Estimation of Long Run Marginal Cost (LRMC)

A report prepared by Marsden Jacob Associates

for the Queensland Competition Authority

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1. Introduction

As part of its current review of prices charged by the Gladstone Area Water Board (GAWB), the Queensland Competition Authority (the Authority) has requested a review of the theoretical and practical issues involved in defining the Long Run Marginal costs (LRMC) for pricing of water services.

Marsden Jacob Associates (MJA) has reviewed relevant technical literature and decisions adopted by regulators and others related to the treatment of LRMC in the water industry. In addition, we have tested the practical implications of alternative calculation methods. On this basis we make recommendations on the appropriate method for estimating LRMC.

A workshop was held with the Authority on the 22 September 2004 to discuss the main issues and our findings. This report summarises MJA's key findings and recommendations with regard to using LRMC as a pricing methodology for setting volumetric water charges.

The opinions expressed in this report are those of MJA and do not necessarily reflect the view of the Queensland Competition Authority.

1.1. Principles

In order to guide our recommendations on the appropriate method for estimating LRMC it is instructive to recall the pricing principles set out by the Authority in the "*Statement of Regulatory Pricing of Principles for the Water Sector*", 2000 p.3:

> *"To achieve the objectives of monopoly price regulation, including promoting economic efficiency, the Authority considers that prices of water delivered to an end user should:*
>
> - *be cost reflective - that is, reflect the costs of providing the service and, usually where the demand for water exceeds its supply, potentially incorporate a value for the resource;*
> - *be forward looking - in that they represent the least cost which would now be incurred in providing the requisite level of service over the relevant period;*
> - *ensure revenue adequacy - the revenue needs of the business must be addressed where possible;*
> - *promote sustainable investment - where the services are to be maintained into the future, the investor must be given the opportunity to enjoy an appropriate return on investment;*
> - *ensure regulatory efficiency - the pricing method which minimises regulatory intrusion and compliance costs relevant to a particular circumstance should be adopted; and,*

- *take into account matters relevant to the public interest. Many such matters are identified in the Queensland Competition Authority Act 1997."*

As we will discuss in the following sections, the concept of LRMC fulfils the criterion of cost reflectivity and is forward-looking. While LRMC is not concerned with the principle of revenue adequacy, this can be achieved by the implementation of a two-part tariff with the volumetric charge calculated according to LRMC.

The opportunity of earning an appropriate return on investment is a question of setting an appropriate level for the cost of capital. As such it is not an issue specifically related to the choice of cost concept. Similarly, matters of public interest are not readily evaluated in relation to costing water services and should not influence the choice of costing concept. The principle of regulatory efficiency, on the other hand, is important as it suggests that the choice between different LRMC measures should include an evaluation of the relative complexity and practicality of the different approaches.

While we recognise the importance and relevance of all the above principles, we regard them as too generic in nature to allow us to choose between different LRMC measures. We therefore outline below a number of finer criteria designed to assist in our evaluation of the appropriate LRMC concept. These are:

- *Demand efficiency* - users should be charged no more or no less than it costs to produce the unit of service to them;
- *Supply efficiency* - the water utility should be able to recover sufficient costs to sustain the provision of services required by customers;
- *Based on a solid theoretical foundation* – any cost concept or methodology employed should be based on solid theoretical framework;
- *Fair and objective* – the pricing methodology should be based on objective decision criteria and result in a fair outcome;
- *Pricing stability* – the charges, and components making up the charges, resulting from application of the methodology should not fluctuate substantially from year to year;
- *Transparency and reliability* – the pricing regime should be explainable and credible to consumers and defendable to government and regulators and minimise potential for error;
- *Practical and understandable*– the pricing methodology should be understandable, easy to use and practical; and
- *Flexibility* – the methodology when applied to different circumstances should be adaptable and sensibly yield different outcomes.

1.2. The Concept of Marginal Cost

Marginal Costs (MC) measure the costs of increasing the production output by one additional unit or the costs saved by reducing the production output by one unit, holding the production levels of all other services constant.

The concept of marginal cost has a central place in pricing theory and practice and in regulatory practice especially. Marginal cost also plays a defining role in the identification and measurement of cross-subsidies and in pricing rules intended to set prices for third party access to essential infrastructure necessary for competition in downstream markets.[1]

When setting prices according to marginal cost in the water and other network industries there are, however, several issues to be overcome:

- First, bulk water supply businesses and other utilities are characterised by substantial fixed costs and economies of scale. As a result, marginal cost is typically substantially less than average costs so that pricing at marginal cost alone would result in the under recovery of costs and ultimately the failure of the business. Charging on the basis of marginal cost would fail the criterion of revenue adequacy.
- Second, marginal costs are typically not stable in the short run. This instability is exemplified by the saw-tooth or factory roof pattern as short run marginal costs fall to zero following each extension of capacity and then rise to full cost as capacity becomes exhausted, new investment is installed and short run marginal costs fall to zero fall to zero once again.
- Third, there are number of practical alternatives to choose from when estimating marginal costs in practice.

1.3. Report Structure

In *section 2* we discuss marginal cost pricing and the relevance of Long Run Marginal Cost (LRMC) over Short Run Marginal Cost (SRMC). In particular we discuss three approaches to LRMC when capital is indivisible. These approaches are: Marginal Incremental Costs (MIC), Average Incremental Costs (AIC) and Long Run Incremental Costs (LRIC).

In *section 3* we review experience from the UK and others in the water industry.

In *section 4* we present our numerical analysis of different LRMC concepts and identify practical pricing issues.

In *section 5* we discuss the principles outlined in the previous section that may guide the Authority in their final choice of implementation methodology.

In *section 6* we assess the two methodologies for estimating LRMC against the adopted pricing principles and draw together our conclusions on the theoretical and practical merits of each before recommending a preferred methodology for use by water businesses.

[1] Considerations related to third party access and cross subsidies are not dealt with explicitly in this report.

Appendix A summarises key characteristics of cost concepts often used in a regulatory setting.

Appendix B provides an overview of different costing formulas.

2. Marginal Cost Pricing

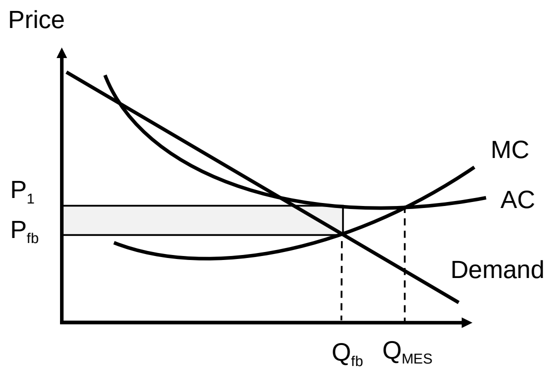
This section commences with an overview of marginal cost pricing before moving on to a discussion of the key costing concepts relating to marginal cost pricing, such as forward-looking costs, time horizons related to the measurements of costs (i.e., short run vs long run marginal cost) and different methodologies for estimating long run marginal costs in the context of the specific characteristics of the water business.

2.1. Overview of Issues

According to standard economic theory, prices should be set at marginal cost (MC) since, in the absence of externalities, this maximises economic welfare.[2] This is because such prices reflect the costs involved in providing an additional amount of output. Where the user values an extra unit more than it would cost to produce it, it is economically efficient to produce that unit, and vice versa. Setting prices equal to MC means that users will continue purchasing extra units until it is no longer economically efficient to produce them at that price. MC based pricing therefore send signals to consumers and producers encouraging them to balance the benefits obtained by consuming a good or service with the costs of providing it.

In the context of the water it is typically the case that the business is a natural monopoly because the infrastructure cannot be economically duplicated. Average costs (AC) are falling in the relevant range (Figure 2.1). The minimum efficient scale (MES) is so large compared to demand that there is only room for one business.[3,4] The shapes of the cost curves reflect some very large fixed costs, say of building a dam or a water distribution network. MC is relatively low. As soon as the dam and distribution network has been established, it is relatively inexpensive to transport an additional unit of water over the network (e.g. pumping and chemical costs).

FIGURE 2.1: UNDER RECOVERY



To set the price equal to MC is known as the first-best solution in terms of allocative (or demand-side) efficiency. The problem with this first-best solution, when dealing with a natural monopoly, is that it does not allow the utility to cover (fixed) costs because MC is

2 Note that we in this section do not explicitly distinguish between short-run and long-run costs. In section 2.3 we discuss short and long-run concepts.

3 This implicitly assumes that potential entrants face a similar cost structure.

4 In Figure 2.1 the MES is large relative to the size of the market depicted by the demand curve – suggesting a monopolistic market. However, a monopoly may face increasing average costs, at least over some output range. Whether a utility in fact has increasing average costs can be tested by calculating both average costs and marginal costs, since marginal costs per definition will be higher than average costs in this case.

less than AC in the relevant range. This is illustrated in Figure 2.1, where a price equal to P_1 would be required for full cost recovery. If prices were set equal to P_{fb}, under recovery would be equal to the shaded rectangle.

No standalone water utility could invest in infrastructure if prices were set equal to MC, unless compensated in some way e.g. by subsidies. Demand-side efficiency would be achieved at the expense of supply-side efficiency.

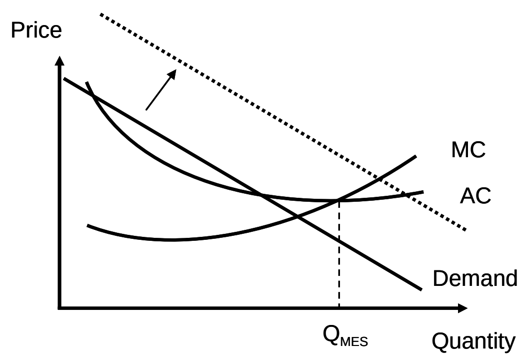
Coase's solution[5] to the competing needs of demand-side efficiency and supply-side efficiency was the introduction of a two-part tariff. Incremental consumption (e.g., per kL of water delivered) is priced at marginal cost but the fixed charge is set so that total revenue covers total costs.[6] In the Australian water industry, two-part tariff structures are now widely applied.

Thus, two-part tariff structures in Australia can be described by the following revenue requirement:

$$\textit{Revenue from annual charges} \quad = \quad \sum_{i=1}^{N}(A_i + C_i \times Q_i)$$

The first part of the tariff recovers the fixed portions (i.e., the connection and the access charges, denoted *A*) of the utility's annual costs. The second part recovers the variable, or marginal, costs of the operation by way of a volumetric charge (denoted *C*) multiplied by the quantity demanded (*Q*).

FIGURE 2.2: RISING AC



The discussion above assumes that average costs are not rising in the relevant output range and MC is below AC. As low cost water services are fully utilised, higher cost sources need to be added in order to meet demand growth, even though the business may have monopoly advantages. Moreover, as the area serviced expands, distribution and pumping costs may rise. Thus water business may face rising rather than falling average costs.

This is illustrated in Figure 2.2. Note that average costs rise due to a depletion of technological possibilities in production and not from diseconomies of scale. In other words, even if prices where set according to MC there would be not be room for an entrant to enter the market and provide services at a lower cost.

5 Coase R. (1946). "The Marginal Cost Controversy." Economica, 13 (8), 169-89.

6 We interpret "full cost recovery" as encompassing two broad types of costs – operating and maintenance costs and capital costs. Some may argue that there exists a third element – environmental costs, or externalities. Valuation of these costs will not be addressed in this report. From the perspective of the utility externalities are not of concern for cost recovery. Externalities are however, important from society's perspective.

Such a scenario is problematic for the implementation of a two part tariff. If the volumetric charge was set according to MC the business would over recovery costs. In a two-part tariff this could only be counteracted by a negative fixed charge. This is not practically feasible. Managers and/or regulators must therefore decide whether to trade-off demand-side efficiency by lowering the volumetric charge to average cost level or alternatively setting the volumetric charge according marginal costs while using other regulatory instruments to counteract the issue of over-recovery.

2.2. A forward-looking concept

Costing systems can be backward-looking, forward-looking, or a mixture of the two. Backward-looking systems are based on the historic cost basis. "Looking forward" implies that the expected development in prices, first of all asset prices, and expected development in demand will need to be taken into account.

Marginal cost pricing is a forward-looking concept. It depends on using estimates of future capital costs (or capital costs looking-forward) to calculate water charges, rather than historical costs. The simple rationale is that historical costs are “sunk costs” or cost which cannot be altered by changing current behaviour. In contrast future capital costs related to system expansion are costs that can be altered by increasing or decreasing water demands, notably by bringing forward or delaying capacity expansion.[7]

When calculating marginal costs, the costs associated with the existing system should therefore be ignored. As Kahn notes[8]:

> *“Marginal costs look to the future, not to the past: it is only future costs for which additional production can be causally responsible; it is only future costs that can be saved if that production is not undertaken.*
>
> *If capital costs are to be included in price, the capital costs in question are those that will have to be covered over time in the future if service is to continue to be rendered. These would be the depreciation and return (including taxes) of the future investments that will have to be made.*
>
> *These incremental capital costs per unit of output will be the same as average capital costs of existing plant only in a completely static world, and under conditions of long-run constant cost. As for the former and by far the important qualification, in a dynamic economy, with changing technology as well as changing factor prices, there is every reason to believe that future*

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7 From a theoretical perspective, the use of forward-looking costs has the advantage: costs and capital are valued on the basis of an alternative (economic) cost approach, instead of an accounting costs approach. From an efficiency point of view this is very appealing, because a price based on opportunity costs sends the right signal to consumers about the value of the resources the consumer/the competitor/society is forgoing by using this service.

8 Kahn, A. (1988) The Economics of Regulation: Principles and Institutions, Massachusetts Institute of Technology, vol. 1, p. 98.

capital costs per unit of output will not be the same as the capital costs historically incurred installing present capacity."

A forward-looking perspective implies the existence of a long term capital plan for the utility, an instrument required in any event for effective operation and planning.

2.3. Short-run vs. Long-run

Marginal cost can be estimated in either a long-run (LRMC) or a short-run (SRMC) perspective. The fundamental difference between SRMC and LRMC is the time frame under consideration and the implications for a firm's ability to adjust its production process to minimise costs. As noted by Turvey:[9]

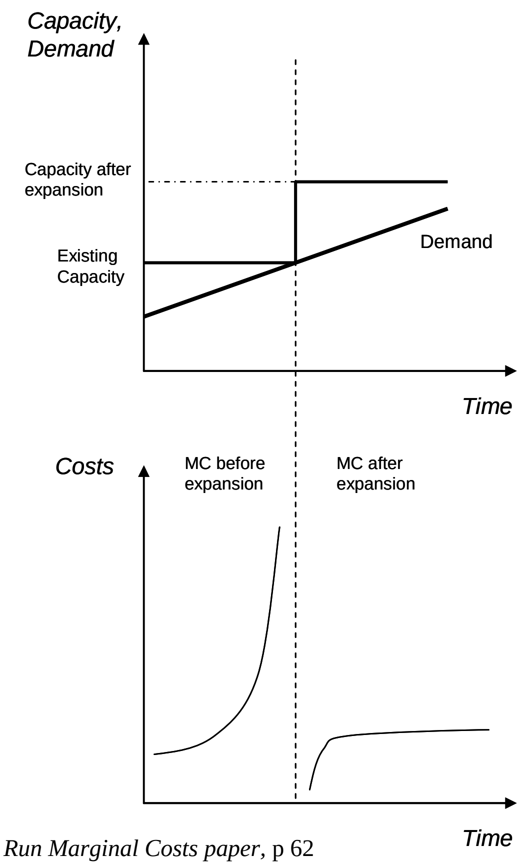
> *"…the term LRMC is used to signify the cost effect of a change which involves some alteration in the amount or timing of future investment. SRMC, on the other hand, takes capacity as given, so relates only to changes in operating costs for example when the transport of additional water requires only additional pumping costs."*

During water shortages, SRMC rises steeply, because production capacity is operating at limits of it design capability, or because inefficient production capacity has to be taken into service.[10] In the extreme case, additional supplies can only be secured for one customer by reducing supplies to another customer; SRMC then rises to the value of water to the customer who is not being served, rather than being defined by production costs. In contrast when there is excess capacity, SRMC will be very low.

This situation is depicted in **Error! Reference source not found.**, where marginal costs rise sharply in response to capacity constraints and then fall away as a result of significant excess capacity following expansion.

Recognition of the instability and implications of SRMC based pricing in terms of both pricing efficiency and equity means that long-run marginal cost (LRMC) is now preferred over SRMC as the appropriate basis for cost-reflective

FIGURE 2.2: VARIABILITY OF MARGINAL COSTS



[9] Turvey (2001), *Annex A: Some comment on Ofwat's Long Run Marginal Costs paper*, p 62

[10] The potential for increased costs in the short run can be exemplified by the problems experience by Yorkshire Water (UK) in 1995 during a drought. The drought resulted in severe stress to the water supply system, in the West Yorkshire districts of Bradford, Calderdale and Kirklees, necessitating the emergency measure of tanking in water from outside the region.

pricing. This was already recognised by Turvey (1969)[11] who criticised the standard use of marginal costs for inadequately incorporating time within the marginal capital cost function. Similarly, Mann et al. (1980)[12] notes that failure to consider the long-run will generate socially unacceptable instability in tariffs and charges over time.

In this respect it is necessary to understand the concept of long-run. The distinction between the short and long run in economics is purely conceptual - it does not correspond to any particular arbitrary time period. However, from a theoretical perspective the long run should be understood as *the time horizon where all costs are variable*. In practice, the long run has been interpreted in different ways including:

- the planning horizon;
- the average life of assets; or
- the time period until the next expansion to meet demand growth.

What constitutes the long run depends on the specific case we are investigating. If we are considering the fixed factor to be the size of the plant (or capacity), then the long run will (as a minimum) be the time period before the business undertakes investment in additional capacity.

In the water sector, investments tend to be lumpy, require building in of substantial spare capacity and are typically very long lived (up to 100 years). Water utilities must also meet certain obligations in terms of supply and quality. Consequently, setting efficient prices for water services requires consideration of the greater level of inflexibility inherent in the sector's infrastructure, which in turn suggests adopting investment planning periods of at least 20 years.

Since most water assets have an asset life (both physical and economic) in clear excess of 20 years it is important that calculations take account of this by including a residual value to ensure that the values of the assets are properly reflected at the end of the planning period.

Where major augmentation is scheduled to occur close to the end of the planning period, there is an issue as to whether the assessment should be truncated just prior to that augmentation, or alternatively, where a major augmentation is expected to occur just following the end of the planning period to extend the period to include it. However, with a planning period of 20 years and the inclusion of a residual value any expansions occurring close to the end of this period will have very limited influence on the final results. Nevertheless, if the intention is to signal the average cost of lumpy additional capacity, rather than the marginal cost of the first increment in demand serviced within in the planning period, the planning period should not be truncated but extended to include the augmentation.

[11] Turvey, Ralph, "Marginal Cost", Economic Journal, Vol. 79, pp. 282 – 299, 1969.

[12] Mann, Patrick C., Saunders, Robert J., Warford, Jeremy J. "A Note on Capital Indivisibility and the Definition of Marginal Cost", Water Resources Research Vol. 16, No. 3, pp. 602-604, June 1980.

2.4. Estimation of Marginal Costs

From a practical perspective, LRMC can be defined as including both short-run and long-run costs. LRMC may therefore be disaggregated into two main types of marginal costs: Marginal *Operating Costs* or MOC (short-run); and Marginal *Capacity Costs* or MCC (long-run), associated with bringing forward investment projects.[13]

MOC are generally simpler to estimate than MCC, as they usually have a more easily defined relationship with incremental increases in demand. In water, marginal operating costs are typically related to the cost of electricity and chemicals. Note, however, that SRMC is a forward-looking concept and in theory entails an estimation of possible future outcomes and associated costs. SRMC may also curve upwards above 'pure' operating costs in situation where demand exceeds supply. For all practical purposes in the water industry, however, estimating SRMC by reference to operating costs seems a reasonable proxy.[14]

Estimating MCC is more difficult. These are the costs associated with investments as a result of an incremental increase in demand.

MCC can be estimated in different ways. QCA has previously examined some of these issues in its consideration of the pricing of bulk water services provided by GAWB. Specifically, QCA has considered whether LRMC should be defined as average incremental costs (AIC) or according to the methods referenced to Turvey[15] including the "perturbation" method or Present Worth of Incremental System Cost (PWISC) method. We find this latter collection of terms neither informative nor simple and therefore use the term Marginal Incremental Cost (MIC) method.[16]

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13 This separation of into a short-run and long run component suggests that SRMC will always be below LRMC. However, as we have seen in **Error! Reference source not found.** SRMC may rise substantially in the event of scarce capacity and may therefore increase above LRMC. In general, SRMC is below LRMC only in the presence of excess capacity.

14 In practice, SRMC may be estimated based on existing operating costs or following a capacity expansion path.

15 The concept of Turvey marginal cost is not well defined in the literature. Turvey has proposed a number of variations of his preferred methodology for estimating LRMC. For example in Turvey (1976) he includes a numerical example in which he amortises the present value of the capital expenditure and divides by the demand volume. This always gives a higher LRMC estimate than the formula given in the PWISC formula used here. The PWISC definition is by Mann et al. (1980), which is sourced from Turvey, R., "*Optimal Pricing and Investment in Electricity Supply*", George Allen and Unwin, London, 1968. Note that in this source, there is an implicit assumption that investments take place every year. However, PWISC may of course be defined in terms of any increment of output.

16 The insight that Turvey is a marginal incremental cost can be illustrated by rewriting the most common form of the Turvey formula (see section 2.4.1) as:

$$\frac{\partial I}{\partial t} \Big/ \frac{\partial Q}{\partial t} \quad = \quad \frac{\partial I}{\partial t} \times \frac{\partial t}{\partial Q} \quad = \quad \frac{\partial I}{\partial Q},$$

where both the cost and the demand increments are expressed as present values. This common formulation of Turvey's measure illustrates that his measure of incremental costs is concerned with smaller rather than larger increments in demand.

There are, however, a number of other concepts related to the measurement of LRMC used in a regulatory setting. These are LRIC (Long Run Incremental Cost), LRAIC (Long Run Average Incremental Cost), TSLRIC (Total Service Long Run Incremental Cost) and TELRIC (Total Element Long Run Incremental Cost). In practice, the four concepts are related and often used interchangeably. Unless specifically stated, we will therefore refer to LRIC which should be understood as encompassing all four concepts.

In the following we discuss the three cost concepts MIC, AIC and LRIC. We commence with MIC and AIC as these historically have been applied to the water industry. An overview of selected cost concepts, including a brief evaluation of each, is provided in Appendix A. Formulas are summarised in Appendix B.

2.4.1. Marginal Incremental Costs - MIC

MIC may be defined as the difference in the present values of the investment programs with and without an incremental increase in demand. In this case the Marginal Capacity Cost (MCC) component of the MIC will be relatively low when capacity utilisation is low and the next investment project is some distance in the future, but will rise as capacity utilisation increases and the timing of the next project draws nearer to signal the magnitude of the forthcoming investment. Thus, MIC has some of the familiar characteristics of SRMC i.e., instability and saw-tooth changes.

Turvey's[17] methodology for estimating the MIC may be summarised as:

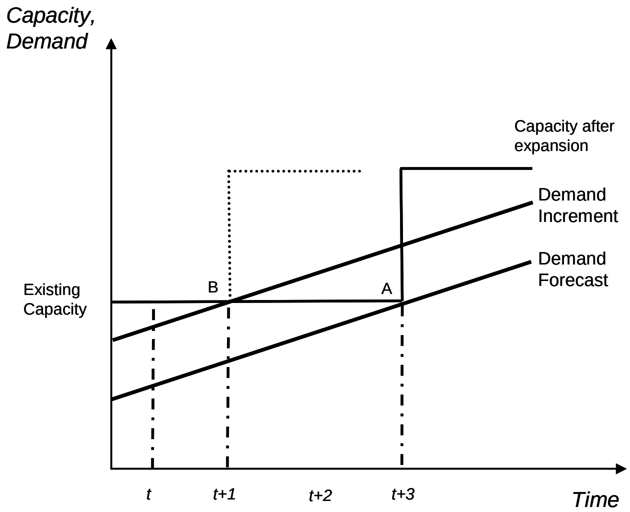
1. forecast the relevant expected demand into the foreseeable future;
2. estimate the system requirements and augmentations that would be required over time to meet expected demand levels;
3. estimate the likely cost of these requirements;
4. adjust the demand upwards by an increment;
5. reconsider the system requirements and augmentations that would be required to meet this new demand pattern and their associated costs; and
6. calculate the MCC as the difference between the net present values of the investment program(s), divided by the total increase in demand.

This framework is illustrated in Figure 2.3 below.

17 Turvey, R, *What are marginal costs and how to estimate them*, Undated and Turvey (1976), *Analyzing the marginal cost of water supply*, Land Economics, 71(4), 158 – 168.

Turvey marginal cost is based on the axiom that, given some growth in demand, additional capacity increments cannot be totally avoided, but can be postponed (advanced) with reductions (increases) in annual demand. The marginal capital cost is therefore the change in the present worth of the next increment in capacity divided by the change in annual demand necessary to postpone (or advance) the building of that capacity increment.

FIGURE 2.3: FRAMEWORK FOR ESTIMATING MIC



In practice this means that the MCC is the cost in net present value terms of moving the next planned capacity augmentation forward by a single year and then dividing the cost by the one-off volumetric increase (or increment) in current demand that would require the planned capacity augmentation to be moved forward. This is illustrated by the formula below:

$$MIC_t^{MCC} = \frac{NPV_t(capex) - NPV_{t+1}(capex)}{\Delta demand}$$, or more formally

$$MIC_t^{MCC} = \left[\frac{I_j}{(1+i)^{j-t}} - \frac{I_j}{(1+i)^{j+1-t}}\right] \Big/ [Q_{t+1} - Q_t],$$

where t = year for which MIC is being calculated

I_j = capital expenditures in year j (the year in which the next large investment expenditures takes place or the year in which the system reaches capacity)

i = the opportunity cost of capital

Q_t = water demand in year t

Note that the MIC definition does not look beyond the next lump of investment, and therefore ignores the effect on unit costs of subsequent increases in output.

With regard to the estimation of the SRMC or MOC, the MIC approach may be illustrated as follows:

$$MIC_t^{MOC} = \frac{\Delta opex}{\Delta demand}$$, or more formally

$$MIC_t^{MOC} = \frac{O_{t+1} - O_t}{Q_{t+1} - Q_t},$$

where O_t is the operating expenditure in year t. SRMC under the MIC approach is therefore the change in operating expenditure divided by the change in demand, where the increment taken is the change in output that occurs during one year.[18]

2.4.2. Average Incremental Costs - AIC

Another way to calculate the MCC is the Average Incremental Cost (AIC) method.

This method has been proposed by Mann et al. (1980).[19] In this paper they note that AIC is calculated by:

> *"discounting all incremental costs which will be incurred in the future to provide for estimated additional demand over a specified period, and dividing that by the discounted value of the incremental output over the period"*

In other words, AIC is the present value of the stream of (least cost) capital expenditure needed to satisfy the projected demand divided by the present value of the stream of demand itself. For an individual unit, the Incremental Cost (IC) is divided by the number of units in the increment to get the AIC.

The basic methodology for estimating the AIC may thus be summarised as:

1. forecast the relevant expected demand characteristics into the foreseeable future;
2. estimate the system requirements and augmentations that would be required over time to meet expected demand levels;
3. estimate the likely cost of these requirements; and
4. calculate the MCC as the average cost per unit of anticipated demand of the total increment to capacity required the forecast period.

As a formula the AIC method for MCC may be illustrated as follows:[20]

$$AIC_t^{MCC} = \frac{NPV(Capex)}{NPV(Demand)}, \text{ or more formally}$$

$$AIC_t^{MCC} = \sum_{k=1}^{T} \left[\frac{I_{t+k-1}}{(1+i)^{k-1}} \Bigg/ \frac{Q_{t+k} - Q_t}{(1+i)^{k-1}} \right]$$

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18 This definition is a discontinuous version of the traditional continuous micro-economic definition of SRMC, where it is a derivative of the total cost function and therefore expresses the 'true' cost of an additional unit.

19 Mann et al. (1980) source their definition of AIC from Saunders, R. J. and J.J. Warford, *Village Water Supply: Economics and Policy in the Developing World*, John Hopkins University Press, Baltimore, Md., 1976.

20 The formula may also simply be written:

The notation is similar to that used in the previous section except that *T* is the number of years for which water expenditures and demand are forecast (the planning horizon). In contrast, under the MIC approach, the capital expenditure only relates to the next augmentation. The other major difference is that under the AIC method account is taken of incremental demand over the whole planning period whereas under the MIC approach the demand is simply the incremental demand in the first year.

The AIC definition thus gives marginal cost estimates which smooth out lumps in expenditure over time while at the same time reflecting the general level and trend of future costs which will be incurred as water consumption increases.

With regard to the estimation of MOC, the AIC approach may be illustrated as follows:

$$AIC_t^{MOC} = \frac{NPV(opex)}{NPV(demand)}\text{, or more formally}$$

$$AIC_t^{MOC} = \sum_{k=1}^{T}\left[\frac{O_{t+k}-O_t}{(1+i)^{k-1}} \Big/ \frac{Q_{t+k}-Q_t}{(1+i)^{k-1}}\right]$$

SRMC under the AIC approach is therefore the present value of the stream of incremental operating expenditure needed to satisfy the projected demand divided by the present value of the stream of demand itself. This is in contrast to the MIC approach that only considers the increment of change in output which occurs during one year.

2.4.3. Long Run Incremental Cost – LRIC

Long run incremental costs may be calculated as:[21]

$$TB\ LRIC_t^{MCC} = \frac{Annuitised\ capex}{\Delta demand}\text{, or more formally}$$

$$TB\ LRIC_t^{MCC} = \left[\frac{i}{1-\left[1/(1+i)\right]^n} \times I_j\right] \Big/ \left[Q_{j+1} - Q_j\right]$$

where *n* refers to the (economic) life of the investment and *j* again refers to the year in which the next major investment is completed. The investment *I* is multiplied by a capital recovery or annualisation factor, in this case an annuity factor. This definition is also sometimes referred to "Textbook" LRIC (TB LRIC).

21 Based on Mann et al. (1980).

As defined above TB LRIC does not extend beyond the next investment. However, it could be redefined to look at the average of the next of several investments.

As a result, during the years t through j TB LRIC^{MCC} will remain constant. At year j+1, j is reassigned to be the next year in which a large investment takes place. In this respect LRIC changes immediately following a new investment to reflect the incremental cost of the next capacity investment.

SRMC in the context of TB LRIC is the same as defined under MIC above.

While the LRIC definition above is concerned with an increment to an existing plant (or an increment on an increment), the practical implementation of LRIC takes another form in the regulation of the telecommunications sector. Here LRIC may be defined as follows:

$$TEL\ LRIC_{t,m}^{MCC} = \left[\frac{i}{1-\left[1/(1+i)\right]^n} \times I_{t,m} \right] \Big/ Q_{t.m} ,$$

where subscript m refers to a particular service. In other words, the annual capital cost required to produce service m, where demand is Q_m. Again it is important to stress that LRIC in telecommunications is not concerned with an increment to existing capacity but entails a re-dimensioning and hence re-costing of the existing network. To arrive at the unit cost estimate costs related to m are therefore not divided by an increment in demand but by total demand for the particular service. SRMC under this definition is simply the annual operating expenditure relating the particular service.

The increment is often defined as a whole group of services using the network. In this regard TSLRIC refers to the increment in costs occurring in the long run of offering a complete (total) service in addition to other services. In contrast, TELRIC refers to the increment in costs caused by identifiable elements that are needed in the production of a service, like switching or transmission between switching centres or a certain advanced function implemented in the switch. While TSLRIC and TELRIC may differ in theory, the approach taken to estimate both types of cost in practice means that they yield similar results.

The main argument for using this LRIC approach is that the cost (or access price) of services should not distort the build/buy decision of new entrants. Entrants will be encouraged to use existing facilities if, and only if, it is economically desirable to do so. Just as important, access charges based on these principles also mean retaining investment incentive for incumbents to upgrade or extend the existing network when new technology is available. When charges are set on this basis, infrastructure competition is encouraged in those areas where it is efficient to have competing infrastructure, whereas service competition is encouraged in those areas where the investment in competing infrastructure is not efficient.

This interpretation of LRIC in telecommunications and departure from the textbook version of LRIC is a result of practical difficulties in modelling and calculating the service costs related to the access services based on additions to the existing network and signalling costs faced by entrants that are changing rapidly due to technology developments. Given the nature of water and wastewater infrastructure, such problems are nowhere as critical in the water industry. Moreover, the use of “full service”, as typically used, moves LRIC towards an average cost concept rather than marginal cost measure.

2.4.4. Comparison of MIC, AIC and LRIC

The approaches outlined above considered the concept of marginal costs from different perspectives.

While AIC calculates the level at which future increments of output must be priced to ensure total incremental cost recovery given forecast demand, the MIC method considers the change in forecast capacity costs arising from a permanent increment or decrement in the forecast demand. “Textbook” LRIC is the annualised cost of the next proposed investment measured relative to incremental demand.

In this respect, the MIC method is often stated as being more explicitly concerned with ‘decision making at the margin’[22] and within the increment. This feature also has the effect of increasing price instability, as prices are more directly adjusted to send the ‘correct’ economic signals. In contrast, AIC is based on a long term planning period and therefore has the property of dampening price changes over time (even in the event of new investment) and hence ensuring stable prices. LRIC on the hand will be constant until a new investment takes place where it will be adjusted to reflect new investment. AIC, therefore, is distinguished from LRIC and MIC by the fact that it takes a longer view of costs.

2.5. Least Cost Schedule

A common feature of the definition of the approaches is that they assume that the investment (or series of investments) necessary to meet output have been optimised. This means that the resulting costs are such that a least cost schedule is created.[23]

In principle, there are number of ways to achieve this “optimal” cost schedule. One way is mathematical modelling involving operations research and multi-period linear programming. Any mathematical model, however, is a simplified representation of the real world and as such may fail to accurately solve the problem. In addition, algorithms may be incorrectly specified, input values inaccurately estimated etc. Without expert input it may be difficult to implement more advanced forms of numerical analysis in practice, while providing confidence in the results.

[22] Decision making at the margin refers, for example, to neo-classical economic decision making where individual consumers and producers make decisions by equating marginal private benefit to marginal private cost and decision making at the society’s level is made by equating marginal social benefit to marginal social cost.

[23] Note that economic efficiency requires that services are always produced using the least cost method of production.

From a practical perspective, it may therefore be more appropriate to rely on general business skills when developing a least cost schedule. This could entail using different investment analysis techniques, ranking expansion alternatives on whole-of-life, annualised cost per unit (eg. annual yield for a dam, peak day capacity for WTP, peak hour capacity for balancing storages and peak flows per second for pipelines and rising mains.

For example, using AIC methodology the following approach could be adopted:

- develop a detailed model of future demand for water services;
- project the base case demand for 30 years into the future;
- develop potential demand management options;
- calculate the LRMC of different options investment options and rank the alternatives; and
- choose the least cost schedule.

2.6. Summary

From an efficient pricing perspective taking into account both demand and supply side efficiency the charges should be so that:

$$\textit{Revenue from annual charges} \quad = \quad \sum_{i=1}^{N} (A_i + LRMC_i \times Q_i)$$

This two part tariff structure ensures that:

- the demand side efficiency criterion is met by sending efficient signals to the customers through the marginal costs of operation taking into account a forward-looking charge for future capital expenditure and incremental changes in operating costs; and
- the supply side efficiency criterion is met by using the fixed charge as a balancing item to ensure full cost recovery.

Note that contrary to what has been assumed in the previous sections, demand may be declining or constant. In this case the volumetric charge component is still LRMC. However, LRMC will not include any capital expansion costs and hence be to equal to SRMC.

The question then remains how best to estimate the LRMC?

Above we have discussed three distinct approaches: the Marginal Incremental Cost (MIC) method, Average Incremental Cost (AIC) method and Long Run Incremental Cost (LRIC) method. All methods have been developed to solve problems of capacity indivisibility and price instability over time. Indivisibility of capacity is a condition typical of water businesses, where capacity is often installed meet future demand for a number of years hence. Construction costs are high in relation to operating and maintenance costs. Strict marginal cost pricing would therefore result in significant fluctuations in price, which in turn would be source of considerable concern for customers.

MJA's analysis indicates that the AIC method is likely to be more stable over time. Hence from a price stability objective the AIC method is preferred.

However, before reaching a firm preference for one method over the other, it is important to understand and assess a range of practical issues associated with the implementation of the approaches. Since AIC and MIC are the two methodologies most often employed in the water industry, we focus our attention on these in the following section.

3. International Experience

It is clear from the previous section that a long-run approach to costing involves defining the relevant increment to measure. The concept of Incremental Costs (IC) has been developed to overcome some of the shortcomings of pure marginal cost pricing as discussed in the previous section. Rather than measuring the cost of providing a single additional unit of output, the incremental costs express the costs of providing an additional increment of output, say 10 GL of water.

LRMC cost concepts are also used within aviation and energy sectors. In the aviation sector, for example, LRMC may be used to set the price of access. As in the water industry the cost structures in aviation suffer from lumpiness and natural monopoly characteristics. As in water, there comes a point when increases in capacity can only be addressed by a major project i.e. some facilities simply cannot be expanded incrementally by their very nature (another whole runway or tunnel or road is required).

In the following we limit ourselves to practical experiences in the water sector. Our survey of the literature of the use of LRMC pricing in the water sector yielded surprisingly few practical and complete examples of the use of LRMC. In this respect it is apparent that the use of LRMC is not well advanced as in for example telecommunications. The most recent and transparent experience is Ofwat in the UK, however, LRMC costing has also been promoted by the Canadian Water Waste Water Authority and the World Bank through projects in developing countries.

3.1. Ofwat

In 2001 Ofwat published a series of reports under the heading “The role of Long Run Marginal Costs in the Provision and Regulation of Water Services”. The aim of these reports were to explain views on the relevance of LRMC in water service provision and in regulatory policy, publish and comment on existing estimates of LRMC, explain how greater consistency in the estimation of LRMC could be promoted, and consult on proposals for the future scope and format of LRMC submissions.

Table 3.1 shows the LRMC estimates provided by different water companies in the UK.

TABLE 3.1: LRMC BY COMPANY AND AREA (INCREMENT)[24]

Water company	resources	treatment	bulk transport	local distribution	Total LRMC
	p/m³	*p/m³*	*p/m³*	*p/m³*	*p/m³*
Water and sewerage companies					
Anglian					
Anglian	16	12	15	1	45
Hartlepool	n/a	n/a	n/a	n/a	13-27
Dwr Cymru	n/a	n/a	n/a	n/a	47
Northumbrian*					
Northumbrian	11	5	28	13	58
Essex	n/a	n/a	n/a	12	56
Suffolk	65	0	0	20	86
Severn Trent	13	15	15	15	58
South West	22	21	n/a	7	49
Southern	n/a	n/a	n/a	n/a	37
Thames	42	3	2	1	49
United Utilities	20	5	11	12	49
Wessex	12	12	25	75	125
Yorkshire					
Yorkshire	25	0	0	2	27
York	0	10	13	4	27
Water only companies					
Bournemouth & West Hampshire	17	9	0	26	53
Bristol	14	2	0	0	16
Cambridge	40	4	0	9	54
Dee Valley	10	19	0	25	54
Folkstone & Dover	36	3	19	0	58
Mid Kent	0	95	25	0	120
Portsmouth	3	0	1	5	9
South East					
Northern	16	9	11	23	60
Southern	24	45	30	23	123
S. Staffordshire	9	6	16	11	41
Sutton & E. Surrey	39	0	n/a	25	64
Tendering Hundred	33	7	0	9	48
Three Valleys					
Three Valleys	8	14	13	0	35
North Surrey	34	28	24	4	n/a

Source: Ofwat "Tariff structure and charges 2002 – 2003 report", Table 26, p. 65.
Available at: http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/AttachmentsByTitle/of_trf99.pdf/$File/of_trf99.pdf

Separate estimates of LRMC are made by increment: 'resources', 'treatment', 'bulk transport' and 'local distribution'. The sum of these increment costs yield the total LRMC.

Key observations that can be drawn from the Ofwat assessment include:

[24] Total LRMC figures may not add up due to rounding.

- variations in the LRMC occur as a result of varying prices per m^3 of water for water abstraction, treatment, and transport and distribution, depending upon local circumstances;
- LRMC include costs of provision of additional resources that might involve a variety of different schemes ranging from new boreholes, increased abstractions, or winter storage mechanisms; and
- distribution costs are included since additional distribution costs might be involved for new sources of supply.

Ofwat does not view the LRMC estimation as a standardised calculation. However, water companies are required make explicit their assumptions, and present a thorough analysis that is demonstrably consistent with the company's Water Resource Plan. Thus, Ofwat seeks to foster consistency in the approach to estimating LRMC and in the level of analysis.

Ofwat does not strongly recommend a specific approach to calculating LRMC. In particular it notes:[25]

> *"Companies should clearly specify the methodology used for calculating LRMC (average incremental cost or perturbation approach). It is preferable for companies to include analysis based on both approaches, which is likely to be based on similar underlying investments."*

However, most, although not all, companies in the UK have adopted the AIC approach. The AIC approach requires consideration of the relationship between future costs and volume growth. However, it is necessary to separate out changes in future costs that are independent of volume growth. Water company studies of LRMC submitted to Ofwat suggest variation in terms of cost inclusions and exclusions in the AIC approach, in particular on issues dealing with metering, leakage, security of supply, and demand management.

Ofwat's view on these issues are summarised below:

- *Metering*: A number of LRMC submissions did not clarify whether metering costs have been included. The Ofwat view is that metering influences demand, the demand reduction associated with metering may be treated as a substitute for development of new resources and treatment facilities. For this reason, the costs associated with metering should be included in LRMC;
- *Leakage*: Leakage reduction forms a significant part of many companies' least cost investment schedules, by making more treated water available to customers and therefore constitutes a direct substitute for development of new resources and treatment works. On this basis, Ofwat believes that costs associated with reducing leakages, in present and future periods, should be reflected in companies' LRMC estimates.
- *Security of supply*: The majority of the LRMC submissions did not clarify the purpose of an intended individual scheme (i.e. whether it is for security of supply or growth). According to Ofwat, the cost of restoring security of supply and the output of such

[25] Ofwat, *The Role of Long Run Marginal Costs in the Provision of Water Services*, p. 60, 2001.

schemes should generally be excluded from estimates of LRMC based on the AIC approach. This is because these are future costs that must be borne regardless of growth in demand. Ofwat note, however, that it may be appropriate in some circumstances be appropriate to consider the costs of restoring security of supply as avoidable, for example if demand were to fall and in this case present an alternative calculation based on the costs of security of supply schemes.

- *Demand management*: Where water companies choose demand management measures as part of their least cost supply-demand balance program, these costs should be included in the calculation of LRMC. This is particularly appropriate where demand management defers the need for major resource investments.

Ofwat has provided guidance on which costs should be included and which costs should be excluded, to ensure standardisation of LRMC estimates. Indeed as noted by Ofwat:[26]

> *"Most companies have provided estimates of LRMC, with a breakdown of the components of their estimate. However, company submissions have contained varying levels of supporting analysis and explanation. In many cases it has been difficult to reconcile company submissions with water resource plans, underlying scheme details or companies' analyses of leakage economics. Many submissions do not clarify the methodology for deriving the least cost investment plan, or the nature of the alternative basis for the LRMC calculation. Sensitivity analyses have also not been presented by many companies."*

A key conclusion that can be drawn from the Ofwat experience is the importance *ex ante* to provide guidelines on the key inputs and assumptions when requiring water companies to engage in a LRMC exercise.

3.2. Canadian Water and Wastewater Authority

The Canadian Water and Wastewater Authority (CWWA) published a Rate Manual in 1993, the *Municipal Water and Wastewater Rate Manual*. This Manual sets out the Canadian approach to rate setting. It discusses the methods and theory underlying the logic and process of charge setting and comes with a fully documented charge software model (a spreadsheet to develop retail charges on a simple two-part tariff, featuring a volumetric charge and a fixed charge that varies by meter size).

The CWWA approach to charge setting is based on three principal goals: full cost recovery, the equitable distribution of costs among customers and the efficient use of both water resources and financial resources. In this respect the CWWA promotes a two part rate structure featuring a constant volumetric charge plus a meter charges that vary by size of service. The volumetric charge is based on LRMC and calculated using a AIC methodology. The cost model includes an option for peak load pricing where MCC is allocated to the summer charges.

[26] Op cit. p. 55.

3.3. The World Bank

In 1977, the World Bank investigated alternative concepts of marginal costs for application in the water supply sector.[27] To our knowledge, this is the first attempt to consistently discuss different approaches to LRMC in the water sector.

The conclusions reached by the World Bank staff are:

- It is not possible to establish a set of precise marginal cost estimation rules that can be followed in all circumstances; and
- compromises are required that will depend on:
  - the degree of capital indivisibility;
  - the elasticities of demand; and
  - prices which currently prevail.

While the authors do not recommend one particular approach, there do conclude that:[28]

> *"It is when capital indivisibility enters the picture that AIC can become more appropriate, for then compromises must be reached between the need to avoid price fluctuations, the need to signal justification of investment, and the need to make best use of existing capacity."*

Indeed, the AIC is now a well recognised concept within the World Bank and frequently used in water supply projects.

[27] Saunders, R. J., Warford, J.J., Mann, P.C., *Alternative Concepts of Marginal Cost for Public Utility Pricing: Problems of Application in the Water Supply Sector*, World Bank Staff Working Paper No 259, 1977.

[28] Op cit. p. 54.

4. Price Setting in Practice

In the following we present our case study of different LRMC concepts and discuss practical pricing issues.

4.1. Case Study

A hypothetical case study was developed in order to gain insights to, and understanding of, the two methods for calculating LRMC. The case study was based on a series of augmentations of water treatment plant in order to meet forecast demand.

Key capital expenditure assumptions are set out in Table4.1. The existing plant capacity is assumed to be 1,185ML per day with annual demand assumed to increase from 241,000ML to 556,800ML over the assumed 30 year planning period. The incremental demand in the first year is 6,025ML. Current incremental operating costs are assumed to be $24 and $15 per ML for energy and chemicals, respectively. These are assumed to increase to $30 and $24 per ML with the future augmentations.

TABLE 4.1: CAPITAL COST AND CAPACITY ASSUMPTIONS

Upgrade	Capacity (ML p.d.)	Cost ($M)
Existing	1,185	-
Upgrade 1	35	5
Upgrade 2	100	10
Upgrade 3	500	40
Upgrade 4	500	40
Upgrade 5	600	45

Figure 4.1 illustrates the forecast demand and the cost and timing of a series of augmentations required to meet the demand over a 30 year planning period. For the purpose of the example, incremental operating costs are assumed to relate to short run costs such as energy and chemicals. In practice, however, future operating costs could involve one-off (or stepped) increases in scale of operating costs, e.g. increase in labour costs to manage and operate the augmented treatment plant(s).

FIGURE 4.1: CASE STUDY EXAMPLE – FORECAST DEMAND AND AUGMENTATION WORKS

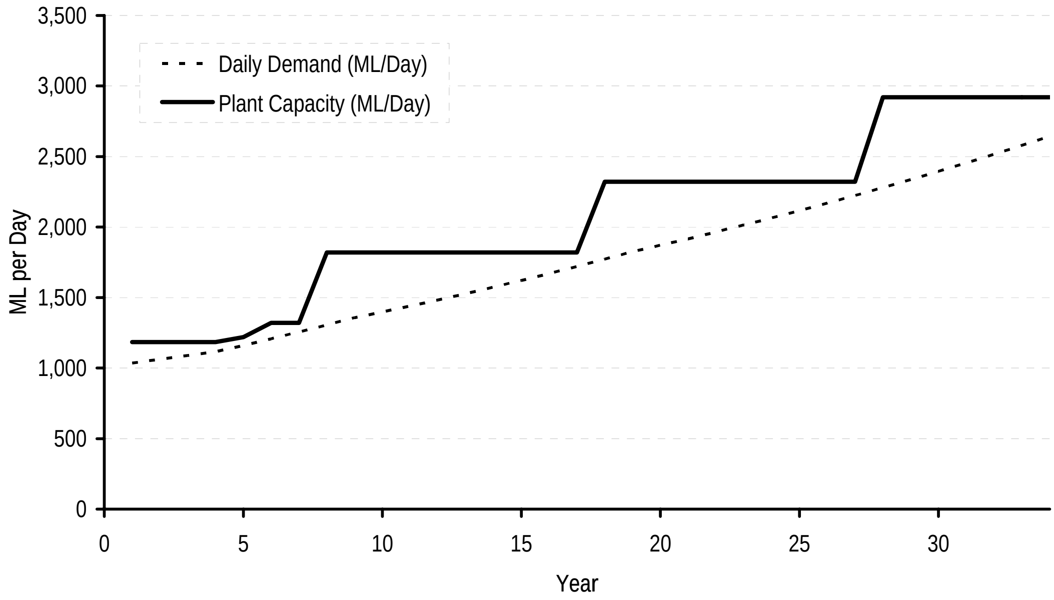

Table 4.2 sets out the calculated LRMC using the MIC method for the separate cases of where a residual value is included and where it is excluded.

TABLE 4.2: LRMC UNDER MIC

Component	Unit	Including Residual Value	Excluding Residual Value
PV of Upgrade 1	$M	3.71	3.74
PV + 1 of Upgrade 1	$M	3.50	3.52
Difference	$M	0.21	0.22
Demand Increment	ML	6,025	6,025
LRCC	$/ML	34.89	35.10
SRMC	$/ML	39.0	39.0
LRMC	$/ML	73.89	74.10

An issue that arises using the MIC method is whether the SRMC should be based on the immediate SRMC (i.e. the $39 per ML) or the SRMC following the first upgrade (i.e. $54).

This uncertainty is removed in the case of the AIC method as the future stream of incremental operating costs are transferred to a present value and in turn divided by the present value of demand to derive a unit cost per ML (refer Table 4.3).

TABLE 4.3: LRMC USING AIC

Component	Unit	Including Residual Value	Excluding Residual Value
PV of Capital Costs	$M	50.3	58.7
PV of Demand	ML	1,600,398	1,600,398
LRCC	$/ML	31.44	36.68
PV of Incremental Operating Costs	$M	86.4	86.44
Unit Cost	$/ML	54.00	54.00
LRMC	$/ML	85.44	90.68

On the basis of our hypothetical example, the AIC results in a slightly higher LRMC. This reflects the fact that the first upgrade is relatively small, resulting in a commensurately small MCC calculated under the MIC method and the use of existing incremental operating costs (i.e., SRMC). However, as illustrated in Table 4.4, using the MIC approach results in the MCC of future upgrades (i.e. Upgrades 2 to 5) not only being higher, but varying substantially in magnitude.

TABLE 4.4: FUTURE MCCS USING MIC

	Unit	Upgrade			
		2	3	4	5
PV of Upgrade	$M	7.05	25.10	14.01	8.80
PV of Upgrade brought forward	$M	6.65	23.68	13.22	8.31
Difference	$M	0.40	1.42	0.79	0.49
Demand Increment	ML	6,025	6,025	6,025	6,025
LRCC	$/ML	66.23	235.78	131.66	82.71

4.2. Practical Pricing Issues

4.2.1. Developer Charges

Infrastructure charges are used to recover a proportion of the cost of hydraulic infrastructure from developers and major customers. These charges are also known as developer or headworks charges. Where applied to residential developments, they are usually levied at the subdivision and building stage. For a water business, contributed assets and infrastructure or developer charges are typically a substantial - but by no means uniform - component of total revenue.

In the context setting prices according to LRMC, a key issue is how developer charges 'fit' within this concept and should be recovered. LRMC includes the capital cost of future augmentation. Demand forecasts will take account of future developments and hence influence on the timing of augmentation and the investment schedule. It could therefore be argued that the developer charge should be zero.

On the other hand, developer charges also serve the purpose of sending locational cost signals and creating incentives for locational "efficient" demand growth.

Developer charges set to zero may also introduce problems related to cost recovery. That is, given the industry-wide practice of funding future capacity requirements (or system augmentation) through developer charges, it would be inequitable to allow a "free ride" for new developers/consumers/developments that utilised part of a "future capacity requirement" when previous developers and consumers had already made a capital contribution towards recovery of that sunk capacity investment.

There appear to be two options for handling this issue.

One option would be to calculate developer charges according to the standard algorithm set out below but net the present value of revenue derived from developer charges from the LRMC estimate.

$$\textit{Developer charge per lot} \quad = \quad \frac{NPV\left[K^{E} + K_{t}^{N} - (R_{t} - C_{t})\right]}{NPV(lots_{t})},$$

where K^{N}_{t} = new investment to service growth in each year *(t)*

K^{E} = value of existing infrastructure apportioned to growth

R_t = the future periodic revenues expected from customers in the development area in each year *(t)*

C_t = the future annual operating, maintenance and administration costs of providing services to customers in the development area in year (*t*)

$lots_t$ = additional lots to which a developer charge can be applied in year (*t*)

The other option would be to calculate the LRMC and developer charges independently. Whilst this would mean that the business was in fact recovering future capital twice – through the LRMC as well as developer charges, it would not necessarily lead to excessive pricing as the access charge would be reduced in order to meet the regulated revenue target for the business. This option would ensure that separate price signals would be provided in relation to the cost future augmentations: first, through the annual charge via the LRMC as the basis for the volumetric charge; and second, as a locational signal to developers through the developer charge.

4.2.2. Sending 'Correct' Signals

The purpose of efficient pricing – as distinct from cost recovery – is to provide customers with a signal of the costs of providing that level of service, that is, to determine required service levels and to modify customer behaviour in the light of changing supply costs.

For example, there is scope to use the tariff structure as a demand management tool to counteract congestion and environment costs and to avoid unnecessary extensions of infrastructure capacity to mitigate these costs. The tariff structure can also provide the economic signals and incentives for the water businesses to modify and upgrade their own networks and behaviour in order to reduce total system costs.

In this respect, costing of the services according to LRMC is only the first step in determining prices for services. Once costs have been determined these will have to be transformed into prices. While pricing in many cases will follow from the outputs of the costing exercise, there are cases where this will not be the case.

On example is that pricing according to peak load. Theoretically, unless capacity is fully utilised during the off-peak period as well as during the peak the rule should be that off-peak users pay just the SRMC, while the peak users pay for MCC and SRMC incurred during the period.

Peaking characteristics are important is determining and dimensioning the capacity of water systems. If peak demands can be reduced this will reduce capacity requirements and hence financial requirements over time.

For example charging higher water prices during the summer, peak period months than during the winter, or off-peak months, offers a means of lowering peak period water demands, thereby lowering overall costs in the long run. Seasonal charges are therefore a potentially effective means for realising more efficient use of water resources when demands on a water utility's system vary systematically across seasons. Their primary advantage is that they provide to consumers an accurate signal of the cost of consumption, including the cost of capacity during peak use periods.

Another example is geographical variations in marginal costs (sometimes termed zonal or nodal prices). While a LRMC model with sufficient detail will seek to model nodal (different prices at each supply point) cost differences, the 'pure' cost distinctions may not apply directly to the final price setting. In this respect it may be necessary to adjust the cost estimates for pricing. Note, however, that zonal charges that are set with little or not reference to the underlying costs may only increase inefficiency in water charges. In this respect it is recommended that cost estimates are provided separately by zone or node where there are likely to large cost disparities.

5. Assessment Against Principles

In this section we discuss and assess the two methodologies for calculating LRMC against the developed pricing principles outlined in section 1.1.

5.1. Demand Efficiency

Demand efficiency requires that customers are charged no more and no less than it costs to produce the unit of service to them. This requires that customers be charged no more and no less than it costs to provide the additional capacity. Charging above this level will force customers to pay too much and consume too little. Conversely, pricing below the marginal costs of service provision leads to the use of the service beyond an efficient level. That is, the incremental level of service has costs in excess of perceived benefits.

As noted previously, demand efficiency requires that prices be set at incremental cost defined by LRMC. However, this principle alone does not allow us to choose between AIC and MIC methodologies as both, in theory, are designed to address the issue of demand efficiency.

5.2. Supply Efficiency

Supply efficiency requires the recovery of sufficient costs to sustain the provision of services required by customers. Supply efficiency therefore requires that revenue be sufficient to recover direct business operating costs and capital charges to replace or renew assets. For a water business, total costs are driven by substantial fixed costs and pricing to cover incremental costs alone would be inadequate and ultimately the business would fail.

In order to reconcile the two efficiency objectives of supply and demand a two-part (or multiple-part) tariff should be introduced, where volume taken, or capacity given is priced incrementally and the balance is apportioned as an access charge/connection fee. This fixed balancing item can be apportioned in a number of ways, e.g. number of connections, serviced population or by more advanced methods like Ramsey pricing, where allocations are made on the basis of price responsiveness.

Use of a two-part tariff can be implemented using either methodology thereby meeting the supply efficiency objective.

5.3. Based on a Solid Theoretical Framework

A third basic principle is that any pricing methodology should be based on a solid theoretical framework. As is clear from discussion in previous sections, the concept of LRMC is one such concept. When coupled with a two-part tariff structure the outcome is one that balances both demand and supply side efficiency.

5.4. Fair and objective

Pricing should reflect the cost of service provision and these costs should be equitably distributed.

Equity or fairness is not easily dealt with in economic terms, as it involves social factors, such as politics and ethics. Economic judgements are normally not concerned with whether behaviours regarding equity are valid or not, but merely describes the consequences of these judgments in efficiency terms, and observes what those value judgments are. However, other things equal, the principle of 'horizontal equity' should apply, i.e. the same price should be charged for the same level of service where it costs the same. Different prices may, however, need to be charged for the same level and quality of service where the costs are different. Such measures would be reflected in the LRMC if implemented appropriately.

5.5. Pricing stability

The resultant charges from applying the methodology should not fluctuate substantially from year to year. In other words, prices should not change within what is constituted a 'reasonable' interval. While both MIC and AIC seek to solve the problem of charge instability by incorporating capital costs in the long-run, our analysis has shown that the MIC method tends to be more susceptible to significant changes from year to year, in particular in the case when capacity expansion draw near. Similar outcome is not the case for the AIC method.

From a pricing stability perspective therefore AIC is the preferred approach.

5.6. Transparency

There are major advantages in cost and decision rules being fully transparent. This is required to allow the cost recovery and pricing regime to be explainable and credible to customers and defendable to shareholders and regulators.

In this respect it is therefore it is advisable to keep any pricing principle simple. Complexity will increase non-transparency in the price determination process. In this respect our analysis of the different methodologies available for determining LRMC indicates that the AIC method is preferred as it is conceptually and computationally simpler, with less room for judgement once a least-cost expansion strategy has been developed. This conclusion is supported experience from the UK, suggests that water businesses tend to prefer AIC at the expense of the MIC method.

5.7. Practicality

A sixth principle is that of practicality, or administrative ease of use. A key question here is whether relatively sophisticated pricing methods can be reasonably applied in a large number of water utilities.

Administration and management costs increase with the complexity of the pricing and tariff structure. The efficiency gains from a finely disaggregated tariff structure obviously must exceed the transaction costs involved – otherwise why bother? For example, any gains must exceed the additional administrative, political and other transaction costs which might be incurred. However, while practicality seems to be a reasonable principle, it has also the potential to be abused. In this respect a balance must be found.

In our view, LRMC pricing is not a precise science and guidelines are required to standardise treatment of input parameters and assumptions such as discount rates and use of residual values. In particular, any costing exercises will rely on a series of subjective evaluations that within reasonable intervals will yield substantially different results. In this respect overly complex models may not improve estimates.

The principle of practicality therefore suggests that a simple and transparent methodology is preferred. As stated above, the AIC method is judged to result in less risk of inconsistency in application when undertaken by different water businesses.

5.8. Flexibility

The principles underlying the cost recovery and pricing regime should not lead to rigid pricing formulae which would give the same result regardless of circumstance. Rather, the common set of principles when consistently applied to different circumstances will sensibly yield different outcomes. Consequently, the principles need to be clearly understood within government and water businesses so that these regimes can be adapted as circumstances and situations differ, change and evolve.

In our view, such flexibility may be achieved by applying AIC.

In addition, the AIC methodology will limit the opportunity for regulatory gaming. Our analysis of the MIC method suggests that there is greater room for 'gaming' the outcome of the model. Use of the AIC method is therefore judged to more likely yield more consistent results over time than the MIC method. Moreover, it will act to move water businesses to think longer term which, in our view, is appropriate given the long term nature of water assets and the lead times generally required to implement large-scale augmentations to system capacity.

5.9. Other Issues

International experience suggests that there is general agreement on the basic principle of using LRMC in the calculation of the volumetric charge for water services. Moreover, there is an apparent practical preference for the use of the AIC method over the MIC method within the water industry, although there does not appear to have been a formal recommendation to this effect by regulators such as Ofwat. The fact that water businesses generally have a clear preference for the AIC method suggests that this method is easier to understand and implement.

5.10. Summary of Principles

Of the two pricing methodologies examined in detail, use of AIC is the option that best meets the principles outlined above. This is summarised in the table below.

TABLE 2 SUMMARY OF THE RELATIVE MERITS OF MIC AND AIC

Principle	MIC	AIC
Demand efficiency	Encourages decisions on the 'margin'.	Seeks to send the right signals and provides a stable and sustained signal.
Supply efficiency	Does not ensure full cost recovery for either the increment or the business	Does not ensure full cost recovery for the business, but ensures cost recovery of forecast incremental cost.
Based on a theoretical solid foundation	Both methodologies are based on work by academics in an attempt to overcome the problems of discontinuities, indivisibility and price instability.	
Fair and objective	Both methodologies reflect the cost of provision. They are not explicitly concerned with fair or equitable outcomes. MIC may provide less horizontal equity over time given the inherent greater volatility in pricing.	
Transparency	Is conceptually more difficult to understand and explain than AIC and hence may reduce credibility.	Is easy to understand and explain.
Pricing stability	Tends to be more susceptible to significant changes from year to year.	Will produce stable price schedules.
Practicality	In principle a practical approach, however, conceptually more difficult to understand giving rise to practical implementation difficulties.	A simple approach that is easy to understand and implement.
Flexibility and adaptability	Will yield very different results in different circumstances. Will however, create opportunities for regulatory gaming and, as such, may be regarded as 'too' flexible.	Will yield different results in different circumstances. Is adaptable and minimises opportunities for regulatory gaming.

5.11. Conclusion

On the basis of our established criteria and our review of the theoretical and practical issues involved in defining LRMC for pricing of water services, we recommend the use of the AIC methodology.

Additionally, this judgement is supported by the following general assessment:

- *AIC is easy to understand*. Our own simulations and experience from the UK suggest that AIC is better aligned for practical implementation than the MIC method.
- *AIC is computationally straight forward*. It is sometimes stated that MIC is more simple than AIC. From a practical perspective this conclusion is misconceived. The MIC and AIC method are subject to similar data and computational requirements. While the MIC method in principle only requires a consideration of the forecast changes to total cost and demand this still requires some consideration of the relationship between future demand and costs.
- *AIC is consistent with infrastructure planning*. An accurate implementation of the AIC methodology is consistent with more general approaches adopted in infrastructure planning.
- *AIC forces businesses to think long-term.* While the MIC method may be implemented for a shorter planning horizon or until til next planned augmentation, AIC should look further and hence force water utilities to consider long term developments of their business.
- *AIC produces stable results*. The MIC method tends to be more susceptible to significant changes from year to year, in particular in the case when capacity expansion draws near. A similar outcome is not the case for the AIC method.
- *AIC minimises regulatory gaming.* The MIC method creates the opportunity to more easily manoeuvre within certain price ranges. In this respect MIC increases the opportunity for regulatory gaming with different outcomes. Contrarily, it more difficult to play out similar gaming opportunities.

5.12. Recommendation

We recommend that QCA moves to implement AIC as its preferred methodology for estimating LRMC by water businesses.

However, in making this recommendation it is also important that in calculating LRMC for either pricing or cross-subsidy purposes that water businesses clearly document:

- the role of cost-volume relationships;
- the treatment of common and shared costs;
- the level of service and planning scenarios used for investment planning.
- information on demand forecasts. This will reflect, for example, assumptions about the ramp up of capacity utilisation of programmed resource schemes, and assumptions about the water savings expected from demand management options;
- the specific project(s) modelled including consistency with water resource plans and assessments of the economic level of leakage, including any constraints applied in deriving the least cost programme;
- detailed information on investment costs, unit costs, lifetimes, price trends, etc. Such information should be detailed the investments scheduled for the immediate future and progressively less detailed for the periods further into the future;

- an assessment of any significant environmental costs that should be taken into account in deriving the least cost investment programme; and
- appropriate sensitivity analyses to test the calculations in order to identify those inputs to which the model outputs are most sensitive and report on theses sensitivities.

Appendix A

Cost Concept	SRMC	LRMC	LRIC	TSLRIC
Description	Includes only those cost items that vary in the short run, i.e. the costs associated with producing an additional unit of output.	The additional cost incurred by the firm in producing an extra unit of output in the longer term when all inputs including capital can be varied, i.e. including the costs of building additional capacity to meet future demand.	The incremental cost measures the change in the total costs by providing an increase or decrease in output by a substantial and discrete increment. In the long run, capacity may be changed. LRIC therefore includes both the capital costs associated with a change in capacity and volume sensitive costs. Incremental cost methodologies are normally forward-looking and can be expressed per unit by dividing the incremental cost by the number of units in the increment. Avoidable costs are a similar concept, except that they refer to the costs that would be avoided were a unit of demand not met.	TSLRIC measures the difference in cost between producing a service and not producing it. TSLRIC is LRIC in which the increment is the total service. Depending on what services are the subject of a study, TSLRIC may be for a single service or a class of similar services. TSLRIC includes the incremental costs of dedicated facilities and operations that are used by only the service in question. TSLRIC also includes the incremental costs of shared facilities and operations that are used by that service as well as other services.
Rationale	The starting point for economic efficiency is marginal cost pricing. Standard economic theory prescribes that prices be set equal to short run marginal costs in order to inform consumers of the resource cost incurred in production. This should ensure that resources are put to their best possible use. SMRC is designed to encourage the efficient use of existing capacity.	Same as for SRMC, however, LRMC pricing is designed to signal to consumers the marginal costs of capacity expansion. The use of SRMC pricing may stimulate growth in demand which would be inefficient to meet in the longer term, whilst the use of LRMC pricing may leave existing capacity under utilised.	LRIC is closely related to the LRMC concept. The difference between the two concepts is that a unitary increment is changed to a substantial and discrete increment in output. The link to the marginal cost concept suggests that the average incremental cost as a price will lead to economic efficiency in the same manner as LRMC.	Same as for LRIC

Cost Concept	SRMC	LRMC	LRIC	TSLRIC
Practical Considerations	In the context of utility pricing, SRMC are highly variable as a result of the modularity of capacity: if a small increase in demand can be accommodated within the existing capacity then the short-run marginal cost will be close to zero; if not then a large cost will be incurred to increase the capacity by more than enough to cope with the small increase in demand, and the corresponding SRMC will be very high (SRMC would rise to whatever price level is necessary to curtail demand to match available supply) It would not be appropriate (or even practical) to set prices on the basis of such highly variable costs, and therefore it is necessary to consider not SRMC but rather LRMC.	The challenge when calculating LRMC is to identify how, on average, capacity and hence costs increase with demand. LRMC is typically disaggregated into two main types of marginal costs: marginal operating costs (MOC); and marginal capital costs (MCC), associated with bringing forward investment projects. MOC are generally simpler to estimate, as they usually have a more easily defined relationship with incremental increases in demand. Estimating MCC is more difficult. These are the costs associated with bringing investment forward as a result of an incremental increase in demand. The most common approaches to estimate the LRMC are: The Marginal Incremental Cost (MIC) Method and Average Incremental Cost (AIC) method.	Incremental costs are normally easier to measure than marginal costs. This is because the increment can be sized in an operational manner. However, when calculating forward looking LRIC different planners' individual technical solutions and evaluations may create disputes on the exact Figure. The key practical differences between LRIC and LRMC used for regulatory purposes is that LRMC typically only considers additions in terms of large increments (or services) while the LRIC approach entails a reconsideration of the entire network (allowing for sufficient capacity over the long run). Some-times the acronym "FL" is added to LRIC (FL-LRIC) to underline the forward-looking approach. LRIC are divided by the number of units in the increment to get the Long Run Average Incremental Costs (LRAIC). The terms LRIC and LRAIC are often used interchangeably, with the "A (Average)" being implicit in LRIC.	Same as for LRIC. Regulators tend to distinguish between TELRIC (Total Element) and TSLRIC. TELRIC refers to the increment in costs caused by identifiable elements that are needed in the production of a service. It may be argued that to two approaches are not equivalent; however, in practice the two approaches will yield similar results. TELRIC is a standard coined by the FCC (USA), and is connected to the "unbundling" of the incumbent's business. Generally, this unbundling is limited to certain elements of the network infrastructure, and that is why it is termed TELRIC. TELRIC is TSLRIC where the increment is a network element, plus a reasonable allocation of forward-looking joint and common cost.
Evaluation	SRMC is a useful notion as it provides the price floor, representing the minimum cost of utilising a capacity that must be recovered in the short run. However, in the long run, capacity must be rebuilt.	LRMC are in effect a smoothed or averaged version of SRMC. LRMC therefore effectively avoids volatility in pricing and should therefore be preferred to SRMC. Further, LRMC allows recovery of fixed costs, although will exclude common costs.	LRIC is a practical concept. As with the marginal cost concept, incremental costs ignore the full recovery of costs. Regulators therefore often add residual joint and common costs to ensure full cost recovery.	Same as LRIC.

Appendix B

Cost methodology	Formula
Marginal Incremental Cost	$MIC_t = \dfrac{O_{t+1} - O_t + \dfrac{I_j}{(1+i)^{j-t}} - \dfrac{I_j}{(1+i)^{j+1-t}}}{Q_{t+1} - Q_t}$
Average Incremental Cost	$AIC_t = \dfrac{\sum_{k=1}^{T} \dfrac{O_{t+k} - O_t + I_{t+k-1}}{(1+i)^{k-1}}}{\sum_{k=1}^{T} \dfrac{Q_{t+k} - Q_t}{(1+i)^{k-1}}}$
"Text Book" Long Run Incremental Cost	$TB\ LRIC_t = \dfrac{O_{t+1} - O_t}{Q_{t+1} - Q_t} + \dfrac{I_j}{Q_{j+1} - Q_j} \times \dfrac{i}{1 - [1/(1+i)]^n}$
"Telecom" Long Run Incremental Cost	$TEL\ LRIC_{t,m} = \dfrac{O_{t,m} + I_{t,m} \times \dfrac{i}{1 - [1/(1+i)]^n}}{Q_{t,m}}$
Notation	I = capital expenditure Q = demand O = operating expenditure t = year for which costs are being calculated j = the year in which the next large investment expenditures takes place or the year in which the system reaches capacity i = the opportunity cost of capital n = asset life m = a particular service T = the number of years for which demand is forecast (the planning horizon)