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LAHORE WATER SUPPLY - TARIFF STUDY

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Central Projects Staff
Public Utilities Department

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LAHORE WATER SUPPLY - TARIFF STUDY

ABSTRACT

This note is the report of a mission which examined water supply and sewerage pricing policy in Lahore, the intention being to provide guidance on economic aspects of tariff setting to the engineering and financial consultants hired by the Lahore water supply authorities. The report analyzes the way in which marginal cost should be estimated, given the reliance of Lahore upon ground water supplies, and indicates the engineering and hydrological data that need to be collected in order that this may be done. It then discusses the implications for tariff policy of illustrative estimates of marginal cost, special emphasis being placed upon the metering decision.

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August 7, 1974
I. INTRODUCTION

1.01 Charging for water supply involves problems of finance, of fairness, of administrative feasibility and of efficient resource allocation. This report concentrates mainly on the fourth of these topics; it therefore considers in some detail the nature and structure of marginal costs and the metering decision.

1.02 The fact that this report does not devote equal space to all the issues is explained by its purpose. It is not in itself a complete tariff study. Such a study is now to be undertaken and this report is merely intended to guide those who are to work upon it. It thus proposes few conclusions. Its aim is to explain and introduce those economic concepts which will form one important and very necessary part of the full study and which are less well known than they should be.

II. MARGINAL COSTS OF WATER SUPPLY

2.01 The aim of this section is to show how marginal production costs may be calculated with the aid of numerical examples. The figures used are not all realistic, some being purely imaginary, so they do not provide a correct answer but merely illustrate the principles and method of calculation. The consultants will therefore need to make their own calculations using figures provided by engineers and using the following exposition as a guideline.

2.02 The capital costs of a new tubewell are approximately as follows. The cost of the site is not included, but should be. If it is on land already owned the relevant cost is what the land could be sold for. The figures relate to an electric pump and would be slightly different for one powered by a gas motor.

<table>
<thead>
<tr>
<th>Cost Description</th>
<th>Rupees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinking and lining well</td>
<td>150,000</td>
</tr>
<tr>
<td>Well chamber</td>
<td>55,000</td>
</tr>
<tr>
<td>Pump and motor, including</td>
<td>105,000</td>
</tr>
<tr>
<td>installation</td>
<td></td>
</tr>
<tr>
<td>Chlorination equipment</td>
<td>30,000</td>
</tr>
<tr>
<td>Mains link with system</td>
<td>52,000</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>392,000</td>
</tr>
</tbody>
</table>
2.03 These costs relate to a well with a rated capacity of 4 cusec at 210 ft. head, i.e. 2,160,000 gallons/day. The actual yield from such a well will however differ from this for a number of reasons:

(a) Low voltage will reduce output or, below 370 V, require the pump to be stopped in order to avoid damage to it;

(b) Repairs to the pump or motor or treatment of the well will occasionally interrupt supply; there is also a daily interruption of about half-an-hour for lubrication, etc.;

(c) At times of high demand (summer daytime) the head will be much lower than 210 ft., more nearly 165 ft., and the pump will then deliver 6 cusecs, i.e. a daily rate of 3,240,000 gallons;

(d) At times of low demand (winter nights) about half of the pumps are switched off after 9 p.m. and another 20% between 10 and 11 p.m. in order to avoid too great a rise in pressure;

(e) Incrustation of the well screens will gradually reduce efficiency by 5% a year. Efficiency can now be partially restored by occasional rehabilitation treatment however, so that in future tubewells will have a useful life nearer 20 than 10 years;

(f) The gradual decline in the water table will increase the head, so lowering the amount of water produced by a given pumping effort.

2.04 We are not in a position to quantify most of these factors. Possibly the most important single piece of information - the actual output of tubewells - could easily be obtained by metering them. This is not now done. Other information may be much more difficult to obtain, especially item (f). In order to construct an example we therefore proceed by guessing that in its first year, a new tubewell will supply an average of 2,200,000 gallons a day and that if the water table did not fall (we come back to (f) later) it would yield only 2,100,000 gallons per day in its second year (and less in each subsequent year). This is the additional yield rather than the amount actually pumped from a new well, which will be somewhat greater. The reason is that a new tubewell has a greater efficiency than older ones, so that it is the latter which are turned off at night in winter. Thus a reduction in the night operation of older ones involves a corresponding reduction in energy consumption. The value of this saving, though neglected below, ought in principle to be included as a negative cost item for a new tubewell.

2.05 Under these circumstances, for each extra tubewell added to the number constructed in a year, a subtraction of 21 of a new tubewell in the following year would:
(i) Increase the amount pumped in the first year by 2,200,000 gallons a day on average; and

(ii) Leave approximately unchanged the amount pumped in subsequent years.

We can thus obtain an approximate estimate of the marginal capacity cost of pumping 1,000 gallons by taking the cost of a new tubewell, subtracting 21/22 of the discounted cost of a new tubewell constructed a year later and dividing by the amount pumped in a year in '000 gallons. This is defined as one year's interest plus economic depreciation (which may differ from conventional accounting depreciation) per 1,000 gallons. Using constant prices and a discount rate of 10% to reflect the scarcity of capital in Pakistan, this gives us:

\[
\frac{392,000 - \frac{21}{22} \times 392,000}{365 \times 2,200} = 6.4 \text{ paisas per 1,000 gallons}
\]

2.06 To this must be added one year's operating and maintenance costs of a 1 cusec tubewell. If these amount to 240,000 rupees for electricity plus 50,000 rupees for labor, lubricants, spares, etc., the cost is:

\[
\frac{290,000}{365 \times 2,200} = 36.1 \text{ paisas per 1,000 gallons}
\]

This gives a total marginal cost per 1,000 gallons pumped of 6.4 + 36.1 = 42.5 paisas. If leakage amounts to 25%, the cost per 1,000 gallons supplied to consumers is 1/3 of this, namely 56.7 paisas. This figure, it should be noted:

(i) Excludes distribution costs;

(ii) Leaves out the complication of a declining water table;

(iii) Is purely illustrative and needs to be recalculated by the consultants using the best data available.

2.07 Before turning to consider points (i) and (ii), the principle behind the calculation requires explanation. Marginal cost is defined as the addition to system costs per additional 1,000 gallons supplied to consumers in the year in question, given the amount supplied in subsequent years. The calculation merely provides a simple approximate measure of this concept. Hence the apparent unreality of 21/22 of the cost of a tubewell does not matter. We could equally well have proceeded by saying that if, for example, 5 five-year old tubewells would yield the same as 4 new tubewells, the discounted average over five years of marginal production capacity cost

1/ Constant prices are used in all calculations in this paper, because we are primarily interested in real resource costs. Sensitivity of the results to variations in the discount rate should be tested.
could be calculated by subtracting the cost of 4 tubewells, discounted for five years, from the undiscounted cost of 5 tubewells. Such a calculation would apply the same concept. This cost difference would be the cost of pumping an extra 2,200,000 gallons this year, plus an extra 2,100,000 gallons next year, plus extra amounts of decreasing magnitude in each of the remaining three of the five years.

2.08 We now turn to the complication of the decline in the water table. This involves questions of hydrology where we are ignorant, so what follows has to be couched in very general terms. We gather that the rate at which water is pumped depends on:

- initial pumping capacity used and its age (because of declining efficiency with age);
- delivery head; and
- the depth of the water table.

This latter factor in turn depends, among other things, on the past history of the amount of water pumped. The more that has been pumped up till now, therefore, the lower will be the water table and so the lower will be the rate at which water is pumped for any given pumping capacity and age and any given delivery head.

2.09 If this is correct, it follows that the additional pumping by one new tubewell will slightly reduce the amount pumped by the system as a whole in subsequent years. This involves a cost. The extra tubewell now necessitates a fractional increase in pumping capacity in subsequent years in order to avoid the reduction in these future years. Hence the cost of installing and operating this fractional extra capacity is part of the cost of the extra 1,650,000 gallons a day (i.e. after allowing for leakage, 3/4 of 2,200,000) provided to consumers by the new tubewell. Once again, this fits in with the concept of marginal cost as the effect on system costs of providing more water now, given the amount to be provided in future years.

2.10 The marginal production cost of 56.7 paisas therefore needs to be increased by the discounted marginal cost of the future reductions in system output that would be caused by supplying an extra 1,000 gallons now, i.e. of pumping an extra 1,333.3 gallons of which 333.3 leaks back into the ground, and which may or may not replenish the aquifer. Thus if marginal cost is \( m \) and if these reductions next year, the year after and so on are \( d_1 \), \( d_2 \), \( d_3 \), etc., we have:

\[
m = 56.7 + \frac{m d_1}{1.1} + \frac{m d_2}{1.21} + \frac{m d_3}{1.331} + \cdots
\]

hence

\[
m = \frac{56.7}{1 - \frac{d_1}{1.1} - \frac{d_2}{1.21} - \frac{d_3}{1.331} - \cdots}
\]
Thus some estimate of $d_1, d_2, \ldots$, however rough, is needed in order to find marginal cost, $m$.

2.11 It is very important to note that the "system" which is relevant here is the whole aquifer, not just LIT. LIT's own marginal cost may have to be used in the calculation, but the $d$'s are the declines in the output of all tubewells in the area, not only LIT's. Each $d$ is the effect of supplying an extra 1,000 gallons in one year on the level of the water table in a subsequent year multiplied by the effect of a unit change in that level on the total amount of water pumped by all the tubewells in the system in that subsequent year. The first of these factors is a matter for a hydrologist, the second for an engineer.

2.12 Since the purpose of the calculation is to provide an estimate of marginal cost at today's prices, and since at least in the near future tubewells will not differ much from today's, one single value of $m$ is used in formula (1) to derive formula (2).

2.13 There is an additional cost involved in lowering the water table. It will interfere with the hand pumps and bucket wells of people who do not have piped water, mostly poor people. The best way to look at this cost may be to say that it would be unfair to penalise them at the expense of LIT's consumers so that these consumers, through LIT, ought to bear the cost of preventing them from being made worse off. According to circumstances this might involve providing them with water by lorry, extending the system to give them standposts or deepening their wells for them. Thus the marginal cost of LIT's supply would include an item of this sort and LIT should spend it in the most appropriate way to help these people. Otherwise they could be said to be exploited by LIT and its consumers.

2.14 The marginal cost per thousand gallons calculated as 56.7 paisas grossed up by dividing by one minus the discounted sum of the $d$'s is an annual average figure. It is obvious, however, that this must conceal considerable variations within the year. It is only during the months of May, June and July, and perhaps in April and August during daytime only, that an increase in water consumption necessitates extra pumping capacity. At present, since capacity is inadequate, pressure becomes low and supply shortages occur at these times. It is therefore difficult to know how big the seasonal swing in consumption would be if pressure were always kept at an acceptable level. Some indication may nevertheless be obtained by comparing average daily consumption in December 1973-January 1974 with that in May-June 1974 for random samples of 10, 9 and 8 metered residential consumers in Gulberg, Samnabad and Ichra respectively. The percentage excesses of May-June average daily consumption over December-January were, in the same order: 29, 28 and 44. Thus the seasonal demand swing must be large.

2.15 Outside this 3-5 month period of high summer demand, extra water can be supplied at no more cost than that of extra pumping. We assume that this is approximated by the estimated annual average marginal operating and maintenance cost of 36.1 paisas per thousand gallons. Allowing for 25% leakage the marginal cost of supplying an extra thousand gallons will be
48.1 paisas, grossed up to allow for the discounted cost of the d's. This is the "off-peak" marginal cost. As calculated, this might be a slight overestimate; those costs which are incurred irrespective of the amount of water produced will, on a per gallon basis be somewhat lower during the off-peak than during the (shorter) peak period, even though the rate of consumption during the peak is higher.

2.16 Let us take the peak as equivalent to 120 days, i.e., three whole months plus the daytime hours in April and August. Suppose that during the period a new 4 cusec tubewell will pump at an average daily rate of 2,800,000 gallons. Then, proceeding as before, the marginal capacity cost per thousand gallons pumped is:

\[
\frac{392,000 - \frac{21}{22} \cdot \frac{392,000}{1.1}}{120 \times 2,800} = 15.43 \text{ paisas}
\]

2.17 To this must be added 36.1 paisas operation and maintenance costs. For reasons explained in paragraph 2.15, this is probably a slight underestimate.

2.18 Adding these two marginal costs together and multiplying by \( \frac{4}{3} \) to allow for losses gives, per '000 gallons of water supplied during the peak period, a figure of 68.7 paisas. This has to be grossed up to allow for the discounted cost of the d's to obtain "peak" marginal cost. Thus the most relevant description of marginal cost, leaving distribution costs aside, is that per thousand gallons it is:

- Over 48.1 paisas "off-peak"
- Over 68.7 paisas "peak"

This is just as useful information as the fact that the weighted average (which takes account not only of the length of the peak and off-peak periods but also the different rates of consumption during the wet and dry seasons) of these two marginal costs is over 56.7 paisas per thousand gallons.

2.19 The grossing up on account of the d's is now a little more complicated than it was. These future decreases in amounts supplied need to be valued at weighted average marginal cost, \( m \), which according to formula (2) is:

\[
m = \frac{56.7}{1 - \frac{d_1}{1.1} - \frac{d_2}{1.21} - \frac{d_3}{1.331} - \ldots}
\]

Applying formula (1) to off-peak marginal cost, we now have:

\[
\text{off-peak marginal cost} = 48.1 + 56.7 \left( \frac{d_1}{1.1} + \frac{d_2}{1.21} + \frac{d_3}{1.331} + \ldots \right)
\]

while

\[
\text{peak marginal cost} = 68.7 + 56.7 \left( \frac{d_1}{1.1} + \frac{d_2}{1.21} + \frac{d_3}{1.331} + \ldots \right)
\]
Unfortunately, we are not able even to guess the value of the d's. None-
theless, they are a very important part of the picture since they enable
us to translate into cost terms the crucial feature of Lahore's water supply
situation, the depletion of its limited groundwater resource.

2.20 Extra water consumption means extra sewage to be pumped, whether
wastewater is discharged directly into sewers or indirectly via surface
drains. It does not, at present, involve any treatment, so costs are low.
Thus if the marginal annuitised capital cost plus the marginal operating
cost of sewage pumping is, say, 3 paisas per thousand gallons and if each
extra thousand gallons of water supplied is assumed to add 500 gallons
(i.e., a marginal return ratio of 50%) to the sewage load, there is an
additional marginal cost of 1.5 paisas per thousand gallons to be reckoned
with. This is a negligible amount. However, the marginal cost of sewage
pumping is included in subsequent analysis for illustrative purposes.
Assumptions upon which the estimate of 1.5 paisas is based are as follows:

(a) Capital cost per cusec of pumping capacity 8,000 rupees,
anuitised over 20 years at 10%, divided by 22,450 x 8,760,
i.e., by the number of gallons per hour equal to one cusec
times the number of hours in a year. Multiplied by 1,000
this gives .48 paisas per 1000 gallons.

(b) Electricity cost per year of 3,000 rupees per cusec, equal
to 1.5 paisas per 1000 gallons.

(c) Operation and maintenance costs .52 paisas per 1000 gallons.

(d) Marginal return ratio from water to pumped sewage of 0.5.

2.21 Sewage, sullage, and storm water are pumped into channels which
provide some irrigation for nearby fields but whose main purpose is to
discharge into the river Ravi. The only treatment is a coarse screening
of the effluent to protect the pumps. This is one reason why the above
costs are low. The other is that their capacity is sized to deal with
little more than dry weather flow. When there is rain the sewers become
surcharged, the level rises and the mixture of sewage and storm water over-
flows into the channels leading to the river. There are no large communities
immediately downstream of Lahore to suffer from the pollution of the river
Ravi: there are presumably some environmental costs of the foregoing means
of sewage disposal; these are probably unquantifiable in monetary terms, but
should at least be analyzed qualitatively.

2.22 Finally, we turn to water distribution costs which have so far
been ignored. The size of a distribution network without much storage is
ideally related to maximum hourly flows but it seems more useful and is
practicable to relate it to the number of connections. We do this with
the aid of the following figures. The second column shows the approximate
total increase from 1967 to 1974 in the total length of mains of each diameter.
It is the sum of the amounts laid from 1967/8 to 1973/4 inclusive, excluding 12" mains connecting new tubewells to the grid. These are excluded since their cost was allowed for above as part of the cost of new tubewells, being included in production cost. The third column shows, again only approximately, the total cost per foot laid at 1974 cost levels:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Feet Laid</th>
<th>Cost per foot, rupees</th>
</tr>
</thead>
<tbody>
<tr>
<td>18&quot;</td>
<td>105,600</td>
<td>300.0</td>
</tr>
<tr>
<td>12&quot;</td>
<td>69,898</td>
<td>72.0</td>
</tr>
<tr>
<td>10&quot;</td>
<td>53,285</td>
<td>57.6</td>
</tr>
<tr>
<td>8&quot;</td>
<td>95,415</td>
<td>40.8</td>
</tr>
<tr>
<td>6&quot;</td>
<td>330,502</td>
<td>26.4</td>
</tr>
<tr>
<td>4&quot;</td>
<td>450,515</td>
<td>18.0</td>
</tr>
<tr>
<td>3&quot;</td>
<td>623,596</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Multiplying feet laid by cost and summing gives a grand total cost at 1974 prices of almost 69.5 million rupees. This extension of the network went with a growth in the number of connections from March 1967 to March 1974 of 1,425 rupees. Adding 25 rupees as the cost of making each connection gives 1,450 rupees as the approximate marginal distribution cost per connection.

2.23 This figure is relevant for the future insofar as the future development of the network is likely to evolve in much the same way as in the past. If, however, the main transmission link provided by the 18" steel main was a once-and-for-all investment which is unlikely to be repeated in the next few years, then the figure of 800 rupees per connection would be more appropriate.

2.24 These costs are in capital terms. If annuitised at 10% over a long period they would be 145 and 80 rupees a year respectively.

2.25 Finally, the annual recurring costs of repairing and maintaining the network need to be allowed for as another component of marginal distribution costs.

1/ Because of the extreme uncertainty that future costs would follow a similar pattern to those incurred in recent years, a similar analysis was not carried out in the case of sewerage.
III. TARIFF ISSUES

3.01 Given the estimates of marginal connection and production costs, the next step is to use this information in establishing tariffs. Ideally, one would simply set connection fees equal to the marginal cost of connection, and charges for water consumed equal to marginal production costs. In this way the value of system expansion or of additional consumption would be signalled by consumers' willingness to pay for the services provided, thereby demonstrating the economic justification of such investments. However, the objective of using price as a means of improving investment decisions in this way is subject to a number of constraints, including possible conflicts with the financial objectives of LIT; the need to ensure that the poor obtain at least a minimum supply of water for basic sanitation purposes; and public acceptance. In addition, setting price equal to marginal cost involves problems of measurement; for existing consumers, the main obstacle to an economically rational pricing policy is the difficulty of metering. This section therefore begins with an outline of how the metering decision should be made, this being followed by criteria for setting prices for metered users and ways in which reconciliation between the various objectives of tariff policy might be approached. Finally, there is a brief summary of the pros and cons of various charges that are unrelated to consumption.

The Metering Decision

3.02 The decision on whether or not to meter the consumption of individual consumers should be subjected to cost-benefit analysis. The costs of metering consist of the purchase and installation of the meter, and subsequent maintenance, reading and billing costs. Benefits arise if metering induces consumers to use less water, thereby permitting savings in capital and operating costs to be achieved. In addition, by providing better information to LIT, metering may facilitate detection of losses from the distribution system, and therefore effect savings. However, as an offset to these benefits the reduction in water used by a consumer may involve some loss to him; since price is raised from zero (at the margin) to some positive figure, the benefits of water used for purposes which have a unit value of between zero and the new price will be lost.

3.03 The metering decision should therefore be made by comparing the present worth (or annual equivalent) of metering costs with the present worth (or annual equivalent) of the resultant benefits, i.e. production cost savings less the value of foregone consumption. Since we can rarely say with any confidence how great a reduction in consumption would follow the introduction of metering, the best way to deal with the problem is to ask, with respect to any particular category of consumer, the following questions:

(a) What reduction in consumption would be sufficient to justify metering, and

(b) is that reduction in consumption likely to result?
Such a calculation, carried out for domestic metering in Lahore assumed the following data on metering costs:

- **Purchase of 1/2" meter**: 275 Rupees
- **Installation**: 25
- **Ancillary Equipment**: 5

**Total Annual Cost (assuming a discount rate of 10% and a life of 5 years)**: 305 + 35 = 340 Rupees

3.05 As noted below, these costs are extremely high, improvement in metering practice being a critical element of the decision as to whether or not metering should be adopted more widely.

3.06 Production costs are estimated at 58.2 paisas per thousand gallons. This consists of the marginal cost of water production, i.e., 56.7 paisas which excludes costs due to the depletion of the water table (at present unknown) and makes no distinction between summer and winter consumption, plus 1.5 paisas per thousand gallons which is the estimated marginal cost of sewage disposal.

3.07 Given an annual metering cost of 118 Rupees, the reduction in water production per connection necessary to achieve equivalent savings in production costs would be 555 gallons per day. Present total production is estimated at 62.89 m.g.d.; with connections (including commercial) totalling 90,000 production per connection is 698 g.p.d. On average, therefore, metering would have to reduce production by about 80% to be worthwhile. Clearly this is unlikely: it does not, however, mean that metering should be abandoned altogether. What it does mean is that careful analysis should be carried out to determine which categories of consumer should be metered.

1/ A similar calculation carried out in 1971 came up with a figure of about 50%. The case against metering has become stronger since marginal production costs are now estimated at 3.7 times the 1971 figure, while for metering costs the escalation factor is 5.4. This reflects in part the unfortunate experience of domestic water metering in Lahore in the intervening period.
3.08 A number of adjustments have however to be made to the above calculation. First, some savings in distribution system costs may result from the introduction of metering. A reduction in consumption may permit smaller sized pipes to be used in extensions to the distribution system, or where replacement is being carried out. This suggests that metering will tend, other things equal, to be more appropriate for new consumers particularly those living in areas as yet unserved by the public water supply system. Probably of somewhat less importance but nonetheless worth analysis is the fact that the introduction of metering will tend to involve a loss of head, resulting in additional pumping costs, which should in principle be recognized in estimating the costs and benefits of metering.

3.09 Another aspect of the metering decision that needs to be resolved concerns the loss to the consumer that results from the reduction in consumption. The foregoing comparison can be seen as reflecting the extreme assumptions:

(a) that reduction in the flow of water to a consumer's premises has no cost; i.e., water would otherwise have been put to no useful purpose, and no costs (e.g. repair of plumbing fixtures) are incurred in restricting waste because of metering, and

(b) that the demand for water, after the adjustment due to metering, is perfectly inelastic in the price range between zero and the metered rate. 1/ In other words price changes, once meters have been installed, have no effect on consumption.

3.10 Another feasible assumption, however, is that metering results in a loss to the consumer that can be approximated by a function that relates quantity consumed linearly to price. Algebraically, the metering decision in this case requires an estimation of the reduction in consumption \(R\) which equates the present worth of metering costs \(M\) with the present worth of the benefits \(S-V\) where \(S\) is savings in production costs and \(V\) is the value of water that is now foregone. 2/ Both \(S\) and \(V\) are a fraction of \(R\), i.e.:

1/ The distinction implied in (a) and (b) between water wasted and water used is an important one, and may help to justify the seemingly paradoxical conclusion reached by many water authorities that while metering may have a salutary effect on water production subsequent price changes have a relatively small effect.

2/ A parallel calculation should be made for any savings in production costs due to improved detection of losses from the distribution system. Since remedies for detected leaks are not costless, it should be interpreted as net savings to LIT that result from metering.
S = cR, and

V = 1/2 pR

where c = marginal production cost and

p = price of metered consumption.

If \( M = (S-V) \),

\[ M = cR - \frac{1}{2} pR, \]

so

\[ R = \left( \frac{M}{c - \frac{p}{2}} \right) \]

3.11 Having estimated a value of \( R \) which equates the present worth of metering costs and benefits, a judgement then has to be exercised as to whether the estimated \( R \) is likely to be greater or less than the actual \( R \). Clearly, the assumption that is made about the value of water lost to the consumer as a result of metering could be critical to the decision. If, for example, \( c=p \), and linearity of the demand curve between pre-and post-metering rates of consumption is assumed, an offset of 50% of the savings in production costs would result, and \( R \) would have to be twice as great as if reduction in production is costless and demand thereafter inelastic. Indeed, application to the results quoted above would require a reduction in consumption of 1,110 gallons per connection which is about 60% more than the average amount presently consumed.

3.12 A number of pieces of information are required to conduct this analysis more thoroughly. Information is lacking on both the benefits and on the costs of metering. One task to be completed is the analysis of water use by type of consumer. The general objective of this analysis would be to rank types of consumer in order of the priority they should receive in the metering program, and to determine a cut-off point below which metering would not be worthwhile. The impact of metering, and therefore the relationship between metering costs and potential benefits presumably varies according to category of consumer. It may be necessary to distinguish not simply individual, commercial and residential usage, but also sub-categories. For example, distinctions might be made between residential consumers according to whether or not they are connected to the sewerage system or have septic tanks; or whether or not they have gardens. It is possible that the present definition of consumer categories is not appropriate for this purpose. For example, compulsory metering of commercial or new residential properties may be less useful than compulsory metering of all residential properties with a garden area exceeding a certain size.
3.13 This analysis should include not only comparison of aggregate consumption in premises with and without metering, but also the more difficult task of trying to determine the type of water use by various categories of consumer. This may allow some judgement to be made about the extent to which metering may inhibit wastage, rather than actual use of water, and thereby provide some indication as to the nature of the demand curve for water. For example if water is running to waste simply because a consumer is too lazy to turn a tap off, it can reasonably be assumed that the loss to him of reducing that amount of flow by metering is zero.

3.14 For this purpose it may be of special interest to determine the seasonal pattern of water consumption. Thus during the summer peak period, a given reduction in aggregate consumption will achieve greater production cost savings than an equivalent reduction during the winter season. Moreover, it is likely that summertime activities such as lawn watering and dust damping may be more responsive to metering (or price changes) than uses of water for drinking and washing. To take account of the seasonal complication, a range of values for $R_o$ and $R_p$ should be estimated which satisfy the equation

$$R_o \left( C_o - \frac{P_o}{2} \right) + R_p \left( C_p - \frac{P_p}{2} \right) = M$$

where subscripts o and p refer to the off-peak and peak periods respectively and, as before, judgement exercised as to their likelihood.

3.15 Estimates also need to be made of the impact on distribution system costs of the reduction in per capita consumption that accompanies the introduction of metering.

3.16 On the cost side, the data gaps referred to in Section II need to be filled. In addition, there are some uncertainties about metering costs. At present the metering program is in bad shape, this being reflected in the high cost of metering that is used in the foregoing calculation. Of the 90,000 connections, 7,500 are nominally metered, but of these, 4,000 meters are not working. Meters are frequently stolen or tampered with, often with the connivance of meter readers; honest mistakes are also made in meter reading (particularly for dial-type meters) since some meters record in cubic meters and others in gallons; repair facilities are inadequate; there are difficulties in getting spare parts; consumer complaints are numerous; and the average length of life of a meter is only about five years. It should be possible to remedy some of these problems; for example, the use of meters made of less valuable materials or installed as an integral part of the pipe and without which supply will be lost; replacement of dial by digital meters; standardization of the unit of measure; procurement policies which
ensure adequate spare parts; and recruitment of higher calibre meter readers. The additional costs of such measures should be weighed against the efficiency savings that might result.

3.17 The metering issue is the most important decision LIT has to make on the subject of tariff structure. To illustrate, if production costs are 58.2 paisas per thousand gallons; annual metering cost is 118 rupees per meter; if \( V=0 \); and if metering would reduce the average consumption per connection of 698 g.p.d. by 30%, the annual net social cost of metering would be 74 rupees per connection, a total loss of 6.66 million rupees annually.

3.18 It is therefore necessary that the decision be subject to close scrutiny. While the foregoing calculations suggest that metering should probably be extended to a very few consumers, a comprehensive tariff study might show that metering costs and benefits are considerably different from those outlined above. Whatever conclusion is reached by LIT, however, as long as the charge per thousand gallons reflects marginal cost, it would seem desirable to give the consumer the right to be metered if he so wishes, but not to opt for a flat rate without LIT's consent.

Pricing Policy for Metered Users

3.19 The current charge for domestic, commercial and industrial uses is 2 rupees per thousand gallons, in addition to which there is a scale of minimum monthly charges which range, according to size of ferrule, from 7.50 to 31.50 rupees for domestic consumers, and from 9.50 to 41.50 for commercial. Initial connection fees are 30 rupees.

3.20 A typical residential connection with a 1/2" meter would consume 600 g.p.d., and therefore face a charge of about 30 rupees plus 1.50 rupees meter rent per month. His consumption would have to fall to 250 g.p.d. before he faces the minimum charge for a 1/2" meter of 15 rupees (plus meter rent) per month.

3.21 Ideally, price should equal marginal cost, in which case, according to the estimates in Section II, connection charges should be between 800 and 1,450 rupees (or 80 to 145 rupees annually). We use, for illustrative purposes, 100 rupees for marginal connection cost. As to the charge per thousand gallons of water actually consumed, a feature of the Lahore system is that, in contrast with most surface water schemes where capacity expansion proceeds in large "lumps," capacity can be expanded by relatively small increments. It is therefore possible to make direct use of the fairly rigorous concept of marginal cost developed in Section II in establishing pricing policy. We use 56.7 paisas per thousand gallons as the marginal cost of consumption.

3.22 Excluding any sewerage charges, the monthly bill facing residential consumers with 1/2" meters at various rates of consumption under the marginal cost pricing and the present system would be as follows:
### Monthly Charges in Rupees

<table>
<thead>
<tr>
<th>Consumption Per Connection</th>
<th>MC Pricing</th>
<th>Present System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Charge</td>
<td>Charge</td>
</tr>
<tr>
<td>2,000 g.p.d.</td>
<td>18.33</td>
<td>34.02</td>
</tr>
<tr>
<td>1,000 g.p.d.</td>
<td>18.33</td>
<td>17.01</td>
</tr>
<tr>
<td>500 g.p.d.</td>
<td>18.33</td>
<td>8.50</td>
</tr>
<tr>
<td>250 g.p.d.</td>
<td>18.33</td>
<td>4.25</td>
</tr>
<tr>
<td>100 g.p.d.</td>
<td>18.33</td>
<td>1.70</td>
</tr>
<tr>
<td>50 g.p.d.</td>
<td>18.33</td>
<td>0.85</td>
</tr>
</tbody>
</table>

1/ Includes 10.00 meter rent (from paragraph 3.04).
2/ Includes 1.50 meter rent. To be strictly comparable, the annuitized value of the 30 rupees connection fee (say 3.00 annually) should be included.

3.23 The foregoing suggests that apart from very small consumers, the charges for water actually consumed exceed marginal costs when metering, billing and collection are efficient, while fixed charges are less than the annual equivalent of marginal connection cost. It also indicates that strict adherence to marginal cost pricing is likely to yield insufficient revenues for LIT to function efficiently - for even with existing tariffs the enterprise works at a loss.

3.24 The position is made much more difficult as investment in sewage collection and disposal becomes more important. The ratio of marginal operating costs to marginal connection costs is likely to be very small (marginal operating costs of sewage disposal are estimated at 1.5 paisas per thousand gallons of water consumed, compared with more than 56.7 for water supply, while marginal connection costs for sewerage are probably greater than for water supply). This exacerbates the financial problems caused by marginal cost pricing, and will require, for sewered premises, at least a doubling of the fixed charge component of the water supply tariff shown in the above table.

3.25 This issue is at the heart of the pricing problem for Lahore, which is almost unique in that marginal production costs are so low, while other costs of the enterprise rise less than proportionately as system expansion proceeds and output increases. This means in effect that marginal costs are less than average costs, and financial loss would result from marginal cost pricing, unless inflation raises marginal costs well above historical accounting costs.

3.26 The task of the pricing analyst is thus to ensure that sufficient revenues are obtained to meet the financial obligations of the enterprise, while distorting consumer choice as little as possible. Probably the best way to do this in Lahore would be to set the charge per thousand gallons consumed equal to marginal production cost, and to raise the fixed charge as necessary to achieve financial viability. This will ensure that the rate of water consumption is optimal, while the higher fixed charge is unlikely to deter any metered consumers from continued use of the system.
3.27 It does, however, mean that greater attention needs to be paid to the way in which fixed charges are set for various categories of consumer. This will be largely a matter of equity, or ability to pay, rather than economic efficiency. This is particularly true of charges for connection to the sewerage system. For financial reasons sewerage authorities often find it necessary to make connection to sewers compulsory for properties that are in close enough proximity: this may also be justified in economic terms to the extent that there are external benefits of connection, indicating that an individual householder's willingness to pay for service may understate its social value. In general, estimation of the fixed charge for metered consumers should be approached in the same manner as the establishment of charges for unmetered users, dealt with in a subsequent section.

3.28 The device of an increasing block rate is often employed as a means of generating revenues. It may, on political grounds, be the only way of dealing with the problem, but it should continue to be avoided if possible, as indeed should distinctions in the price per thousand gallons faced by commercial and residential consumers. If the marginal costs of supplying different types of consumer or amounts of consumption are the same, so should price if efficient water use is to be maintained. Since a relatively small number of residences would qualify for metering in Lahore, there is not even a need for a free or cheap allowance for metered domestic consumers.

3.29 Adaptation of the above principles to take account of seasonal variations in consumption should be considered. The incremental costs of summer and winter consumption should be recognized in pricing policy, whether the need for additional capacity is created by demand peaks or supply troughs or some combination thereof. There are, however, problems of implementation. First, although the summer peak is defined as the three months May-July plus daytime hours in April and August, differential pricing would require the whole of April and August to be treated either as peak or off-peak. In practice it would be preferable to treat the whole of the five-month period as the peak in order to avoid creation of new peaks in April and August.

3.30 The second difficulty is the administrative one of carrying out meter reading in such a way that consumers feel that they are being metered fairly. Even though the consumer's bill may not be very sensitive to a few days' delay in reading the meter at the end of the seasonal peak period, it is important that this not occur. Indeed, there are enough problems with the organization of meter reading as it is, and until they are solved, seasonal peak pricing could not be implemented. However, if metering is restricted to a small number of consumers, it should be possible to introduce such a policy. The third difficulty is of course the political one of charging more for water when it is apparently most needed. As a public relations device, general price increases could be advertised which, perhaps subsequently, could be amended to include a reduction in price for off-peak use.

3.31 Finally, a word should be said about water production and consumption by parties other than LIT. The marginal social cost of water abstraction by any party in the Lahore area includes not only the pumping costs privately incurred by that party but also the depletion of the ground water, which

1/ There are at present no charges for connection to the sewerage system: ARV is supposed to be the basis for monthly charges, but so far none have been collected.
imposes additional costs on other users, plus marginal sewage costs. In the case of LIT, a minimum estimate of this cost can be approximated by:

\[ 46.0 + 56.7 \left( \frac{d_1}{1.1} + \frac{d_2}{1.21} + \frac{d_3}{1.331} + \ldots \right) \text{ off-peak} \]

and

\[ 73.7 + 56.7 \left( \frac{d_1}{1.1} + \frac{d_2}{1.21} + \frac{d_3}{1.331} + \ldots \right) \text{ peak} \]

3.32 As noted, this cost should be passed on to consumers of LIT. However, this principle should be extended to other uses of water in the Lahore area - whether abstracted for domestic, agricultural, business or governmental purposes. The tariff study should therefore consider the institutional arrangements that could be made in order to require other abstractors to bear the marginal sewage cost (for which in general they are as responsible as LIT water consumers), plus the marginal capacity cost of water supply imposed on others because of their activity; the appropriate charge would be, if the costs incurred by LIT are representative:

\[ 1.5 + 56.7 \left( \frac{d_1}{1.1} + \frac{d_2}{1.21} + \frac{d_3}{1.331} + \ldots \right) \text{ for peak and off-peak consumption} \]

It would then be up to other abstractors to pass on these costs, plus the pumping costs they privately incur, to their consumers. As noted earlier, it is important that abstraction other than that carried out by LIT be metered in order that knowledge of the hydrology in the Lahore area be understood: it is clearly also a necessity if rational water use is to be achieved.

Alternatives to Metering

3.33 The majority of consumers in the Lahore area should probably continue to be unmetered. There are a variety of methods of recovering costs from unmetered consumers. Currently about 3/4 of connections are charged for on the basis of size of ferrule for the first two taps plus an additional amount for every additional tap. Most of the remainder of connections are charged for on the basis of annual rental value (ARV) of properties: this applies if 10% of ARV is higher than the ferrule-cum-tap method, but is subject to a minimum of 72 rupees per annum.

3.34 Perhaps the major shortcoming of the ferrule-cum-tap method is that it encourages tampering. While about 90% of connections are charged for on the basis of a 1/4" ferrule, an unknown number of ferrules have been taken out by householders and replaced by larger ones. This situation is clearly both inequitable and inefficient. Moreover, charges reflecting the variation in the basis of number of taps are difficult to enforce, access to houses is difficult, the definition of number of taps is ambiguous, and water can be supplied to one house from another by hosepipe. It is unlikely that this method provides any correlation between charges and consumption, as indeed a survey carried out in Lahore bears out.
3.35 The ARV method, too, has its problems. It is well known that correlation between ARV and water consumption is very approximate: it may, however, be a reasonable way of discriminating between the relatively wealthy and relatively poor areas and therefore be crudely related to ability to pay. However, officials of LIT allege that valuation of properties in Lahore is carried out in an unsatisfactory manner, and appeals against valuation cause great uncertainty. Potentially more serious is the proposal that new properties be temporarily assessed at zero. If this measure is approved, ARV will involve new difficulties as a basis for water charging since LIT will have to undertake its own valuation.

3.36 It would, however, be unfortunate, for the reasons described above, if the alternative is to be the ferrule-cum-tap method, and highly inefficient if metering is selected. Further alternatives should be examined. One such is the possibility of charging on the basis of floor area: this at least has the advantage of being an objective measure. To take account of consumption due to lawn watering and other outside uses, garden area could also be part of the charging base, if necessary being subject to a different rate than the floor area of buildings.
IV. CONCLUSIONS

4.01 The preliminary calculations used here suggest that in Lahore the relatively low production cost of water implies that

- metering will rarely be justified

- a two part tariff would be appropriate for those consumers who are metered, with a periodic fixed charge to cover distribution and sewerage costs and other overheads as necessary to meet financial obligations

- greater attention should be paid to equity and ability to pay, not only in establishing the rates for unmetered consumers, but also in setting the fixed charge portion for metered consumers.

4.02 However, it should be stressed once more that the estimates presented in this report are tentative, and to summarize, the type of information that the tariff study needs to acquire in order to estimate marginal costs, to decide on the merits of metering, and to establish tariff policy, includes the following:

- the output of tubewells, involving metering of LIT and non-LIT abstraction

- estimation of losses from distribution systems

- estimation of marginal sewage return ratio for different categories of consumer

- refinement of production costs, e.g. length of life of tubewells; gas versus electric motors

- forward-looking estimation of water distribution and sewerage costs

- rate of depletion of water table and consequent change in marginal cost

- nature of water use and impact of metering on different categories of consumer

- impact of reduction in consumption on distribution system costs

- cost of metering, with possible improvements in method

- merits of alternatives to metering in terms of ability of consumers to pay, ease of collection and correlation with consumption.