Thus for different possible throughput, the cost, expressed in c/kℓ or similar, is plotted as the ordinate with alternative (real) pipe dias. a parameter.

Referring to Fig. 4, the following will be observed:

- At any particular throughput Q_1 there is a certain dia. at which overall costs will be a minimum (in this case D_1).
- At this dia. the cost per m^3 of throughput could be reduced further if throughput were increased. Costs would be a minimum at some throughput Q_2. Thus a pipeline's optimum throughput is not the same as the throughput for which it is the optimum dia.
- If Q_1 were increased by an amount Q_3 so that total throughput

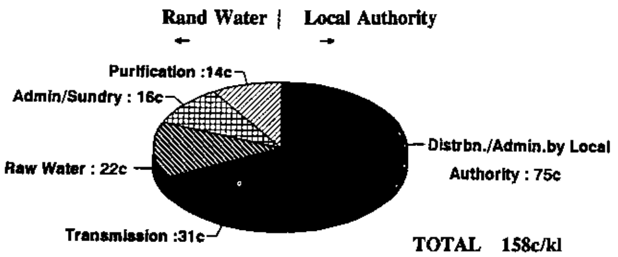


Figure 5
Components of cost of water to Gauteng 1994

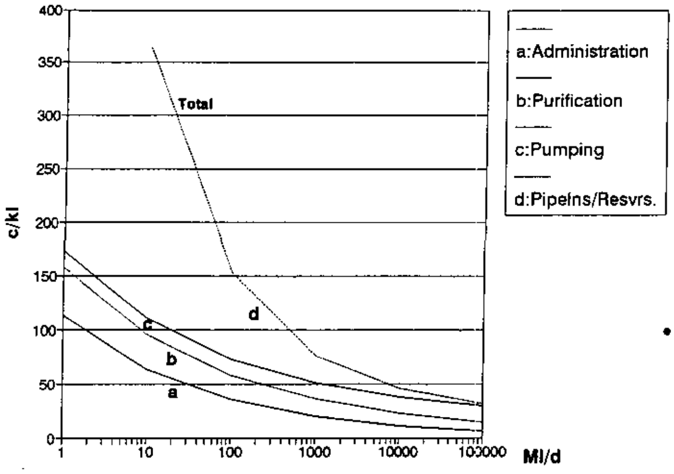


Figure 6
Typical effect of scale on bulk water supply costs (excluding raw water)

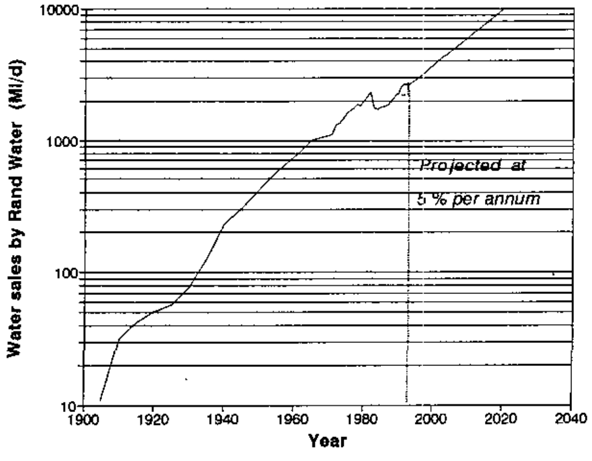


Figure 7
Water sold by Rand Water

$Q_4 = Q_1 + Q_3$, it may be economical not to install a second pipeline (with optimum dia. D_3) but to increase the flow through the pipe with dia. D_1, i.e. Q_4C_4 is less than $Q_1C_1 + Q_3C_3$.

- At a later stage when it is justified to construct a second pipeline the throughput through the overloaded line could be reduced to the lowest cost per m^3.

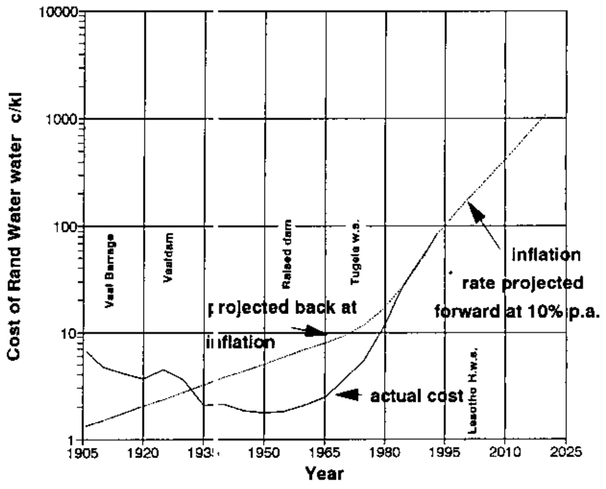


Figure 8
Cost of water from Rand Water

- The power cost per unit of additional throughput decreases with increasing pipe dia. so the corresponding likelihood of it being most economical to increase throughput through an existing line increases with size (White, 1969).

The cost of water to Gauteng an as example

The average cost of water in Johannesburg in 1994 was about 158c/kℓ. A breakdown of the components in that cost is given in Fig. 5. It will be noted that a major component is the distribution of water by the local authorities who purchase it from Rand Water who in turn purchase raw water from the Department of Water Affairs and Forestry.

The effect of scale of supply on costs is not all that marked at the scale at which Rand Water supply. This is because it is not just one source or one pipeline through which the water is supplied and alternative sources are tapped for different sub-regions. Figure 6, however, shows a hypothetical case of how the costs of bulk supply could increase for smaller scale water-supply schemes. This is because the cost of pipelines per unit delivered is higher the smaller the dia. (see **Appendix**)

It may be shown that the cost of water through a pipeline is approximately proportional to the length times dia. squared. The discharge rate at any fixed head is proportional to the dia. to the power of 5/2 so that the cost in c/kℓ delivered is proportional to the dia. to the power of 1/2. By differentiating the equation for cost as a function of flow rate it is also possible to show that the incremental cost of increasing the capacity of a pipeline is approximately 80% of the average cost expressed in c/kℓ (see **Appendix**). This could be interpreted as indicating that a price to less affluent communities could be made lower than the price to established consumers. However, the issues are more complex (Palmer Group, 1994). There are also advantages of health and stability in providing all with potable water (Shaker, 1993) which take the decision beyond a purely technical one.

The effect of obtaining water from further afield

As the demand for water in Gauteng increases so it is necessary to obtain water from further and further afield, each successive project being more expensive than the previous for two reasons, i.e. it is more remote and also because the costs increase yearly with

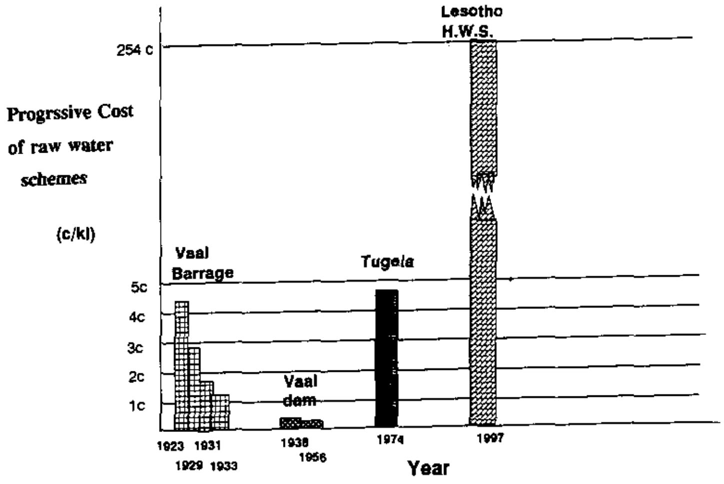


Figure 9
Progressive cost of new raw water schemes for Gauteng

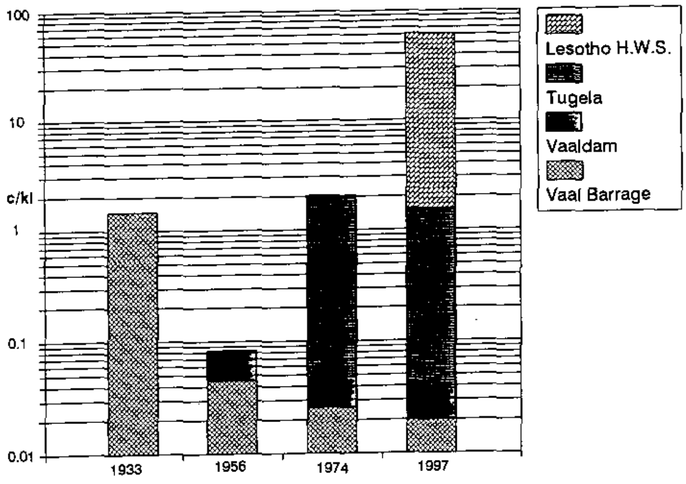


Figure 10
Costs of additional raw water schemes averaged over total supply

inflation. Figure 7 indicates the average annual water sales by Rand Water since 1905. The rate of increase has averaged 5%/a.

Figure 8 shows the actual cost of water supplied by Rand Water to its consumers which increases over the years. In order to distinguish between the effects of price inflation and having to go to successively more expensive schemes, a line has been projected back based on estimated past inflation. It will be observed that the cost of water has increased at a rate greater than the rate of inflation in South Africa since 1955.

Figure 9 indicates the cost of successive raw water schemes tapped by Rand Water. It will be observed that the cost due to obtaining water from successively more expensive sources is increasing at a greater rate than the reduction in cost due to increased scale of supply. (The cost of the Lesotho Highlands Water Project water is still an uncertainty as successive phases of the project have not been implemented and have to be compared with alternatives (Krige, 1992)). Future suggested sources of water include demineralised recycled water (e.g. R3/m^3) and Zambezi/Okavango water (+R4/m^3).

Conclusions

Despite improvements in technology and an increase in the scale of supply (Hirschleifer et al., 1960), the cost of water is not reducing significantly. The factors of inflation and increasingly more expensive supply schemes negate the benefits of improved technology and larger scale. It may be possible by studying marginal values, however, to differentiate water charges and implement a differential water tariff system (Raftelis, 1989).

Socio-economic studies could reveal a willingness to pay at various ends of the scale so that an equitable subsidisation policy could be developed (Forster and Mirrlees, 1993). At the time due regard will have to be made to water conservation and the cost of additional sources of water which is increasing to an extent that could affect further expansion (Rubinstein and Ortolano, 1984). The effect of increased consumption due to lower bulk costs does not appear to be of concern in SA, as costs and prices are likely to increase with increasing usage.

The possibility of changes in technology reducing prices has not been discussed. For example, self-help and labour-intensive installations could be cheaper than high-tech schemes and also provide hidden benefits in labour creation and training. Further advantages of water supply exist, i.e. better health and more time for education and work.

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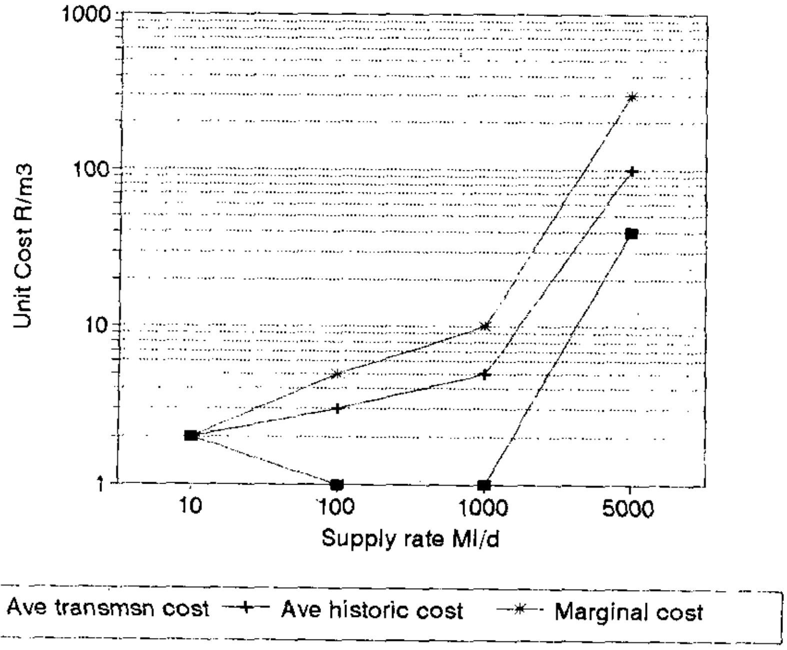

Figure 11
Comparison of cost basis

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Appendix

The marginal cost of water conveyed in a gravity pipeline may be calculated as follows:

If the head loss gradient is $S = K_1Q^2/D^5$
where Q is flow rate and D is dia.,
then:

$$Q = S^{1/2}D^{5/2}K^{1/2}$$

$$dQ = \frac{5}{2}\,\frac{Q}{D}\,dD$$

and cost:

$$C = K_2LD^2$$

$$dC = 2\,\frac{C}{D}\,dD$$

$$= \frac{4}{5}\,\frac{C}{Q}\,dQ$$

So if cost in c/kℓ is K_3C/Q, this is equal to:

$$K_3K_2K_1{}^{1/2}LD^2/S^{1/2}D^{5/2} = K_4L/S^{1/2}D^{1/2}$$

and marginal cost (incremental cost of water) in c/kℓ is:

$$K_3dC/dQ = 0.8\ K_3C/Q = 0.8\ K_4L/S^{1/2}D^{1/2}.$$