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Guidelines for Municipal Water Pricing

Roger McNeill and Donald Tate

Social Science Series No. 25

Inland Waters Directorate
Water Planning and Management Branch
Ottawa, Canada, 1991

(Disponible en français sur demande)

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Abstract

A rate structure for water supply and waste treatment should recover all costs and result in efficient use of water by the final consumer. The water utility should recover both fixed and variable costs, as well as the costs of future expansion. Efficient use of water means that water is supplied up to a point where its value to consumers is greater than or equal to the cost of supplying it. A two-part tariff that includes a volume based price and a fixed connection charge can meet both the cost recovery and efficiency objectives. The volumetric portion of the tariff should be set equal to the marginal cost of water. In off-peak periods, the marginal cost is equal to the marginal operating cost, which only includes variable costs. In peak periods, the marginal cost includes both the marginal operating cost and the marginal capacity cost, where marginal capacity cost is the increase in future expansion costs resulting from a marginal increase or decrease in consumption. The fixed connection charge recovers any additional costs not met by the volumetric price.

The first step in the analysis develops a total cost curve based on the utility's operating budget and current expansion plans. The total cost curve shows the relationship between water supply and total costs to the utility. The second step derives the marginal cost curve from the slope of the total cost curve. The third step estimates the aggregate demand curve for water based on information supplied in this report. The analyst then determines the correct estimate of marginal cost for water from the intersection of the demand curve for water with the marginal cost curve.

Résumé

Une structure tarifaire pour l'alimentation en eau et le traitement des eaux usées permettrait de recouvrer tous les coûts et aurait pour résultat l'utilisation économique de l'eau par le consommateur ultime. Le service public de distribution de l'eau devrait recouvrer les coûts fixes et variables de même que ceux entraînés par une extension future. L'eau est utilisée de façon économique lorsque sa valeur pour le consommateur est égale ou supérieure à ce qu'il en coûte pour la fournir. Un tarif binôme, comprenant un prix selon la quantité et des frais fixes de branchement, permet d'atteindre les objectifs de recouvrement et d'économie. L'élément tarifaire pour la quantité devrait être égal au coût marginal de l'eau. En période de consommation normale, le coût marginal est égal au coût marginal de fonctionnement, qui ne comprend que les coûts variables. Pendant les périodes de pointe, le coût marginal comprend à la fois le coût marginal de fonctionnement et le coût marginal de capacité maximale, ce dernier étant l'accroissement des coûts d'une extension future résultant d'une augmentation ou d'une diminution de la consommation. Les frais fixes de branchement permettent de recouvrer les coûts additionnels pour lesquels l'élément tarifaire se rapportant à la quantité ne suffit pas.

Dans la première étape de l'analyse, on trace une courbe des coûts totaux en fonction du budget de fonctionnement et des plans d'extension du service de distribution. Cette courbe montre le rapport entre la quantité d'eau fournie et les coûts totaux pour le service en question. À la deuxième étape, la courbe des coûts marginaux est établie d'après la pente de la courbe des coûts totaux. La troisième étape consiste à tracer la courbe de la demande totale d'eau d'après les données fournies par ce rapport. Enfin, le point d'intersection de la courbe de demande d'eau et de la courbe des coûts marginaux donne la valeur du coût marginal de l'eau.

CHAPTER 1

Introduction

Water rates, sometimes referred to as user charges, form a major source of revenue for municipal water utilities. The Federation of Canadian Municipalities (FCM), for instance, showed that 63% of total water utility revenue derived from rates charged to consumers. General taxes accounted for an additional 27% of revenue, the remaining sources being the senior levels of government and debt.

In addition to being a revenue source, water rates influence usage through both their structure and their level (Environment Canada 1989). Many Canadian municipalities charge a flat rate that provides no incentive for rational water use. Under this rate structure, the consumer is afforded unlimited access to the public water system in exchange for a fixed periodic payment. Other municipalities use a declining block rate structure that rewards high volume users. Both of these rate structures (flat rate and declining block) discourage conservation of water, increase capacity requirements, and result in economically inefficient use of water. With respect to the level of water rates, many studies have documented evidence that rate of payment affects the volume of water used. Low water charges in many areas of the country result in overuse of water and in revenue shortfalls for utilities. In summary, water rates affect both the revenue raising capability and the overall size of municipal utilities.

The FCM (1985) also documented an approximate $6 billion shortage of funds in Canadian municipalities for water system repair and upgrading. This estimate was later raised to $7.5 billion to allow for inflation and changes to the tax system. The FCM called for a tripartite sharing of these costs among the three levels of government. Concurrently, the federal government was developing the Federal Water Policy (Environment Canada 1987), which called for realistic water pricing[1] as a central measure to encourage both water conservation and the user-pay philosophy of valuing water resources. Working from the water policy, the federal government suggested that the best way of raising funds for infrastructure-related purposes was through a restructuring and raising of municipal water rates. This study is intended as a resource for use by water utilities that are restructuring water rates to achieve economic efficiency and full cost recovery.

The study examines the issues involved in establishing effective municipal rates for water supply. Specifically, the study has three purposes:

1. to outline the theory of marginal cost pricing of water,
2. to translate this theory into a practical approach to rate making in Canadian municipalities, and
3. to provide examples of applying this methodology.

The report concerns only municipalities with centralized water supply systems. It does not consider situations in which small municipalities may have individualized groundwater sources of supply. It deals with industry only insofar as industrial operations draw upon municipal systems for all or part of their water servicing. Finally, as federal researchers, we are

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[1] Defined here as pricing water in such a way that the full costs of both intake and discharge treatment and delivery are borne by users of the service.

very much aware of the jurisdictional issues regarding municipal water management. Accordingly, this study should be viewed in the research context rather than as a precursor to any attempt to establish guidelines in a legal sense.

Chapter 2 examines the issue of water metering, viewed here as a necessary first step toward realistic water pricing. Chapter 3 provides a synopsis of the theory of efficient pricing. Chapter 4 focuses on the costs of operating a municipal water utility and the subsequent revenue requirements. Chapter 5 then examines the issues of rate schedule design and development. Here, the theoretical principles of rate making are combined with the material on cost and revenue requirements developed in Chapter 3. The final chapter provides examples of rate making based on the methodology advocated.

CHAPTER 2

The Importance of Metering

The water pricing method put forth in this paper relies upon measuring the volume of water used by individual customers of the water utility. For this reason, the installation of meters for all customers constitutes the first step toward realistic pricing. Without this first step, realistic pricing of water services will not be possible.

Because the topic of water metering is so important to the issue of water pricing, this chapter deals with the subject in detail. Decisions about metering have proven controversial in many Canadian municipalities, and, we suspect, still are. This chapter examines the controversial issues in order to provide decision-makers with adequate information and background. It first outlines the state of water metering in Canada and then discusses the benefits and costs of water metering. The final section concerns an outline of the effects of metering on water use. A recently completed study dealing with the metering issue in Canada (Canadian Water and Wastewater Association (CWWA) 1989) is referred to throughout the chapter.

THE STATE OF WATER METERING IN CANADA [1]

Across Canada, approximately 50% of the connections to water utilities are metered. Of the municipalities with a population of over 1000, 27% are fully metered, 21% are partially metered, and 52% are not metered at all. The nonmetered population tends to be concentrated in the smaller municipalities (with an average population of 20 000 versus one of 34 000 in metered municipalities), although substantial portions of some of the largest cities (e.g., Calgary, Toronto, and Vancouver) are also unmetered. In the partially metered municipalities, 72% of industrial services, 67% of commercial/institutional services, and only 31% of residential services are metered.

Water use volumes vary substantially between metered and nonmetered areas. Water pumpage in the former varies between 0.5 and 0.7 cubic metres (m^3) per day; in the latter it is 1 m^3 per day or more. This reflects a common research finding that water use declines, often by as much as 30%, following the installation of water meters and the implementation of volume based pricing.

In geographical terms, the Prairie provinces lead in the use of meters by a wide margin. Over 70% of Prairie municipalities are fully metered, and only 12% are not metered at all. In contrast, fewer than 18% of municipalities in British Columbia, Quebec, New Brunswick, and Newfoundland have full water metering. The remaining provinces vary between 25% and 50% in their use of municipal water metering.

The Canadian experience with water metering suggests that there is still a long way to go before municipalities are "universally metered." Universal metering will cost a total of $700 million for equipment and installation across Canada (Tate 1989, p. 15). As noted, in many areas metering has generated controversy, and certainly expenditures on this magnitude require examination of their benefits and costs.

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[1] Data in this section are from CWWA (1989), Chapter 2.

THE BENEFITS AND COSTS OF WATER METERING[2]

Several economic principles underlie the evaluation process for the metering decision. This section outlines these principles, starting with a definition of benefits and costs, followed by a discussion of how they can be measured.

Defining Benefits and Costs

A fundamental, but frequently misunderstood, step in conducting benefit-cost analyses concerns the precise determination of which factors constitute a true economic cost or benefit. In general, benefits and costs are those impacts that represent a gain or loss in real resources, as opposed to impacts that represent a transfer of income from one group in society to another.

For example, higher water rates transfer income from consumers to the owner of the water system, usually a public utility. Nothing of value is lost from the municipality's collective pool of income (i.e., the combined wealth of all municipal residents — consumers and producers). Hence, the increase in consumer costs does not constitute an economic cost. Although the reduced water use resulting from higher water prices does represent a real cost to residents, since consumers are led to lose something they value, such as green lawns or cleaner cars, the extra revenue earned by the municipality from higher water rates is not an economic benefit, since nothing of value has been gained by the municipality overall. But the reduced capital and operating costs do indeed constitute a real economic benefit, since the municipality (i.e., society) can use the otherwise dedicated resources for other more highly valued investments.

Benefits of Water Metering

Without water meters, consumers pay the same amount for water services no matter how much water they use. Upon the introduction of meters, consumers pay in proportion to their water usage, and demand falls accordingly. As a result, benefits accrue to the municipality in the form of smaller water and wastewater capital requirements and lower system operating costs. Figure 1 will assist in examining these economic benefits.

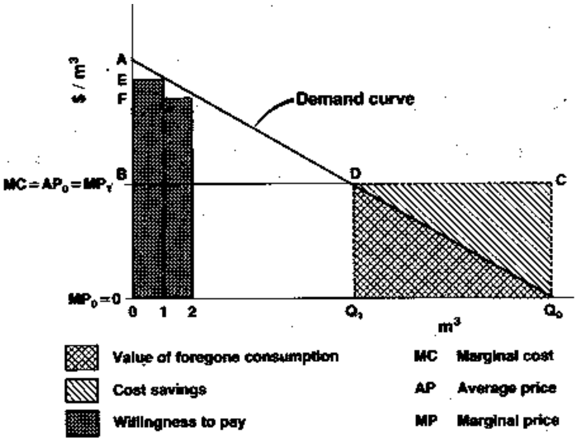

Figure 1. Benefits and costs of water metering.

The demand curve for water services, AQ_0, slopes downward to the right, indicating that as the price of water services rises, demand for those services falls. The municipality, prior to metering, charges its customers on a constant, or flat rate, basis. Since there is no extra expense for using an additional unit of water, the "marginal price" of water is said to be zero. At the point where the marginal price of service is zero (i.e., MP_0), demand equals Q_0. Upon introduction of meters, however, the marginal price of water exceeds zero, since customers must pay extra for additional units of water used.

Determining the savings (i.e., benefits) that occur to the municipality as a result of metering depends on estimating the change in water use upon installation and the costs associated with satisfying different demand levels. The first step is to determine the marginal cost of service, which is the additional cost incurred in supplying an extra cubic metre of water to consumers.[3] As shown in Chapter 4, the price of water should equal its marginal cost, under the pricing

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[2] This section draws heavily upon, and sometimes repeats, the CWWA study referred to earlier (CWWA 1989, pp. 3-2 to 3-7). This study was funded by the Inland Waters Directorate, Environment Canada, to support the water pricing strategy of the Federal Water Policy.

[3] Calculation of marginal costs of water supply is central to Chapters 4 and 5, and will be discussed extensively there. Essentially, marginal costs are those that vary with demand. These may include both operating and capacity costs.

system recommended in this paper. Accordingly, in Figure 1, the new price ($\$B/m^3$) equals the marginal cost of producing the extra unit of water. Multiplying the change in demand resulting from metering ($Q_0 - Q_1$) by the marginal cost of service provides an estimate of the total cost savings attributable to metering. Rectangle Q_1Q_0CD in Figure 1 represents these savings.

This discussion excludes the potential reduction in capital and operating and maintenance (O&M) expenses associated with wastewater collection, treatment, and disposal. Though not included in Figure 1, these benefits should be estimated in the same manner as outlined here. In some cases the benefits of reduced wastewater capital and O&M expenses may outweigh the cost savings from reduced water supply.

Costs of Water Metering

The purchase and installation of meters make up the most obvious costs of the metering decision; these costs are relatively easy to compute. The costs of ongoing meter maintenance and possibly higher billing expenses must also be considered.

The value of foregone water consumption under a non-zero pricing scheme imposes an additional, but more obscure, cost. Area Q_1Q_0D represents this cost. Intuitively, this cost relates to the expense borne by consumers of maintaining dirtier cars, browner lawns, and the like, because of their reduced water consumption. To conceptualize this in terms of the diagram, one must apply what economists call the "willingness to pay" concept.

In economic analysis, the demand curve (such as AQ_0) represents the relationship between price and the quantity demanded. In the demand curve of Figure 1, consumers are willing to pay a price equal to OE for the first cubic metre of water, OF for the second, and so on. Without meters, since consumers demand a quantity of water equal to Q_0, their marginal willingness to pay for an extra unit of water is zero.

Upon introducing meters, water use falls to Q_1. At this level of usage, consumers are willing to pay $B for an additional cubic metre of water (i.e., the price established per cubic metre). To approximate the average value consumers give to water use in the range Q_0 to Q_1, the midpoint between $0 and $B per cubic metre can be chosen. The value of foregone water use for consumers equals this average value times the change in demand due to metering (represented by Q_1Q_0D in Fig. 1). This value, which represents the cost of foregone water use, is then added to the purchase, installation, and operation cost of the meters to derive a total cost of the metering decision.

Net Benefits of Water Metering over Time

The costs, and more especially the benefits, of water metering extend over time, and analysis requires that the temporal dimension be taken into account in assessing the overall net benefits of metering. Since the benefits and costs do not occur uniformly through time, adjustments are required to make them comparable.

Comparability requires converting dollar estimates of future impacts into equivalent current values (Fig. 2). From today's viewpoint, future receipts (benefits) and payments (costs) are worth less than the same amounts due or payable today.

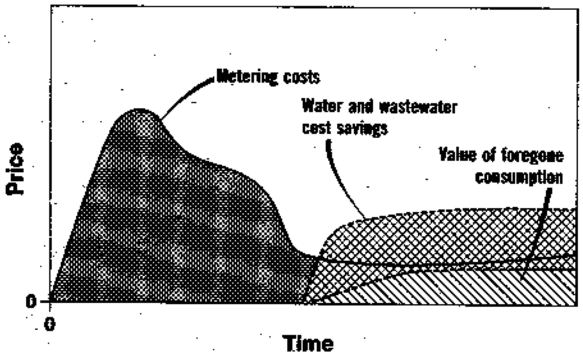


Figure 2. Time profile of water metering: benefits and costs.

For example, at a 10% interest rate, $2 seven years in the future is worth only $1 today, simply because a dollar invested at a 10% rate will double in value in seven years. Discounting techniques translate future receipts and payments into amounts that if set aside now at expected long-term interest rates, would accumulate to the future amounts. These techniques allow all benefits and costs to be considered in terms of current opportunities. In other words, discounted present values reflect current opportunities foregone in undertaking to pay future costs (e.g., metering now will have benefits in the future).

The analyst is now in a position to assess whether metering is justifiable in economic terms. To do this, the present value of the costs (i.e., after discounting) are subtracted from the present value of the benefits to give the net present value (NPV) of the investment. A positive NPV means that the metering decision is economically justified; a negative NPV implies the opposite. In the latter case, the investment would not be efficient. Alternatively, the analyst can produce a benefit-cost ratio by dividing the discounted stream of benefits by the discounted stream of costs. A ratio greater than one implies economic efficiency. As outlined earlier, the CWWA has produced a computer based benefit-cost model of the metering decision, which is available to Canadian municipalities.

Selected Empirical Studies

Many municipalities throughout the world have examined the issue of water metering, with the result that a wide range of studies is available. Both methodological and local differences mean that many studies are not perfectly comparable. They do, however, provide a general impression of the economic benefits and costs of metering. The studies, carried out under a wide range of conditions, provide both favourable and unfavourable conclusions as to the net economic benefits of meter installation.

Brooks and Peters (1988) looked at the benefits and costs of water metering as part of their Science Council review of water demand management. They conducted no primary study but offered instead an overview of previous work by others. They stress that positive NPV may depend on the water price faced by consumers after metering as well as on the cost of purchasing and installation. They found that meters were

> cost effective if water cost more than 21 cents per m_3 and the meter could be installed for under $500. A 1986 report from New York State states that meters will be cost effective at anything under $650 per meter. The same report said that a meter (device and installation) costs $400 at a residence and $2000 at a large apartment house. A 1984 California report states that the cost of providing metered water to a house at the time of construction was only $80.
>
> —Brooks and Peters 1988, p. 20.

Grima (1972) reported the results of a benefit-cost simulation of the metering decision in the the Borough of Etobicoke, Metropolitan Toronto. Based on the data presented in the report, the benefit-cost ratio of 1.1 indicated that the decision to meter was economically efficient. However, this finding depended on the decline in water use following metering and the financing conditions under which equipment was purchased and installed. Associated Water Services Ltd. (1980) conducted a benefit-cost study of metering for Alberta Environment. The study examined metering installation in communities with fully centralized water acquisition, treatment, and distribution systems. Benefits and costs on a per capita basis totalled $40.47 and $11.00 respectively, giving a positive NPV of $29.47, indicating that the metering decision was economically efficient.

Hanke (1980) reported the results of a study of water use restrictions (including metering) in Perth, Australia, using a monthly basis benefit calculation instead of the annual period normally used. The study concluded that restriction would have been economic in every month and that the total net benefits would have equalled $504 942. In an unpublished paper on the same municipality, Hanke reported a benefit-cost ratio of 1.62, again indicating economic efficiency.

The municipality of Peterborough, Ontario (PWD 1984), conducted an analysis of the decision to meter. The analysis emphasized the benefits of decreased water use but also evaluated the effects of metering on delaying requirements for system expansion. It found that metering would probably lead to a 10% decline in water use, but that the resultant savings, even combined with those due to delayed capacity expansion, would not justify the costs of water metering.

METERING EFFECTS ON MUNICIPAL WATER USE

Many studies have documented the decline in water use with the introduction of water metering. This decline is in part psychological as consumers realize that they can control the size of their water bills through their own actions. But the fall is also an economic response, as consumers optimize their own water consumption based on volume based water rates that are introduced when meters are installed.

The usual pattern is for water use to fall quite substantially immediately following meter installation. Water use then "rebounds" as consumers become familiar with the new pricing regime. Past studies follow different methodologies and measurement techniques, depending upon their purposes. Some have the water use reactions to price and metering as their primary focus; others include these measures incidentally in fulfilling other purposes. For these reasons, it is difficult to draw precise conclusions about the magnitude of the post-metering decline in water use.

Table 1 comprises a sampling of literature pertinent to the effects of metering of water use.

Table 1

Effects of Metering on Water Use

Area	Impact and special details	Source
Western U.S.	Unmetered areas have over 50% higher water use than metered ones on average; over 100% for maximum day and maximum hour	Linaweaver, Geyer, and Wolff (1967)
Etobicoke, Ont.	Unmetered areas have 45% higher water use than metered areas of comparable assessment	Grima (1972, p. 165)
St. Catharines, Ont.	11% drop immediately following metering but use rebounded because prices were low. Two years later, water usage higher than before metering	Pitblado (1967, p. 46)
Boulder, Colo.	34-37% drop in water use following meter installation	Hanke and Flack (1968)
Alberta	10-25% drop in water use following meter installation	Associated Services Ltd. (1984)
Peterborough, Ont.	10% reduction in water use predicted following meter installation	Peterborough Water Department (1984)
California, Central Valley	Household water use reduced up to 55% following meter installation; usage averaged 30% less in metered than in unmetered cities	Minton, Murdock, and William (1979)
Denver, Colo.	Metered customers use 50% of the volume of unmetered customers	Griffith (1982)
Calgary, Alta.	Unmetered water use 46% greater than use in metered residences	Mitchell (1984)
Calgary, Alta.	Unmetered water use 65% greater than use in metered residences	Shipman (1978)
Dallas, Texas	43% drop in water demand following meter installation	Shipman (1978)
Gothenberg, Sweden	Per capita use in unmetered apartments 50% higher than in metered single family residences	Shipman (1978)
York County, Pa.	Substantial increases in industrial waste treatment charges led to reductions in water use in the 30-50% range	Sharpe (1980)

Although by no means exhaustive, it is nevertheless representative. Important qualifications are noted in the table and where necessary are discussed in the text below.

The effects of metering on water use varies according to the type of use. For example, the study by Linaweaver, Geyer, and Wolff (1967) showed that the "domestic" or in-house use showed little variation between metered and flat rate areas. In contrast, lawn sprinkling uses in metered areas were 50% to 75% lower than those in unmetered ones. Because of the latter fact, overall residential usage was about 50% lower in metered than in unmetered areas. As Grima (1971, p. 50) stated,

> Sprinkling and related uses affect the maximum day and peak hour use to a much greater extent than domestic use and the peak uses are most relevant to design and planning. Therefore metering may reduce the need for storage capacity installed to meet peak demands.

The finding is important for reforming existing water pricing practices, and is one of the rationales for the pricing method outlined in Chapter 5.

As noted above, metering often causes an initial substantial drop in water use, followed by a rebound to a less substantial long-term drop. In some cases, the post-metering water use may actually be higher than pre-metering use. Pitblado (1967) found this result for St. Catharines, Ontario, and explained it by pointing out that water prices were kept low, removing any incentive for decreasing water use. This shows that metering will not be particularly effective as a water saving measure unless it is accompanied by pricing reform.

In general, metering has a variable effect on lowering water usage, depending highly upon the post-metering water pricing regimes initiated by municipalities. The literature cited in Table 1 indicates that metering, combined with water charges based on usage, may lead to a 30% to 50% drop in demand. As Grima (1972, p. 53) stated,

> Unmetered consumers have no incentive to use water efficiently or to repair indoor water using fixtures. Total residential water use is about 30-50% higher in flat rate areas, with most of the extra demand occurring during seasonal peaks for lawn watering.

SUMMARY

Metering is the sine qua non of realistic water pricing. Currently, only about 50% of urban water consumers are metered. Utilities can conduct evaluations of metering in the benefit-cost context, and most such studies in the past have found metering to be cost effective. Metering, combined with realistic pricing designed to recover the full costs of system operation, can result in a 30% to 50% fall in water demand, and obviate the need of system capacity expansion.

Economic Theory of Water Pricing

INTRODUCTION

This chapter examines the basic principles of municipal water pricing. It begins by defining two basic goals of water pricing policy: economic efficiency and cost recovery. It then outlines a theoretical model for achieving these goals.

The theoretical model of economic efficiency is based on the criterion of maximizing net value or benefits to society from water use. A review of the theory shows that marginal cost pricing of water will lead to economic efficiency in its use. Subsequent sections of this chapter discuss marginal cost pricing in more detail, using a graphical representation of the consumer demand and marginal cost curves.

The final section of this chapter outlines the problem of achieving full cost recovery under marginal cost pricing. Economic theory suggests that a system of fixed connection charges plus a volumetric price based on marginal cost should achieve both economic efficiency and full recovery of costs.

GOALS OF A PRICING POLICY

As outlined in Chapter 1, municipal water rate making can meet both economic efficiency and cost recovery goals. Both goals are important: the former helps control the growth of water demands and assure rational water use, and the latter ensures that a utility has sufficient capital and operating revenues. Formally, a realistic municipal water pricing policy should have two goals: (1) economic efficiency and (2) full cost recovery. The following sections explain these terms in more detail.

ECONOMIC EFFICIENCY

A pricing system is economically efficient if it results in maximum net value of water use to society. The net value of water supplied through a municipal system equals the value customers receive from water use minus the cost of the supply system. The following sections discuss the theory on which the value and cost of water is based.

Economic Value of Water

The demand curve (Fig. 3) is the basis for determining the economic value of water. The demand curve shows the relationship between the quantity demanded of a product and its price. At any level of consumption, the demand curve represents consumers' willingness to pay

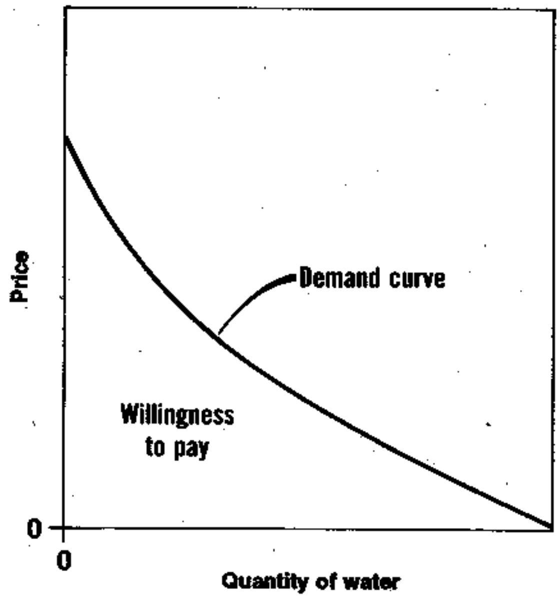


Figure 3. Demand for water.

for an additional unit of water. The value of an extra unit of water declines as consumption increases resulting in a downward sloping demand curve. An aggregate demand curve for a group of consumers can be obtained simply by adding up all the individual demands at various price levels. The aggregate demand curve will also be downward sloping.

The consumers' total willingness to pay is the area under the demand curve in Figure 3. Total willingness to pay can be considered as a gross measure of the value of water to the consumers. The net value of water is the difference between the value to consumers and the cost of supplying it.

The costs of supplying water are represented by the total cost curve (Fig. 4), which shows the total costs required for any level of water delivery. The marginal cost curve (Fig. 5) is derived from the slope of the total cost curve. For any level of water delivery, marginal cost is equal to the slope of the total cost curve in Figure 4. The marginal cost is the cost of producing an additional unit of water at each level of water supply.

Ignoring fixed costs for the moment, total costs are equal to the area under the marginal cost curve (Fig. 5). The net value of this water is shown by the area NV, which is the difference between total consumer value and total costs. Rate setters should select the price and quantity of water delivery that will result in the maximum net value from water use. In other words, a price and quantity in Figure 5 should be selected that maximizes the area NV. Fixed costs can be deducted from the area NV to give the true net value after fixed costs, but this will have no effect on the optimal price and quantity.

Marginal Cost Pricing

The economically efficient price results in maximum net value from water use. This price turns out to be the point where the demand curve intersects the marginal cost curve (P*Q* in Fig. 5). At this point the consumers' marginal willingness to pay is equal to the marginal cost. If consumption were set lower than the optimal point, then the marginal cost of an additional unit of water would be less than the marginal value consumers put on it. Therefore, increased net value could be obtained by increasing consumption and lowering the price. If rate setters set a price below the optimal point, consumption would rise to a point where additional unit of water would cost more than they are valued by consumers. It follows that setting the price

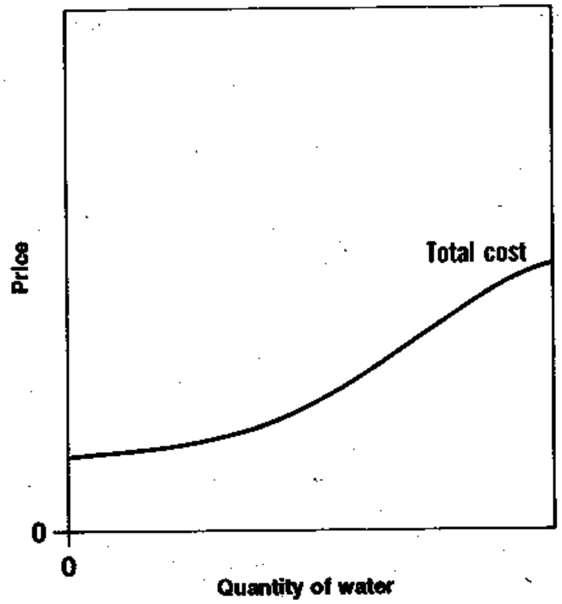


Figure 4. Total cost curve.

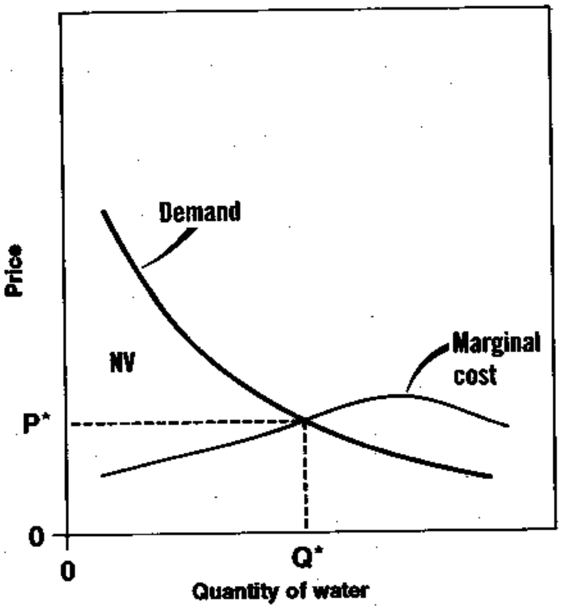


Figure 5. Marginal cost pricing.

exactly equal to marginal cost will result in the maximum net value. The term "marginal cost pricing" means just that: setting price equal to marginal cost in order to maximize benefits.

The marginal pricing rule can be stated formally as

$$\text{Price} = \text{marginal cost} = \text{marginal willingness to pay} \quad (1)$$

Short-Run and Long-Run Marginal Cost

The marginal cost pricing rule has both short-run and long-run interpretations. In the short run, capital costs cannot be varied and marginal costs include only the variable costs of production or delivery. As long as there is adequate physical capacity for the foreseeable future, setting the price equal to marginal cost will maximize benefits. In the long run, utilities must plan for capital expansion, and all inputs, including capital, are variable. The long-run marginal cost represents the marginal cost of capacity expansion over the long term. A permanent increase or decrease from current consumption levels will affect the timing of future expansion requirements. A reduction in consumption will delay the need for expansion, and an increase will advance capacity expansion requirements. The financial costs or savings associated with changing the timing of expansion can be amortized and used as the basis for the long-run marginal cost curve.

During peak demand periods the long-run marginal cost becomes the basis for setting the price. Specifically, the peak period price should be set at the intersection of the peak period demand curve and the long-run marginal cost (Fig. 6). This price applies to the peak period only, since it is the peak demands that place a strain on capacity over time. The increase in peak demands over time result in the need for increased capacity and so any long- term change in peak period demands will have an effect on future expansion costs.

During off-peak periods, rate setters should use the short-run marginal cost as the basis for price setting. A change in off-peak demands will not usually affect the long-term capacity requirements and expansion costs. The only costs associated with a change in off-peak demands will be operating costs such as pumping costs or repairs. Therefore, the price should be set at the intersection of the off-peak demand and short-run marginal cost curves (Fig. 6).

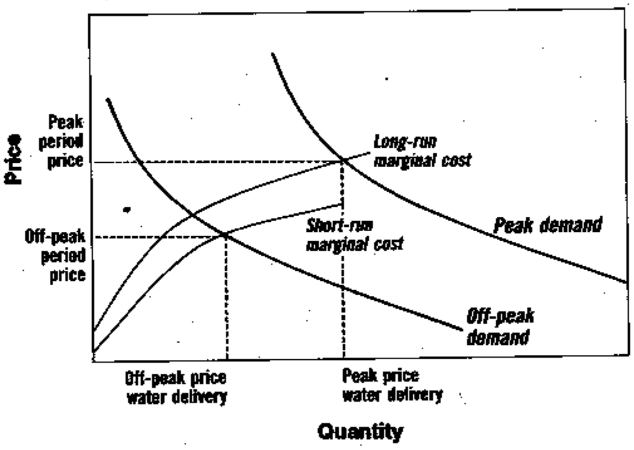


Figure 6. Prices in peak and off-peak periods.

Marginal Waste Treatment Charge

The costs of wastewater treatment are related to the amount of water that is supplied to households. Increasing or decreasing the amount of water going into households will similarly increase or decrease the amount of wastewater exiting from households. In theory, the marginal cost of treatment associated with the change in water consumption should be factored into the price of water. In practice, rate setters may encounter some difficulty in determining the effects of a change in water consumption on costs of treating wastewater. The analyst also encounters the problem of separating out water consumption that does not enter the wastewater treatment system. These problems are discussed in more detail below.

Cost Effects from Reduced Volume of Wastewater

If household demand for water is reduced because of a price increase, then the total volume of wastewater will also be reduced. However, the concentration of wastes in the wastewater will likely be higher since the same amount of raw waste will enter the system. Factors such as water-efficient appliances, improved plumbing maintenance, and in-house conservation will account for much of the reduction in water entering the waste treatment system. These factors will not, however, result in a significant reduction in the amount of human and household waste that enters the system.

The reduction in the volume of wastewater should result in cost savings despite the increased concentration of wastes. In the short term, reductions in costs would occur in the form of reduced energy and maintenance costs for pumping, mixing, and aeration. In the long term, savings would occur in the form of reduced volume-related capacity for collection, holding, and treatment. The effect on some of the other cost components of waste treatment is uncertain. For example, the costs of biological and chemical processes may or may not be influenced by a reduction in volume accompanied by an increase in concentration. Since the total amount of solid waste is not likely to change significantly, sludge treatment and disposal costs would probably remain unchanged. Thus, the total savings depend on the technical design of the wastewater system and the relative costs of volume-related functions such as collection, pumping, mixing, and aeration. Chapter 4 gives some procedures for approximating the marginal waste treatment savings associated with reduced consumption of water.

The volume of wastewater treated does not generally exhibit seasonal peaks, and so, in theory, only a single annual marginal cost, including both capacity and operating costs, should be implemented.

Wastewater That Does Not Enter Treatment System

Some water does not return to the waste treatment system. Outdoor water use, particularly lawn and garden watering, will not usually put any demands on the waste treatment system since any runoff from such activities will enter storm drains or natural waterways. Therefore, the marginal waste treatment cost of this type of water use is zero and no sewage cost should be levied. Unfortunately, utilities cannot distinguish between indoor and outdoor water use since meters only indicate gross water use per connection. Most outdoor water use is seasonal and is usually the cause of seasonal peak demands. During off-peak periods utilities can apply a marginal waste treatment fee with the assumption that practically all of the water used is for indoor activities that contribute to wastewater volume.

The more difficult question is whether or not to apply a waste treatment charge during the peak periods when a significant portion of water use is for outdoor activities. If the waste treatment charge is applied in peak periods, then outdoor water use will be overpriced. If the waste treatment charge is not applied in peak periods, indoor water use will be underpriced. In either case a price distortion will occur.

In general, it is recommended that the marginal waste treatment charge be applied year round, including peak periods. Although this results in a theoretical overcharge for outdoor water use, there are some practical arguments that could be used in favour of higher outdoor water charges. In the first place, water that is used for outdoor water purposes exhibits a higher rate of actual consumption than water used indoors. In fact, if homeowners are efficient in their lawn watering practices, then all of the applied water will be lost through evapotranspiration, and there will be no return flow to surface water or groundwater aquifers. Thus, outdoor water use has a greater impact on net flows or stocks of water than does indoor water use. Even if some return flows from outdoor water use do occur, these flows will contain leached nutrients or urban contaminants that are harmful to the receiving waters.

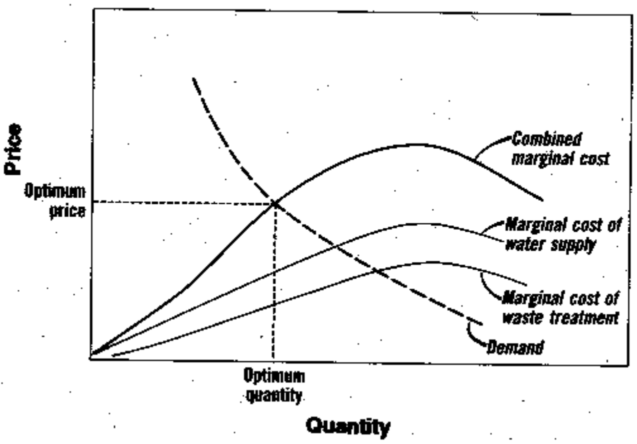


Figure 7. Marginal costs and optimum price.

In theory, a marginal cost curve of post-use treatment for municipal water supply can be displayed, as in Figure 7. By adding this curve to the marginal operating cost curve for water supply in each period, a combined marginal cost curve is obtained. The intersection of the total marginal cost curve with the demand curve defines the optimum price in each period.

FULL COST RECOVERY

A pricing system achieves full cost recovery when it generates sufficient revenue to cover the full cost of the system at any level of water delivery. The accounting of system costs should include fixed costs, variable costs, and a provision for future expansion. If these costs are fully recovered, utilities will require no subsidies from senior levels of government to maintain, upgrade, or expand their water systems.

The marginal cost pricing rule, as presented in equation (1), is concerned only with efficiency and does not consider any financial constraints on the utility. Financial constraints would usually require the utility to break even by recovering all costs without making excess profits. Setting the price at the marginal cost price may result in a financial loss for the utility even though the net value of water use is maximized. The loss will result from the fixed (overhead) costs facing the utility. This situation occurs when average costs are below marginal costs at the optimum price (Fig. 8). The lower section of Figure 8 shows the equivalent total cost curve and total revenue curve. The vertical distance from C to R represents the total revenue shortfall at the optimum price P_o.

In order to recover any revenue shortfall, utilities should put a fixed connection charge on each customer in addition to the volume based price as determined by the marginal cost. The connection charge is fixed in that it does not vary with the amount of water used. Because it does not vary, it will not affect the demand by each customer, and consumption will remain at the optimum level where the marginal willingness to pay equals marginal cost.

The fixed connection charges may account for a significant portion of the total water bill faced by consumers. Thus the comparative size of the connection charge between consumers is an important issue when attempting to design a fair rate structure. The simplest way to obtain the connection charge is to divide the total revenue shortfall by the number of connections. This would result in a lower average price for large volume users although the marginal price would remain the same for all customers. Utilities may consider the lower average price as fair because of cost advantages in supplying large-volume consumers (see next section).

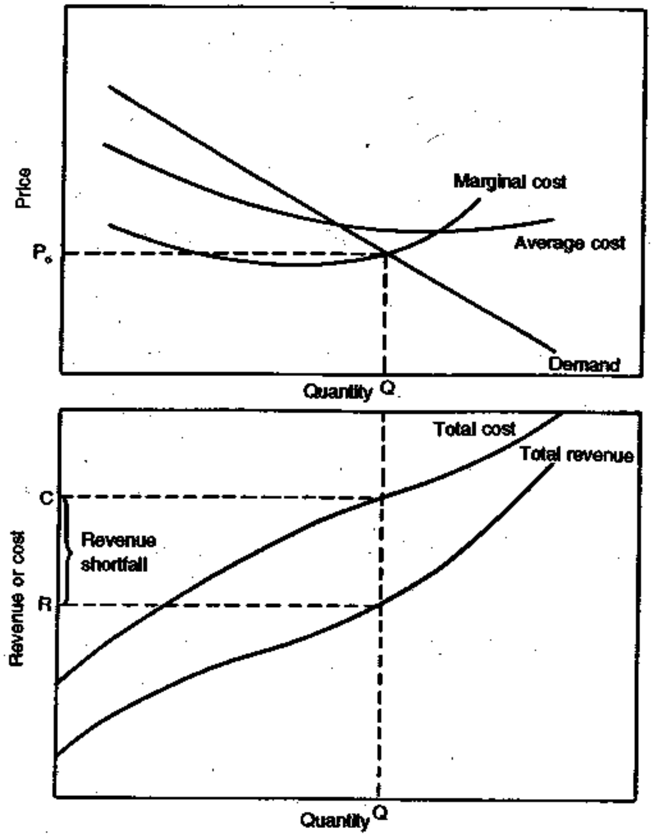


Figure 8. Revenue shortfall with declining average costs.

An alternative method for calculating connection charges is to divide customers into different classes based on volume of water use and then calculate a fixed connection charge for each class. Under this system, the revenue shortfall is allocated on a percentage basis between classes of consumers. Rate setters can use this system to achieve a fair distribution of costs based on the utility's particular mix of customers.

Chapters 5 and 6 give further discussion of using the connection charge as a means of allocating fixed costs. Achieving a fair distribution of fixed costs is often subjective (see next section) and is not the main focus of this report. A more in-depth discussion of cost allocation between customers is available in the American Water Works Association (AWWA) Water Rates Manual (1983).

EQUITY AND FAIRNESS OF MARGINAL COST PRICING

In the past, many rate-setting procedures have been concerned with fair allocation of fixed costs, in contrast to the marginal cost based rate structure described in this report. It is the authors' opinion that marginal cost pricing combined with fixed connection charges is both an efficient and a fair system. Other rate-setting systems have often resulted in flat rate pricing or declining block systems, which are inefficient and unfair to low volume customers.

Under flat rate systems, customers have no opportunity to reduce the cost of their water through their own conservation efforts. Heavy users of water pay the same total bill as light users. Customers who make an effort to conserve water, or who live in smaller homes, end up paying a higher per unit cost of water. A volume based pricing system is much more equitable, since those who use the most water must pay for it. Customers who consume less through their own conservation efforts, or who have more modest water demands, will pay less than those who consume more.

Under declining block rate systems, high volume users pay a lower marginal price than do low volume users. This system is unfair for the same reason that flat charges are unfair; users are not fully rewarded for their conservation efforts. Furthermore, high volume users place the most demands on system capacity, which is often the major component of total cost.

Some utilities can supply high volume consumers at a lower average cost than small consumers and thus use a declining block rate system to lower the average price paid by large consumers. This practice is similar to the practice of giving high volume discounts in the manufacturing and trade sectors because of economies of scale in manufacturing and distributing. A better approach for water utilities is to use the fixed connection charge rather than the volumetric price as a means of increasing or decreasing the average price to various classes of consumers. This method will result in both maximum efficiency and fairness to consumers.

Rate setters should be aware that cost advantages in having high volume consumers may not be as large as those found in the private manufacturing and trade sectors. Because water supply capacity is fixed in the form of reservoirs, pumps, and water mains, there is often little cost saving to the utility by supplying water to one large customer rather than to many small customers. There can be some cost savings in that only one large connection is needed for a big customer, but many small connections are required to serve small users. Even this type of saving may not be significant because the capital cost of connecting with a water system is often borne by the land developer and the householder rather than the utility. Some administrative savings will exist in the form of reduced time for meter reading and bill processing for large customers.

Rate setters who are interested in the issue of cost allocation between different classes of customers are referred to the AWWA water rates manual, which deals extensively with cost allocation. As marginal costs usually do not vary substantially between classes of customers, so the volumetric portion of the rate structure should not generally vary between customers. Only the fixed connection charge should be altered if rate setters wish to achieve different average prices among customer classes.

In general, marginal costs are the same for all classes of customers, and the analyst need not be concerned about the allocation of marginal costs between customer classes. This greatly simplifies the rate-setting process and at the same time treats all customers equally. There may be a few instances in which utilities can distinguish between customer classes that have significantly different marginal costs of water supply. For example, some neighbourhoods or regions may be located at significantly greater distances or elevations than other regions, resulting in higher energy costs for pumping. In theory, these neighbourhoods should be charged a higher volumetric price, reflecting the higher marginal costs. However, differences in marginal costs related to pumping may often be very small relative to capacity and wastewater treatment costs, in which case it may be more practical to ignore them.

Some rate setters may wish to provide a break to low-income families by charging them a lower unit charge than other customers. This can be achieved by providing free delivery of a small amount of water to each household. This amount can be considered the subsistence level, necessary to meet basic indoor uses. The volumetric price would not be applied until consumption exceeded the subsistence level of water. A slight surcharge, over and above marginal cost, would have to be applied to the volumetric price to make up for the decreased revenue resulting from the free subsistence block of water. This method would result in a higher average price of water for large consumers than for small consumers. However, a loss in efficiency results from this system because consumers are not charged the exact marginal cost of water. The rate setter would have to decide if the loss in efficiency is worth the possible increase in consumer acceptance that may occur with this type of rate schedule.

SUMMARY

The major point arising from the theory described in this chapter is that water should be priced at its marginal cost. In the peak period season, the price should include the marginal cost of future capacity requirements, while the off-peak price should be based on marginal operating costs. The marginal cost of wastewater treatment that is related to intake of water should be applied year round.

Revenue shortfalls from marginal cost pricing can be recovered through fixed connection charges to customers. The connection charges also provide a vehicle through which the utilities can increase or reduce the average price paid for water by different classes based on equity considerations.

The next chapter discusses the revenue requirements of water utilities in more detail. It develops the concept of the total cost curve from which utilities can determine total costs and revenue requirements for any level of water delivery and wastewater treatment. Subsequent chapters deal with the estimation of marginal costs and consumer demand required to determine optimal water prices.

CHAPTER 4

Economic Costs and Revenue Requirements

INTRODUCTION

This chapter examines the costs and revenue requirements for water supply and waste treatment utilities, and outlines a process for estimating the relationship between total costs and the amount of water delivered. As discussed in the previous chapter, the amount of water supplied to customers affects both the costs of water supply and the costs of wastewater treatment since the volume of wastewater is closely correlated with the volume of indoor water use. Several cost components of waste treatment such as pumping, mixing, and aeration are directly dependent on the volume of wastewater treated. Capacity requirements for both waste treatment and water supply are also affected by the level of water consumption. Therefore, cost determination and pricing of water supply and wastewater should be considered as a single problem.

Graphically, the relationship between costs and the level of water supply is known as the annual total cost curve. For any level of water delivery, the total cost curve shows the corresponding costs faced by the utility. In this chapter, separate total cost curves are developed for the water supply and wastewater treatment functions. These cost curves are necessary to calculate revenue requirements when the quantity of water delivered changes due to the introduction of efficient pricing.

Total annual costs include future expansion costs, expressed as equivalent annual payments, fixed costs (including debt payment), and variable or operating costs. The sum of these costs represents the annual revenue requirement for a water utility.

The total cost curves provide an economic framework through which the effects of pricing and demand reduction can be analyzed, but they do not replace standard accounting methods for cost reporting and analysis. Financial data from traditional accounting systems still form the empirical basis of this economic framework.

CLASSIFICATION OF CURRENT COSTS

Given its present level of water delivery and wastewater treatment, a utility faces a set of current costs or cash outflows. Utilities will usually keep separate accounts of current costs for the water supply and waste treatment functions. While these accounts usually do not include a provision for future capacity expansion, the data presented in these accounts, when supplemented with cost data on projected capacity expansion, form the basis for estimation of the total cost curves.

Current costs or cash outflows are the annual payments required for such items as labour, materials, and debt servicing. The first step in developing an economic framework for revenue generation is to classify the utility's current costs of water delivery and wastewater treatment as either fixed or variable.

Fixed Costs

Fixed costs are those that do not vary in the short run with respect to the amount of water delivered or wastewater treated. For example, payments on current debt are fixed in the short run since they do not vary if the amount of water delivered varies during the year. Other fixed costs include administration, regularly scheduled maintenance, and replacement of equipment due to obsolescence. These items are fixed since a temporary reduction in the amount of water supplied or wastewater treated would not affect their level. Over the long run, a sustained increase or decrease in water delivery would affect the level of these costs.

Variable Costs

Variable costs are those that vary according to the amount of water delivered to customers and collected as wastewater in the short run. Examples are energy costs for pumping and chemical costs for treatment of water and waste. Some repair and maintenance costs also depend on the volumes of water delivered and/or treated; these constitute part of the utility's variable costs.

Separating Fixed from Variable Costs

Most utilities prepare an operating budget and a projected capital expenditure budget for both the water supply and wastewater treatment functions. The current year's operating budget, based on present levels of water supplied and wastewater treated, provides information that can assist in the classification of costs into fixed and variable. The format and detail of the operating budget may vary from utility to utility, but the general classification of items is normally similar, including items such as debt charges, salaries, energy, chemicals, vehicles, taxes, and insurance. The analyst can classify each of these items into the fixed and variable categories. Payments on debt should be classified as fixed. Some items will not fall completely into either category and will have to be apportioned between the fixed and variable categories.

The rate maker must often use judgment in classifying costs as variable or fixed. Labour costs may present particular difficulties. Some labour costs are volume-related, but a significant proportion arise regardless of water delivery levels or wastewater volume. The former are components of marginal operating costs, the latter of fixed costs. As noted above, some repair costs (e.g., pump repair) vary with water use over time, while others (e.g., cleaning) arise regularly, regardless of the volume of water delivered. In such cases, the rate maker must make a reasonable allocation of costs between variable and fixed, relying upon judgment and knowledge of the system. Examples of these calculations are given in Chapter 6.

As a result of the classification exercise, the analyst can generate a budget table showing fixed and variable costs. Table 2 shows an example of such a budget table for the water supply function. Table 3 displays a similar breakdown of costs for wastewater treatment.

Table 2

Annual Variable, Fixed, and Debt Payment Costs ($) for Water Supply

Item	Fixed costs	Variable costs	Total costs
Administration	40 000		40 000
Salaries	750 000	200 000	950 000
Energy		250 000	250 000
Repairs and maintenance	60 000	50 000	110 000
Chemicals		160 000	160 000
Taxes	400 000		400 000
Insurance	30 000		30 000
Subtotal	1 280 000	660 000	1 940 000
Debt charges	1 600 000		1 600 000
Total			3 540 000

Note: These costs exclude future costs of capacity expansion.

Table 3

Annual Variable, Fixed, and Debt Payment Costs ($) for Wastewater Treatment

Item	Fixed costs	Variable costs	Total costs
Administration	50 000		50 000
Salaries	800 000	250 000	1 050 000
Energy		200 000	200 000
Repairs and maintenance	90 000	80 000	170 000
Chemicals		400 000	400 000
Taxes	400 000	0	400 000
Insurance	50 000	0	50 000
Subtotal	1 390 000	930 000	2 320 000
Debt charges	2 200 000		2 200 000
Total			4 520 000

Note: These costs exclude future costs of capacity expansion.

EXPANSION COSTS

When revenue generation is sufficient to cover only current costs, financial deficits will occur in the future due to costs of expansion. This section presents methods for amortizing future expansion costs into equivalent annual costs. Such methods produce a more stable price schedule over time, avoiding sudden and dramatic price increases that occur when future costs have not been considered in current revenue requirements.

Amortization of Future Capacity Expansion Costs

By using the pricing methodology recommended in this report, the utility will generate enough revenue to cover both current debt payments and costs of future expansion. An amortization procedure converts the future stream of expansion expenditures into constant annual expansion costs. By including annual expansion costs in revenue requirements, the utility can finance its future expansion and produce relatively stable consumer prices over time.

Table 4

Projected Capital Costs ($) of Capacity Expansion

Year	Water supply costs	Wastewater treatment costs
1	0	0
2	0	0
3	1 000 000	0
4	500 000	1 500 000
5	200 000	400 000
6	0	0
7	2 000 000	0
8	1 000 000	2 000 000
9	500 000	0
10	0	0
Present value at 10%	2 921 878	2 205 903
Equivalent annual expansion cost	475 522	359 001

In the example case showing the projected capital expenditures of expansion (Table 4), the planning period extends 10 years into the future. Analysts may wish to use a shorter period because of the difficulty in projecting capital expenditures over time. If a shorter planning cycle is used, the utility will have to repeat the amortization calculations for each cycle, leading to greater price variation. In general, the length of the time period should be long enough to incorporate all significant planned expansions.

The formula used to calculate the present value of the planned stream of expenditures is given by equation (2).

$$PV = \frac{k_i}{(1+r)^n} \qquad (2)$$

where PV = present value of future stream of expenditures

k_i = debt payment or expenditure in year i

r = interest rate

n = year in which expenditure occurs

The annuity formula (equation 3) then transforms the present value of the capital expenditure on expansion into an equivalent series of annual payments. The utility can then accumulate these payments into a fund to meet the costs of future expansion.

$$AP = \frac{PV \times r}{1-1/(1+r)^n} \qquad (3)$$

where AP = annual payment over n years equivalent to present value of capital expenditures

PV = present value of future stream of expenditures

Referring to the example in Table 4, the annual payment into the expansion fund over a 10-year amortization period using a 10% interest rate equals $475 522 for water supply and $359 001 for waste treatment. In some years of particularly high capital expenditure, additional short-term borrowing may be required due to insufficient fund accumulation to date. However, future fund accumulation from the annual expansion debt will allow repayment, and at the end of the 10-year planning period the utility will have met all costs of expansion.

After the 10-year period, the utility will project another 10 years and carry out the same calculations to determine annual revenue requirements for the next cycle. Interest rates and projected capital expenditures will change from year to year, and so calculations of annual revenue requirements may require annual updating. Thus, in practice, the utility may not completely stabilize its annual expansion costs. However, the procedure described here will result in a much more stable annual revenue requirement than the alternative of simply borrowing money in the future to meet capital requirements.

Capacity Related Capital Costs

Many utilities have a five- or ten-year capital expenditure plan that includes major expenditures on both expansion and system maintenance. Some expenditures may relate to repairs and maintenance; these are components of operational costs. Other expenditures may arise (e.g., to replace obsolete equipment) that would have to take place regardless of the amount of water used at present or in the future. These replacement costs form part of the fixed costs in the year that they occur. Before calculating annual expansion costs, the analyst must separate out the capital expenditures that relate directly to capacity expansion.

Some costs may be difficult to allocate because they overlap different categories. For example, replacement of a water main may take place both because it has deteriorated over time and because the utility requires increased capacity. In such cases, the primary criterion for determining the classification of the cost concerns whether or not a demand reduction would enable a delay in the expenditure. If a delay will result because of a demand reduction, then the expenditure constitutes a capacity related capital cost.

Capacity for Fire Protection

Many water supply systems include extra capacity both in their present systems and in their expansion plans so that sufficient water pressure will be available for fire fighting. This can add considerably to the long-term costs of the utility, and the question of how to pay for this extra capacity warrants examination.

Fire fighting capacity can be treated as a necessary feature of a water supply system, and its costs should be included in total costs and revenue requirements. Therefore, fire fighting costs do not have to be netted out of the capacity cost calculations. The extra expense of this capacity in current systems will be covered through the fixed connection charge. Future expansion of capacity for fire fighting will increase the calculated value of expansion costs and will thus increase the volumetric peak period price. The increased price is warranted since it reflects the value that water has in peak periods for both consumption and maintenance of pressure for fire fighting.

TOTAL COSTS AND REVENUE REQUIREMENTS

For both the water supply and wastewater treatment functions, total costs equal the sum of annual expansion costs, debt payment, and other annual fixed and variable costs. Equation (4) shows total costs of the water supply.

$$TC_s = EC_s + DC_s + FC_s + VC_s \tag{4}$$

where TC_s = total annual costs of water supply

EC_s = annual expansion costs

DC_s = annual payments on debt

FC_s = annual fixed costs

VC_s = annual variable costs

Equation (5) shows the total costs for the wastewater treatment function.

$$TC_t = EC_t + DC_t + FC_t + VC_t \tag{5}$$

where TC_t = total annual costs of wastewater treatment

EC_t = annual expansion costs

DC_t = annual payments on debt

FC_t = annual fixed costs

VC_t = annual variable costs

The utility should generate enough revenue to cover the total costs of both water supply and wastewater treatment. By doing so, it can finance current operating costs and future expansion using a stable price schedule.

TOTAL COST CURVES

The total cost curve represents the relationship between total annual costs and the amount of water delivered or wastewater treated. This section outlines procedures for estimating separate total costs for each of the water supply and the wastewater treatment functions. Since water supply costs differ between peak and non-peak periods, the water supply total cost function is further divided into peak period and non-peak period cost functions. By using these total cost curves the analyst can determine revenue requirements for any level of water delivered or wastewater treated.

Total Cost Curve for Water Supply

As described in the previous chapter, the costs of water differ in the peak and non-peak periods because system capacity is designed to meet peak period demands. Capacity expansion costs therefore constitute part of the peak period costs but are not included in non-peak period costs. If peak period demand decreases, then substantial savings in expansion costs will occur over the long run.

Variable costs occur in both periods according to how much water is delivered. Fixed costs, by definition, do not vary with the amount of water delivered in either period. The assignment of fixed costs to peak or non-peak periods is arbitrary and will not affect price determination.

Variable Cost Component

As noted earlier, variable costs relate directly to the amount of water delivered in both peak and non-peak periods. Calculation of the variable costs associated with any level of water delivery in peak and in non-peak periods requires a two-step procedure. The first step is to derive the variable cost per unit of water delivered through dividing the current year variable costs by the present amount of water delivered (equation 6).

$$UVC = \frac{VC_c}{QW_c} \tag{6}$$

where UVC = unit variable cost

VC_c = current level of variable costs

QW_c = current quantity of water delivered

Equation (6) also includes a straight-line approximation of marginal operating cost used as the basis for setting off-peak prices. (See Ch. 5.) The second step in the calculation of variable costs for any level of water delivery involves multiplying the unit variable cost by the volume of water delivered, as shown in equation (7).

$$VC = UVC \times QW \tag{7}$$

where VC = variable costs associated with QW level of water delivery

UVC = unit variable cost

QW = quantity of water delivered

The above procedure assumes that the unit variable costs are constant and that total variable costs are a straight-line function of the amount of water delivered. The straight-line approximation is adequate for a narrow range of volume of water delivered but might be inaccurate over a wide range. It should be sufficiently accurate over the changes in demand that would occur with a move to realistic pricing.

Fixed Cost Component

Fixed costs, by definition, do not vary with the amount of water delivered; thus, the fixed costs associated with the current level of water delivery should be an adequate representation of fixed costs at other levels of water delivery. However, some of the costs currently classified as fixed will increase over the long term as the system expands. Such increases will be captured in the amortization of future expansion costs. Otherwise, the current annual fixed costs will remain constant for a range of water delivery volumes.

The assignment of fixed costs to peak or non-peak period water delivery makes no difference to price determination or calculation of revenue requirements. Fixed costs are recovered through the application of a fixed connection fee per household and are not based on the amount of water delivered. In subsequent sections, the fixed costs are arbitrarily divided on an equal basis between peak and off-peak periods.

Debt Payment Component

Current debt charges are fixed and do not vary with changes in the amount of water delivered. However, they vary over time, unlike other fixed costs, as payment is completed over a number of years. However, in the short run they form part of the fixed costs and are divided equally between peak and off-peak periods.

Expansion Cost Component

System capacity exists primarily to meet peak period demands. Capital expenditures on expanded capacity become necessary when demands on the system grow beyond certain levels. If peak period demand decreases, expansion plans can be delayed, thereby resulting in a cost savings to the utility. The cost reduction depends on the size of the reduction in demand, the projected growth rate in demand, and the capital costs of expansion. A small reduction in demand will result in only a slight delay in expansion, while a large reduction can result in a significant delay, resulting in major savings in interest costs. Thus, the larger the reduction in demand, the lower the amortized expansion costs will be as calculated by equations (2) and (3).

To calculate the relationship between the annual expansion costs and the level of water delivered in peak periods, follow these three basic steps:

1. Introduce an incremental reduction in peak period demand,
2. Reschedule capacity expenditures based on th reduction in demand, and
3. Calculate the annual expansion costs with the rescheduled capacity expenditures.

The three steps are then repeated for a number of incremental changes in demand to give a tabular or graphical relationship between peak period water demand and annual expansion costs. The procedure is described in more detail below.

1. *Introduce an incremental reduction in peak period demand* — The simplest procedure involves introducing a reduction that is exactly equal to one year's growth in demand. All other things being equal, this will result in a one year's delay in expansion. If the projected growth in demand is very slight, introduction of a demand reduction equivalent to two or three years' growth in demand might be more practical.

2. *Reschedule the planned capacity expenditures based on the reduced peak period demand* — Most water utilities have a five- or ten-year expansion plan based on growth projections in water demand. If the current level of peak period demand falls, and the growth rate remains the same, the critical demand level requiring system expansion will not be reached until a later date. The length of the delay depends on the ratio of the demand reduction to the projected growth in demand. If the demand reduction is equivalent to one year's growth in demand, then expansion expenditures will be delayed for one year. If the demand reduction equals two years' growth in demand, then the delay will be two years and so on. Equation (8) shows the relationship between the demand reduction and the length of time that capacity expenditures can be delayed.

$$TD = \frac{\Delta d}{AG} \qquad (8)$$

where TD = length in time in years that expansion can be delayed beyond current plans

Δd = incremental peak period demand reduction

AG = annual growth in peak period demand

Capacity expenditures often occur over a period of years in the planning horizon. If this is the case, each expenditure during the planning horizon can be delayed by the length of time calculated in equation (8).

3. *Calculate the annual expansion costs using the rescheduled expenditures* — This involves taking the present value of the projected expansion expenditures and amortizing it as in equations (2) and (3).

Once these calculations have been carried out, the three steps are repeated until the required schedule relating peak period demand to annual expansion costs has been obtained.

The procedure outlined above was used to generate Table 5. The original expansion plans based on current demands and growth projections are shown in the first column of the table, along with the annualized expansion cost.

In subsequent columns, demand decreases incrementally, resulting in a rescheduling of expansion expenditures. The original expansion plans were based on a 4% annual increase in demand, and in each of the subsequent columns demand decreases by 4% resulting in an additional year's delay in expansion.

Total Costs of Water Supply

The analyst can now calculate total costs over a range of water delivery levels during peak and off-peak periods. In peak periods, total costs are equal to expansion costs plus variable costs plus a portion of the fixed costs. In off-peak periods, total costs are equal to variable costs plus a portion of fixed costs. As previously mentioned, the fixed costs (including debt payment) are arbitrarily divided equally between the peak and off-peak periods.

Tables 6 and 7 show total annual costs of water supply during peak and non-peak periods using the expansion cost values from Table 5. In these examples, fixed costs are set at $300 000

Table 5

Demand (millions of cubic metres) and Expansion Costs ($)

Year	Demand	Capital costs	Demand	Capital costs	Demand	Capital costs	Demand	Capital costs	Demand	Capital costs
0	25	0	24	0	23	0	22	0	21	0
1	26	0	25	0	24	0	23	0	22	0
2	27	2 000 000	26	0	25	0	24	0	23	0
3	28	1 000 000	27	2 000 000	26	0	25	0	24	0
4	29	500 000	28	1 000 000	27	2 000 000	26	0	25	0
5	30	500 000	29	500 000	28	1 000 000	27	2 000 000	26	0
6	31	1 000 000	30	500 000	29	500 000	28	1 000 000	27	2 000 000
7	32	0	31	1 000 000	30	500 000	29	500 000	28	1 000 000
8	33	0	32	0	31	1 000 000	30	500 000	29	500 000
9	34	0	33	0	32	0	31	1 000 000	30	500 000
10	35	0	34	0	33	0	32	0	31	1 000 000
Present value		3 620 652		3 241 497		2 942 270		2 720 245		2 472 950
Annual payment		589 244		535 676		486 978		442 708		402 462

per year, and variable costs range from $375 000 to $300 000, depending on the level of current demand.

Table 6

Total Costs of Peak Period Water Supply

Current demand (millions of cubic metres)	Fixed costs ($)	Expansion costs ($)	Variable costs ($)	Total costs ($)
25	300 000	589 244	375 000	1 264 244
24	300 000	535 676	360 000	1 195 676
23	300 000	486 978	345 000	1 131 978
22	300 000	442 708	330 000	1 072 708
21	300 000	402 462	315 000	1 017 462
20	300 000	366 038	300 000	966 038

Table 7

Total Costs of Off-Peak Period Water Supply

Current demand (millions of cubic metres)	Fixed costs ($)	Variable costs ($)	Total costs ($)
25	300 000	375 000	675 000
24	300 000	360 000	660 000
23	300 000	345 000	645 000
22	300 000	330 000	630 000
21	300 000	315 000	615 000
20	300 000	300 000	600 000

The same data are plotted in Figure 9 to give a visual representation of the total cost curve for peak and off-peak water supply.

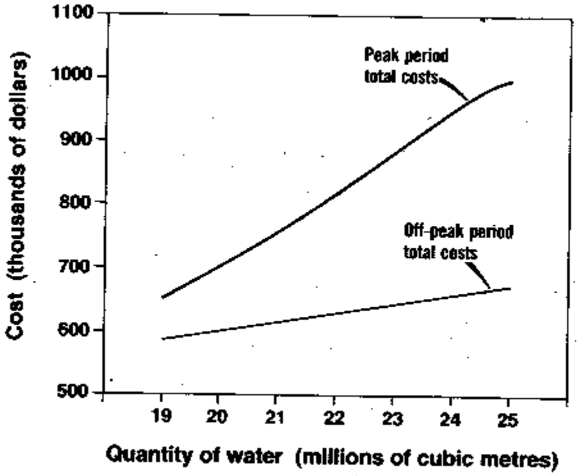


Figure 9. Total cost curve for peak and off-peak water supply.

Total Cost Curve for Wastewater Treatment

The procedures for estimating the total cost curve for wastewater treatment are similar to those used in estimating the water supply total cost curves. However, it is only necessary to estimate a single annual cost curve for wastewater treatment rather than separate curves for the peak and non-peak periods. In general, there is little seasonal variation in the volume of wastewater treated in a system, as it is closely correlated with the indoor water use. Peaks tend to occur within the day, but this is too short a period to meter water use per connection, and so a peak period pricing scheme is generally not feasible for wastewater discharge.

The single total cost curve for wastewater collection contains all of the fixed costs, variable costs, and expansion costs. The procedures for estimating these cost components are discussed below.

Variable Cost Component

The first step is to derive the unit variable cost of wastewater treated through dividing the current year variable costs of wastewater treatment by the present volume of wastewater treated. This is the same procedure as previously set out for calculation of the unit variable cost of water supply in equation (6).

$$UVC = \frac{VC_c}{QW_c} \qquad (6)$$

where UVC = unit variable cost

VC_c = current level of variable costs

QW_c = current quantity of wastewater delivered

The second step in the calculation of variable costs for any level of wastewater treatment involves multiplying the unit variable cost by the volume of wastewater treated as shown in equation (7).

$$VC = UVC \times QW \qquad (7)$$

where VC = variable costs associated with QW level of wastewater treated

UVC = unit variable cost

QW = quantity of wastewater treated

As with the case of variable costs of water supply, the above procedure assumes that the unit variable costs are constant and that total variable costs are a straight-line function of the amount of wastewater delivered.

Fixed Cost Component

As in the case of water supply, fixed costs, by definition, do not vary with the amount of wastewater treated. Thus, the fixed costs associated with the current volume of wastewater treated should be an adequate representation of fixed costs at other volumes of wastewater treatment. Unlike water supply cost calculations, there is no need to apportion fixed costs between peak and non-peak periods, as only one total cost curve is estimated for wastewater treatment.

Debt Payment Component

Current debt charges are fixed, as they were for water supply costs, and do not vary with changes in the amount of wastewater treated. In the short run, they form part of the fixed costs.

Expansion Cost Component

If the volume of wastewater decreases due to a reduction in indoor water demand, expansion plans can be delayed, thereby resulting in a cost savings to the utility. The cost reduction depends on the size of the reduction in wastewater, the projected growth rate in wastewater volume, and the capital costs of expansion. The larger the reduction in demand, the lower will be the amortized expansion costs as calculated by equations (2) and (3).

To calculate the relationship between the annual expansion costs and the volume of wastewater treatment:

1. Introduce an incremental reduction in annual volume of wastewater treated,
2. Reschedule capacity expenditures based on the reduction in volume, and
3. Calculate the annual expansion costs using the rescheduled capacity expenditures.

These steps are similar to the steps carried out for calculation of expansion costs of water supply. The only difference is that wastewater treatment does not generally exhibit seasonal peaks. Therefore, capacity costs relate to the annual volume of wastewater treated, rather than to the seasonal peaks.

As in the case of water supply expansion calculations, the three steps are then repeated for a number of incremental changes in wastewater volume to give a tabular or graphical relationship between peak period water demand and annual expansion costs.

This procedure was used to generate Table 8. The original expansion plans based on current wastewater volume and growth projections are shown in the first column of the table, along with the annualized expansion cost. In subsequent columns, wastewater volume decreases incrementally, resulting in a rescheduling of expansion expenditures. The original expansion plans were based on a 4% annual increase in wastewater volume, and in each of the subsequent columns volume decreases by 4% resulting in an additional year's delay in expansion.

Total Costs of Wastewater Treatment

The analyst can now calculate total costs over a range of wastewater volumes. Total costs are equal to the sum of the variable costs, the fixed costs, and the expansion costs.

Table 9 shows total annual costs of wastewater treatment, using some example values for

Table 8

Wastewater Volume (millions of cubic metres) and Expansion Costs ($)

Year	Volume	Capital costs	Volume	Capital costs	Volume	Capital costs	Volume	Capital costs	Volume	Capital costs
0	25	0	24	0	23	0	22	0	21	0
1	26	0	25	0	24	0	23	0	22	0
2	27	0	26	0	25	0	24	0	23	0
3	28	3 000 000	27	0	26	0	25	0	24	0
4	29	1 500 000	28	3 000 000	27	0	26	0	25	0
5	30	500 000	29	1 500 000	28	3 000 000	27	0	26	0
6	31	1 000 000	30	500 000	29	1 500 000	28	3 000 000	27	0
7	32	0	31	1 000 000	30	500 000	29	1 500 000	28	3 000 000
8	33	0	32	0	31	1 000 000	30	500 000	29	1 500 000
9	34	0	33	0	32	0	31	1 000 000	30	500 000
10	35	0	34	0	33	0	32	0	31	1 000 000
Present value		4 153 398		3 775 816		3 432 560		3 120 509		2 836 826
Annual payment		675 946		614 497		558 633		507 849		461 680

variable and fixed costs, and expansion cost values from Table 8.

The data from Table 9 are plotted in Figure 10 to give a visual representation of the total cost curve for wastewater treatment.

Table 9

Total Costs of Wastewater Treatment

Current demand (millions of cubic metres)	Fixed costs ($)	Expansion costs ($)	Variable costs ($)	Total costs ($)
25	650 000	675 946	200 000	1 525 946
24	650 000	614 497	192 000	1 456 497
23	650 000	558 633	184 000	1 392 633
22	650 000	507 849	176 000	1 333 849
21	650 000	461 680	168 000	1 279 680
20	650 000	419 709	160 000	1 229 709

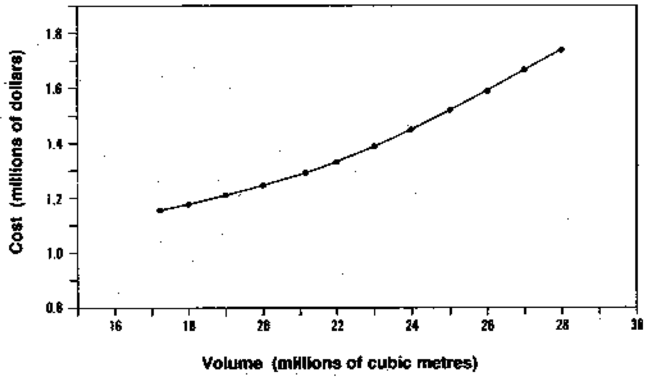


Figure 10. Total cost curve for wastewater treatment.

SUMMARY

This chapter introduced the concepts of variable, fixed, and expansion costs. Variable costs are those that vary in proportion to the amount of water delivered, while fixed costs are independent of the amount of water delivered in the short run. Annual expansion costs are the amortized value of capital costs of future expansion over a selected time horizon.

Water supply costs differ between peak and off-peak periods. Peak period costs include expansion costs as well as variable (operating) costs. Off-peak period costs include variable costs only. Fixed costs occur regardless of the amount of water delivered in either period, and so their assignment to peak or off-peak periods is arbitrary and will not affect the calculation of prices.

A total cost curve for water delivery in each of the peak and non-peak periods can be defined using some approximation methods. The total cost curve relates the total annual costs, comprising fixed, variable, and expansion costs, to the level of water delivered. The total cost curve shows the total costs and revenue requirements for any level of water delivery. Annual revenue requirements, which are equal to total costs, can then be taken directly from the total cost curve for any level of water delivery in peak or off-peak periods.

The volume of wastewater treated does not usually exhibit seasonal variation, and so no difference exists between peak and non-peak costs. A single annual cost curve, comprising fixed costs, variable costs, and expansion costs, relates total costs to the volume of wastewater treated. This cost curve can be estimated using approximation methods similar to those used for estimation of the water supply total cost curves.

CHAPTER 5

Implementing Efficient Pricing

INTRODUCTION

The material presented in this chapter shows in detail the steps required to calculate the components of the generic rate structure advocated in this paper. The calculations require a determination of both marginal cost and water demand curves. A graphical analysis of these curves then yields the optimal prices in peak and off-peak periods.

The same accounting data used in the previous chapter to estimate the total cost curves form the basis for estimation of the marginal cost curves. Estimation of demand curves for water is complex and may require substantial data. If these data are unavailable, the analyst can use the generalized demand curves presented in this chapter. These generalized demand curves are adaptable to the specific conditions of different utilities.

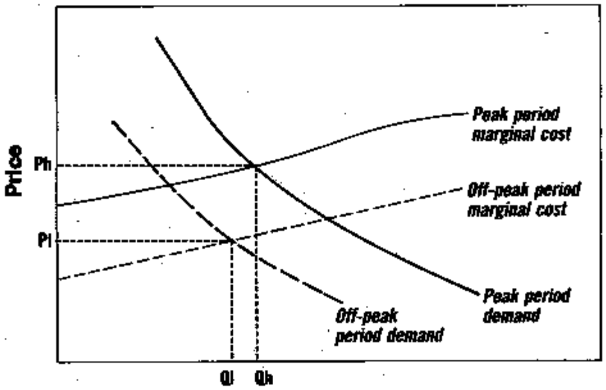


Figure 11. Prices in peak and off-peak periods.

Once the analyst has estimated these functions, they can be graphed to show the optimal prices at the intersection of the demand and marginal cost curves (Fig. 11). In the peak period, price should be set at P_h, which is the intersection of the demand curve with the peak period marginal cost curve. In the off-peak period, prices should be set at P_l, where the demand curve intersects the off-peak marginal cost curve. In addition to the prices P_h and P_l, which are applied on a per volume basis, the customer will also pay a fixed connection charge. The fixed connection charge, which covers any revenue shortfall, can be a single annual charge or can be spread out over the year.

During the peak period, the marginal cost is based on marginal operating cost, marginal capacity cost, and marginal waste treatment cost. The total peak period charge is summarized in equation (9).

$$\begin{array}{lll} \text{Peak period} & = \text{marginal} & + \text{marginal} \\ \text{charge} & \quad \text{operating cost} & \quad \text{capacity cost} \\ & \quad \text{(volumetric)} & \quad \text{(volumetric)} \\ & + \text{marginal waste} & + \text{connection} \\ & \quad \text{treatment cost} & \quad \text{charge} \\ & \quad \text{(volumetric)} & \quad \text{(fixed)} \end{array} \qquad (9)$$

The total volumetric charge per unit of water used in the peak period is the sum of marginal operating and marginal capacity costs per unit.

During the off-peak period, volumetric and fixed charges will continue to apply, but marginal operation costs and marginal waste treatment costs will constitute the volumetric charge as shown in equation (10).

$$\begin{array}{lll} \text{Off-peak} & = \text{Marginal} & + \text{ Marginal waste} \\ \text{period} & \quad \text{operating cost} & \quad \text{treatment cost} \\ \text{charge} & \quad \text{(volumetric)} & \quad \text{(volumetric)} \\ & + \text{ Connection} & \\ & \quad \text{charge} & \\ & \quad \text{(fixed)} & \end{array} \tag{10}$$

Equations (9) and (10) define the basic rate structure for marginal cost pricing. All users pay a volumetric charge based on the marginal cost of supplying water and wastewater treatment plus a fixed connection charge. In the peak period, the volumetric charge will be higher because of the incorporation of marginal capacity cost.

This section outlines the methods for calculating the components of the water charge, including the marginal operating cost, the marginal capacity cost, and the fixed connection charge. The volumetric charge will often be the same for all customer classes and individual customers, since the marginal costs of "producing" and delivering water services are generally the same across all groups. Certain user groups may have significantly higher marginal costs because of distance from or elevation above central reservoirs or pumping stations. Some industrial or commercial customers may have higher marginal waste treatment costs because the by-products of their activities must be removed from wastewater. However, recovery of these types of costs from industry are probably best based on a surcharge related to the amount and concentration of the effluent rather than to the amount of water used by the firm. Marginal capacity costs would not usually vary between customers, since capacity requirements are related only to the amount of water required and not to the type of consumer.

Rate design using marginal cost pricing simplifies the rate-setting principles recommended by the standard AWWA rates manual (AWWA 1983). AWWA uses a system whereby costs are allocated between different customer classes, often resulting in declining block rate (DBR) schedules now in common use. Rate makers commonly justify DBRs by referring to the economies of scale that result from serving large users. Thus, such users face lower unit rates in the higher blocks of the rate schedule. However, DBRs take no account of the fact that large users, by placing heavy demands on the water system, require larger capacity than users of smaller amounts of water. Marginal cost pricing implicitly recognizes the latter fact.

SELECTION OF PEAK PERIODS

Peak demands occur on a seasonal, weekly, and daily basis. During the day, peak demands may occur during certain hours of the morning and afternoon. Weekly peaks can occur on days when there is a concentration of indoor or outdoor water use. Seasonal peaks occur in the summer when outdoor water use becomes prevalent. Utilities will not in general find it practical to institute a daily or weekly peak water charge because of the difficulty in monitoring the time of use. Therefore, the methodology reported in this chapter aims primarily at determining a seasonal peak period charge. Monthly or quarterly meter readings should be sufficient to distinguish between peak and off-peak water use.

The length of the summer peak depends on conditions specific to the utility, such as climate and socioeconomic characteristics of the market served. Most municipalities in Canada will experience a fairly clear peak for at least two months of the summer. In drier areas, this peak will extend for longer periods, starting in the late spring and running well into September. The increase in summer demands relative to the rest of the year has been observed to be as high as 300% in western Canada, with areas in eastern Canada often experiencing peak increases of up to 80%.

The selection of the actual period when peak charges will apply is based on both the frequency of meter reading and the length and size of the peak demands. If meters are read once per quarter, then the minimum length of the peak period charge is three months. Monthly readings give the utility more flexibility, allowing for a shorter or longer peak charge period (in monthly increments). A monthly or quarterly meter reading schedule will generally allow a reasonable match of billing periods to peak demand periods. If particular circumstances require a more exact designation of the peak period, utilities have the option of increasing the frequency of their meter reading schedule in the summer months.

ESTIMATION OF THE PEAK PERIOD MARGINAL COST CURVE

As shown in equation (9), the peak charge is the sum of the marginal operating cost, the marginal capacity cost, and the marginal waste treatment cost. The marginal capacity cost is the extra expense over the long run of capacity expansion that would be required by a permanent marginal increase (or decrease) in water use. The marginal operating cost is the short-run change in costs associated with an increase in water delivery. The marginal cost of waste treatment is the change in wastewater treatment cost associated with a marginal change in water use. These components can be summed to give a single peak period marginal cost curve.

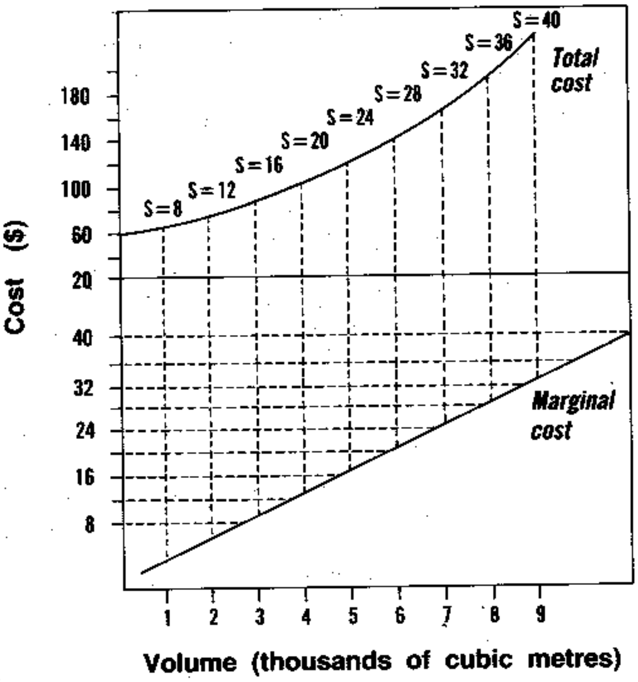
Marginal Cost of Water Supply

The analyst should first estimate the total peak period cost curve for peak period water supply as described in Chapter 4. The marginal cost curve for peak period water supply is derived simply by taking the slope of the peak period total cost curve at a number of points on the x-axis as shown in Figure 12. The resulting marginal cost curve shows the marginal change in operating costs plus capacity costs for a change in water delivery. These are in fact the first two components of the total marginal cost curve, which is derived from the total cost curve.

Marginal Waste Treatment Cost

The third component of the peak use charge is the marginal cost of waste treatment. The annual wastewater treatment marginal cost curve is obtained from the slope of the total cost curve for waste treatment, using a process similar to that shown in Figure 12. The annual curve should then be broken down into peak and off-peak marginal cost curves as described below.

The marginal cost for a unit of wastewater treatment is assumed equal in all periods. Therefore the peak and off-peak marginal cost curves have the same shape. The only difference is that the horizontal quantity scale in each period is changed to reflect the relative consumption in each period, while the vertical cost scale remains the same. Figure 13 shows an example in which 30 million cubic metres of wastewater is treated, 10 million in the peak months, and 20 million in the off-peak period.



Note: S = Slope

Figure 12. Peak period total cost and marginal cost curves.

Summing the Marginal Water Supply and Waste Treatment Cost Curves

Adding the marginal waste treatment cost curve to the marginal water supply cost curve gives the peak period marginal cost curve (Fig. 14). Each point on the peak period marginal cost curve is the vertical summation of the corresponding points on the marginal water supply and waste treatment cost curves.

ESTIMATION OF THE OFF-PEAK MARGINAL COST CURVE

The off-peak marginal cost curve consists of the marginal operating cost plus the marginal waste treatment cost. Calculation of the curve requires separate estimation of these two components, which are then summed over a range of water delivery to give the off-peak marginal cost curve. The following sections give a methodology for approximating these two components of marginal cost.

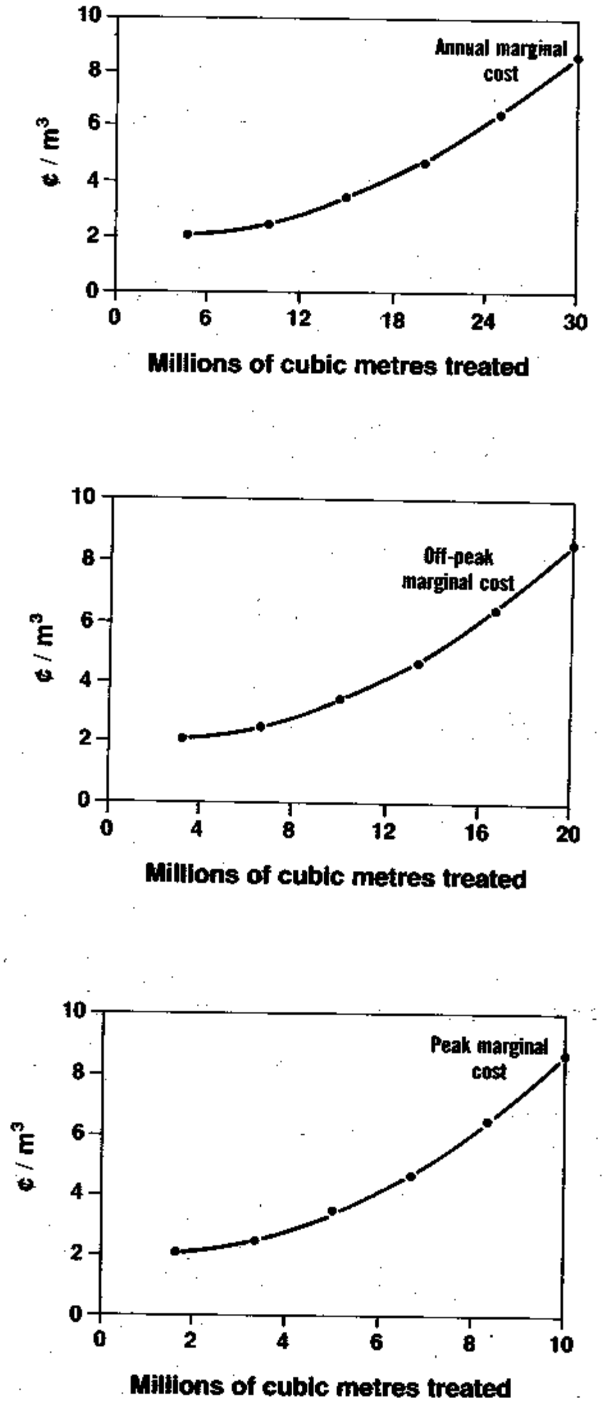


Figure 13. Peak and off-peak marginal waste treatment cost curves.

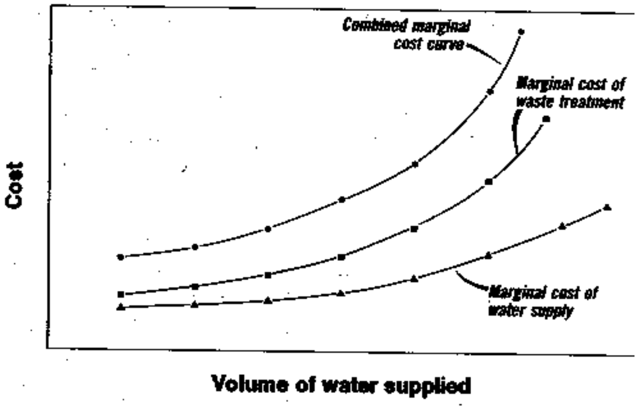


Figure 14. Peak period marginal cost curves.

Marginal Operating Costs

Given adequate system capacity, the marginal operating costs are the costs associated with supplying an extra unit of water to a customer. When graphed against output (Fig. 15), the marginal operating cost usually declines to a certain point and then begins to rise. The marginal operating cost at the current output level should form the basis for the price charged. Although it is difficult to estimate the exact shape of the marginal operating cost curve, a reasonable approximation can be made with a straight

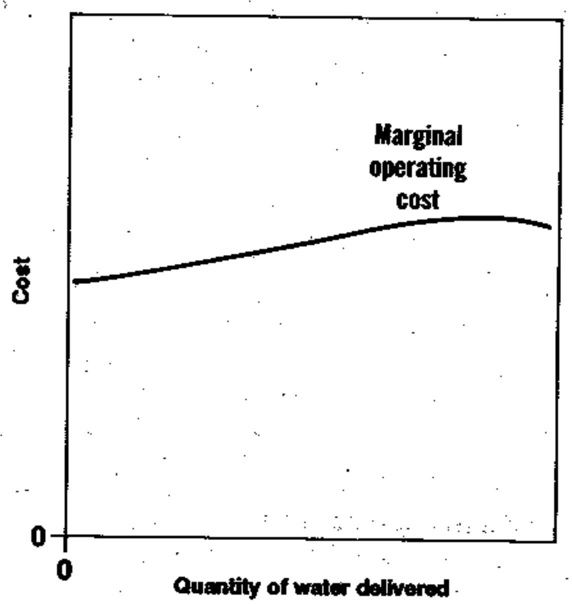


Figure 15. Marginal operating cost.

line, using the assumption that marginal costs are constant.

Marginal operating costs can be estimated by either econometric (statistical) methods or by approximation methods based on the judgment of the system managers. The econometric approach involves the estimation of a cost function and requires a significant amount of data on costs as well as the use of sophisticated statistical analysis. For large systems, the econometric approach should give accurate estimates when data are available. However, for many systems this approach will not be practical because of data and manpower limitations.

An alternative method for approximating marginal operating costs, based on variable costs, is presented below.

Rate setters can approximate marginal operating costs using the variable costs incurred from water system operations. As was discussed in Chapter 3, variable costs vary according to the amount of water delivered to customers in the short run. The unit variable cost, defined in Chapter 3, can be used as a straight-line approximation of marginal operating cost, as shown in equation (11).

$$MOC = \frac{AVC}{Q} \tag{11}$$

where MOC = marginal operating costs per unit of water delivered

AVC = annual variable costs

Q = total annual volume delivered

Marginal Waste Treatment Costs

The marginal waste treatment curve has the same shape and vertical price scale in both peak and non-peak periods. As previously described, the horizontal quantity axis is changed to reflect the quantity of wastewater treated in each period.

Summing the Marginal Operating and Marginal Waste Treatment Curves

The off-peak marginal cost curve is a vertical summation of the marginal operating and the marginal waste treatment cost curves. For each level of water delivery measured along the x-axis, the two cost curves are added as shown in Figure 16 to give the off-peak marginal cost curve.

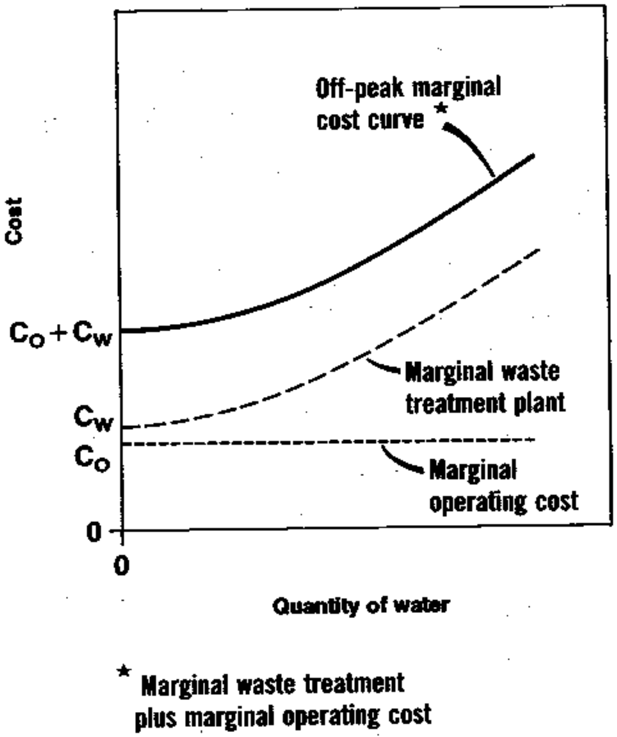


Figure 16. Off-peak marginal cost curve.

ESTIMATION OF WATER DEMAND FUNCTIONS

The demand curve for water is a mathematical or graphical representation of the consumers' response to a change in water price. At very low prices, or at a flat charge, the demand will be high, while at higher prices, the demand will be lower. The demand function for municipal water will be the aggregate of household, commercial, and industrial demand. The procedure outlined below suggests breaking down the demand curve into two categories, household and industrial/commercial, and estimating separate demand curves for each category.

The estimation of demand curves may be the most difficult part of the rate-setting exercise because of a lack of data specific to the utility. The rate setter might have to make rough estimates of the demand curve that can be adjusted once volume based pricing is implemented. The initial consumer reaction to volume based pricing will provide additional data points for demand curve estimation as discussed below.

Elasticity and Shape of Demand Curves

Research has shown that the elasticity of demand for domestic water generally falls between the range of -.1 and -1.0 (Fig. 17), with the median between -.2 and -.3. In the estimation procedures and generic demand curves presented below, elasticities of -.10, -.20 -.25,-.30, -.40, and -.50 are used. Some studies have indicated that the peak period demand is more elastic than the off-peak period demand, while others have indicated little difference in elasticities in the two periods. The analyst will have to select the elasticity that is most appropriate to his utility in each period, depending on the climate, income, and housing characteristics of the area served.

The few studies carried out on industrial/commercial water demand have shown a wide variability in elasticity, mostly between -.05 and -1.0, which is not surprising, given the diversity in the kinds and sizes of industrial establishments. The frequency distribution of elasticities from these studies appears almost rectangular with no apparent median (Fig. 18). However, most municipalities have a mix of industrial and commercial establishments, which would tend to make the aggregate water demand approach the average figure of about -.5. Accordingly, the generic commercial/industrial demand curves given below are between -.3 and -.7. Again the choice of elasticity for rate setting will be up to the analyst.

Demand functions for water are usually curved towards the origin, rather than straight. Absolute levels of water demand change more dramatically at the lower end of the price scale. For example, a change in price from 0 to 10 cents per cubic metre will have a larger effect on the absolute level of consumption than a change in price from 50 cents to 60 cents. The elasticity, which measures the percentage change in quantity relative to the percentage change in price, is more likely to be constant over the length of the demand curve. The estimation procedures described below use curved demand curves with constant elasticities.

Depending on the current pricing system and the amount of data available, different strategies for approximating demand curves will have to be employed. These strategies are outlined below.

Systems Presently Charging Flat Rates

Under a flat rate the effective marginal price of water is zero. The only observed point on the demand curve is at the zero price. The rest of the demand curve can only be extrapolated based on assumptions about the elasticity and the shape of the curve. To aid in this extrapolation, this section provides a set of generic demand curves for each of the two categories, residential and industrial/commercial. Each set contains a number of demand curves with a range of elasticities and consumption levels at the zero marginal price. The analyst should select the elasticity and consumption level that seems most appropriate for the utility. If the area is relatively wealthy, with a hot dry climate, then the less elastic demand curve should be chosen. Analysts should use the more elastic demand curves for areas that have lower incomes or moist climates.

The residential water demand curves represent monthly household demand for water. Figures 19 to 24 show demand curves with different consumption levels at the zero marginal price. The analyst should select the demand curve that most closely matches the expected elasticity and the monthly household demand at zero marginal price. Multiplication of this demand by the number of households served gives the aggregate residential water demand curve for the utility on a monthly basis. Multiplying the monthly aggregate demand curve by the number of months in each of the peak and off-peak periods will give the aggregate household demand for each period.

The industrial/commercial water demand curves provided in this section represent monthly aggregate municipal demand for water. Because industrial/commercial demand varies widely between municipalities, Figures 25 to 29 have a number of optional scales on the quantity axis.

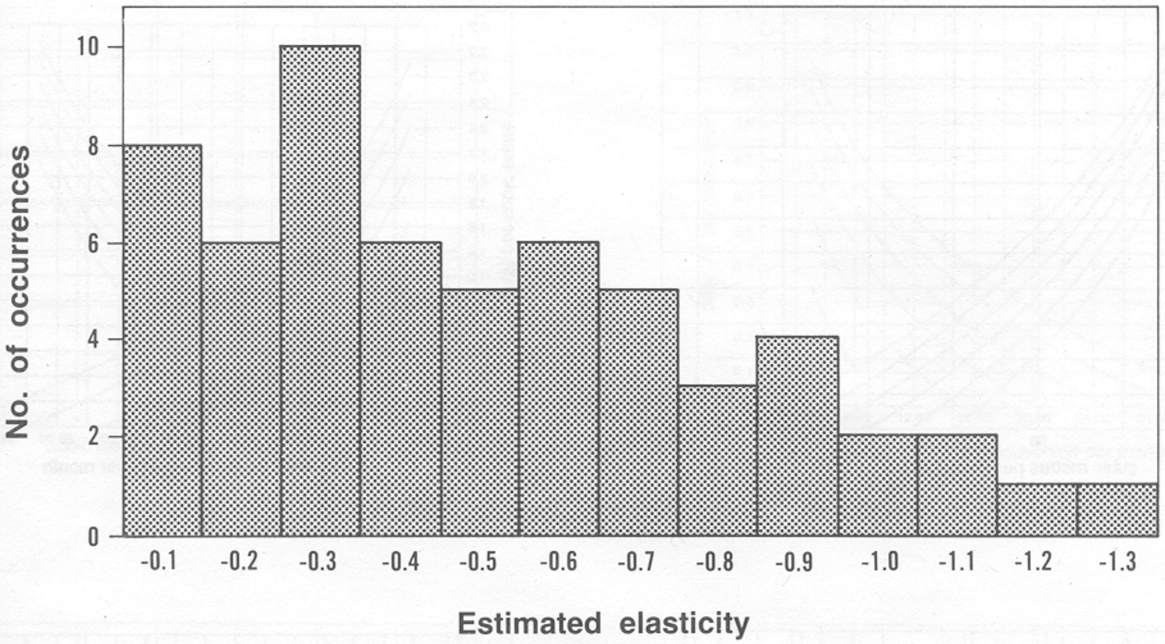


Figure 17. Frequency distribution of price elasticity for residential water demand functions (from various studies in the 1960s, 70s and 80s).

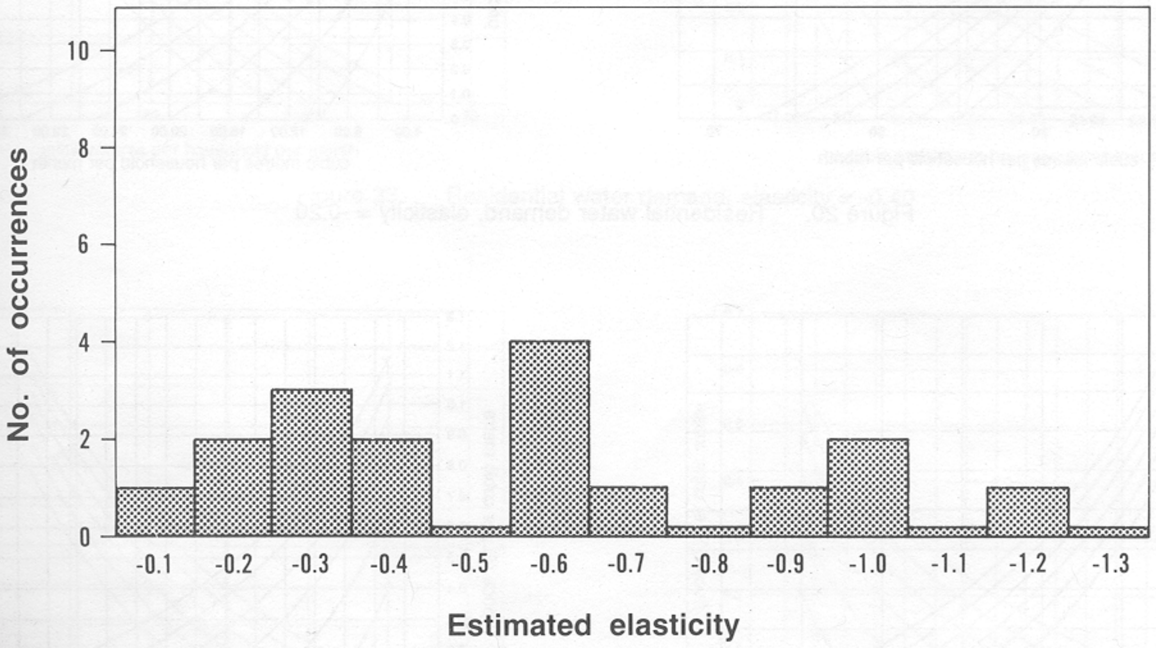


Figure 18. Frequency distribution of price elasticity for industrial water demand functions (from various studies in the 1960s, 70s and 80s).

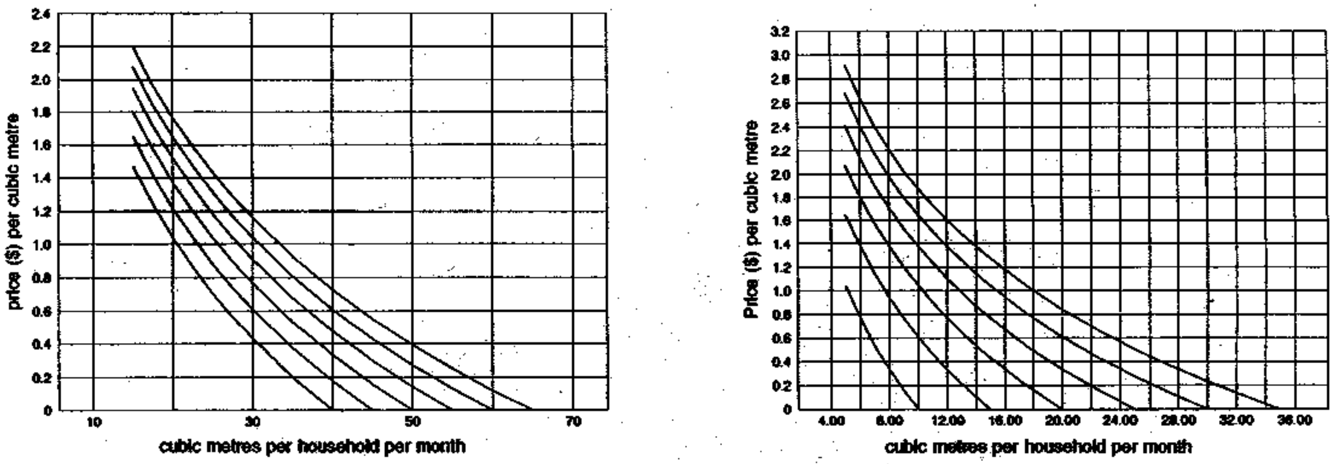


Figure 19. Residential water demand, elasticity = -0.10

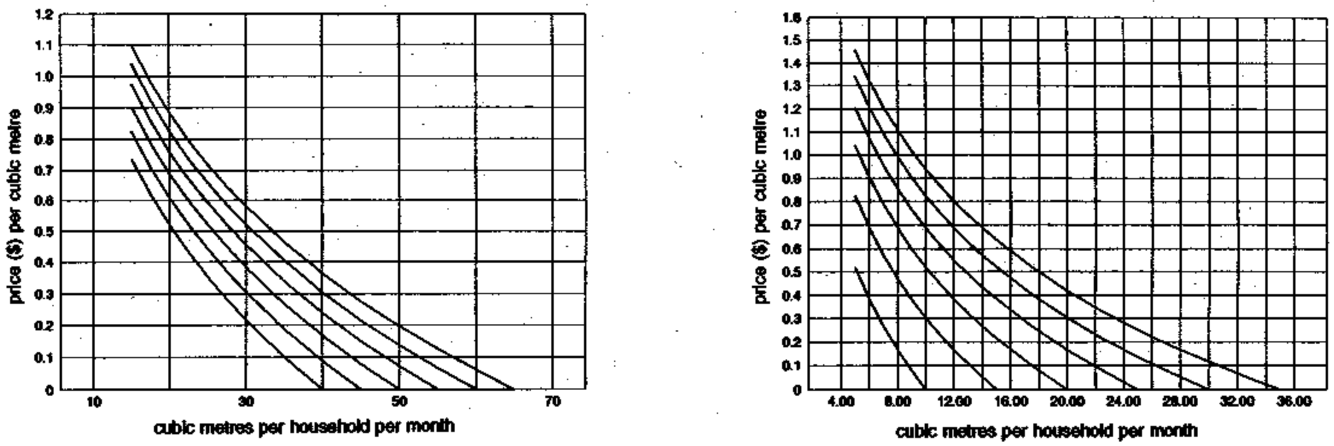


Figure 20. Residential water demand, elasticity = -0.20

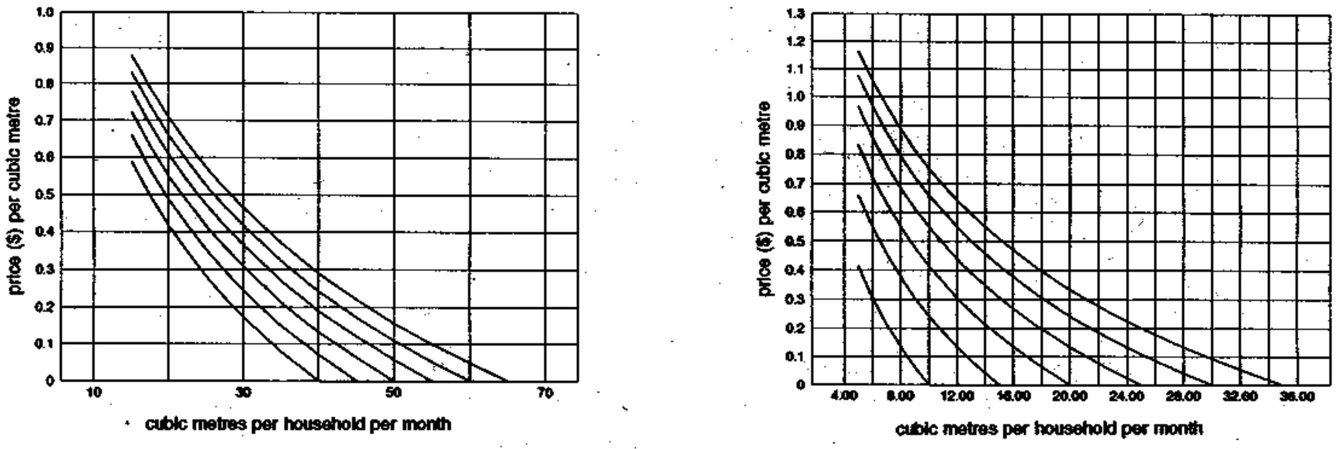


Figure 21. Residential water demand, elasticity = -0.25

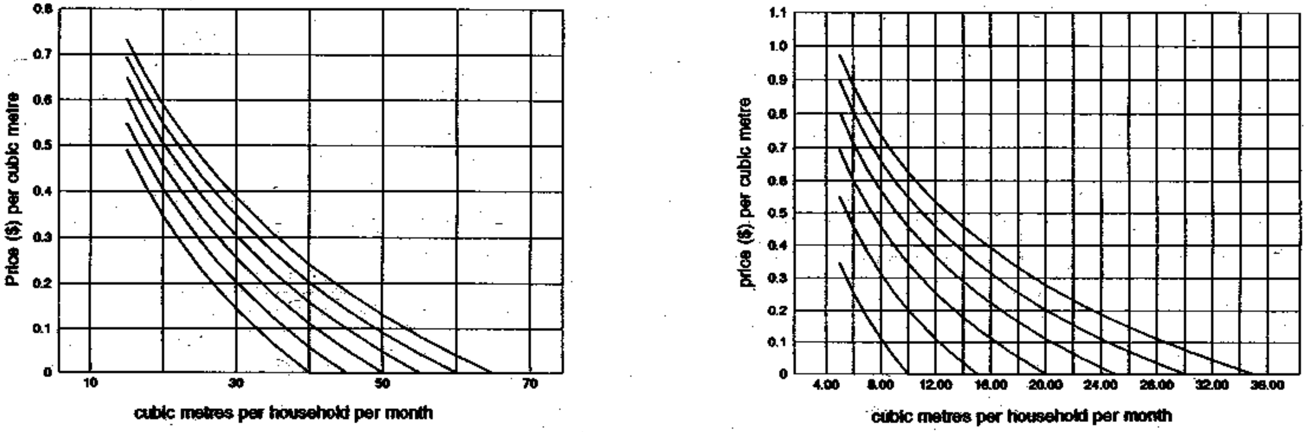


Figure 22. Residential water demand, elasticity = -0.30

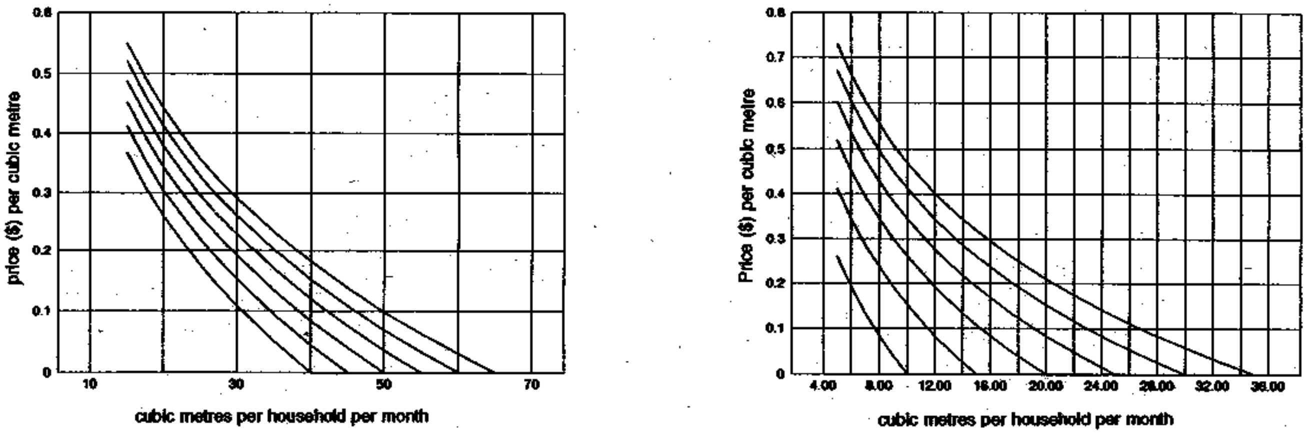


Figure 23. Residential water demand, elasticity = -0.40

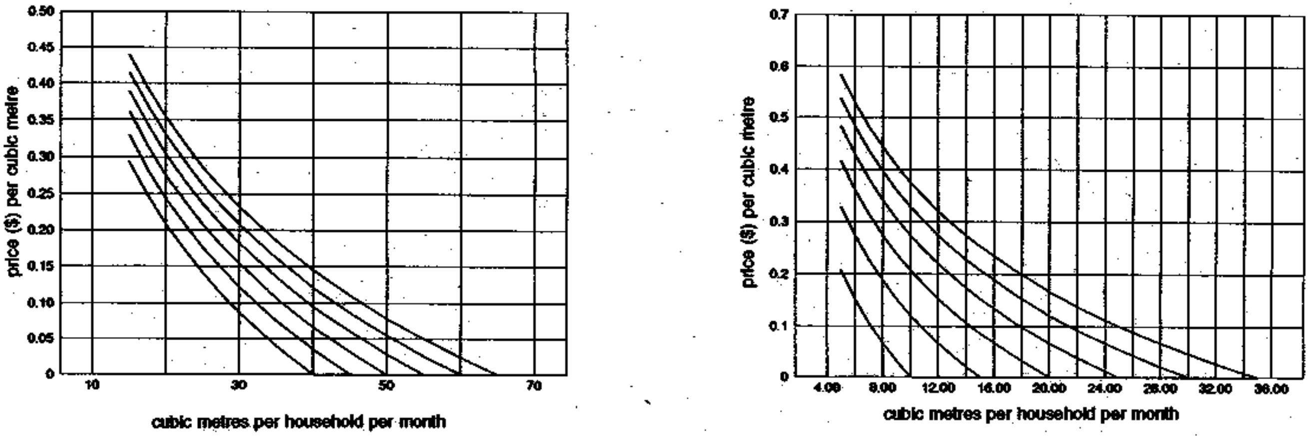


Figure 24. Residential water demand, elasticity = -0.50

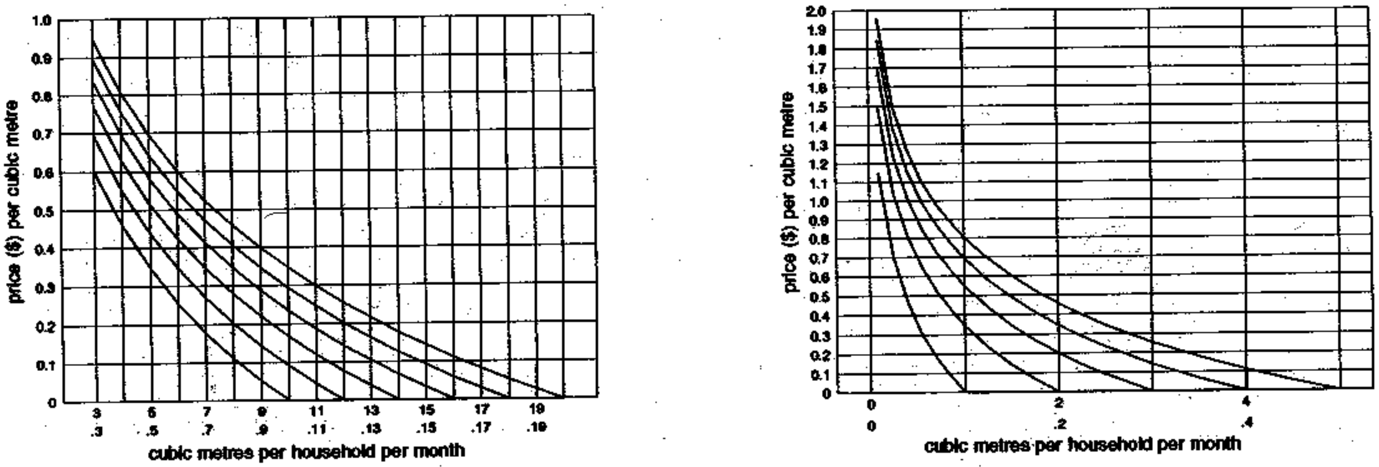


Figure 25. Industrial/commercial water demand, elasticity = -0.30

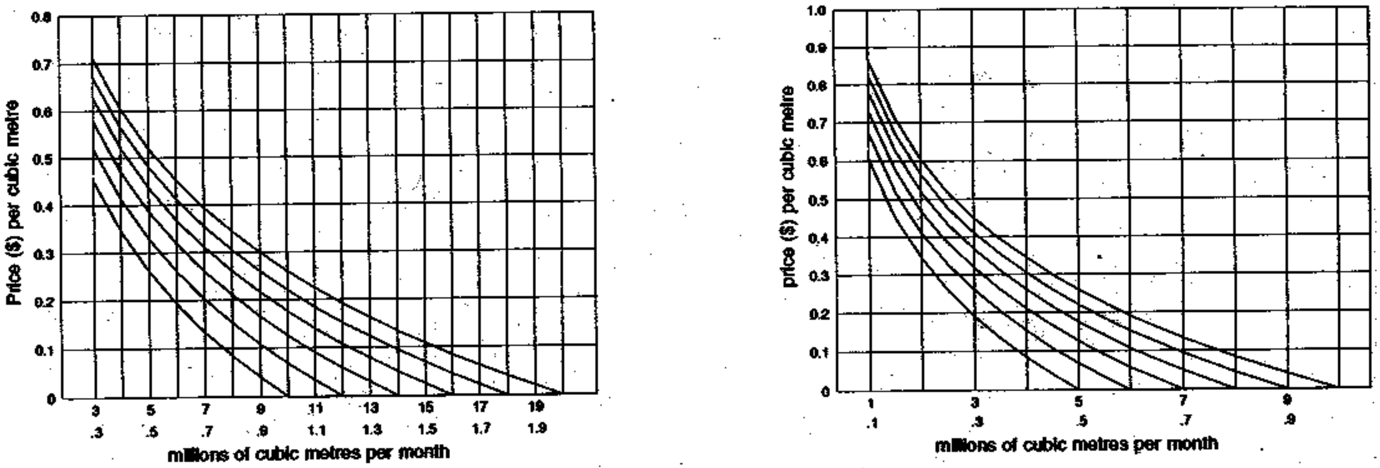


Figure 26. Industrial/commercial water demand, elasticity = -0.40

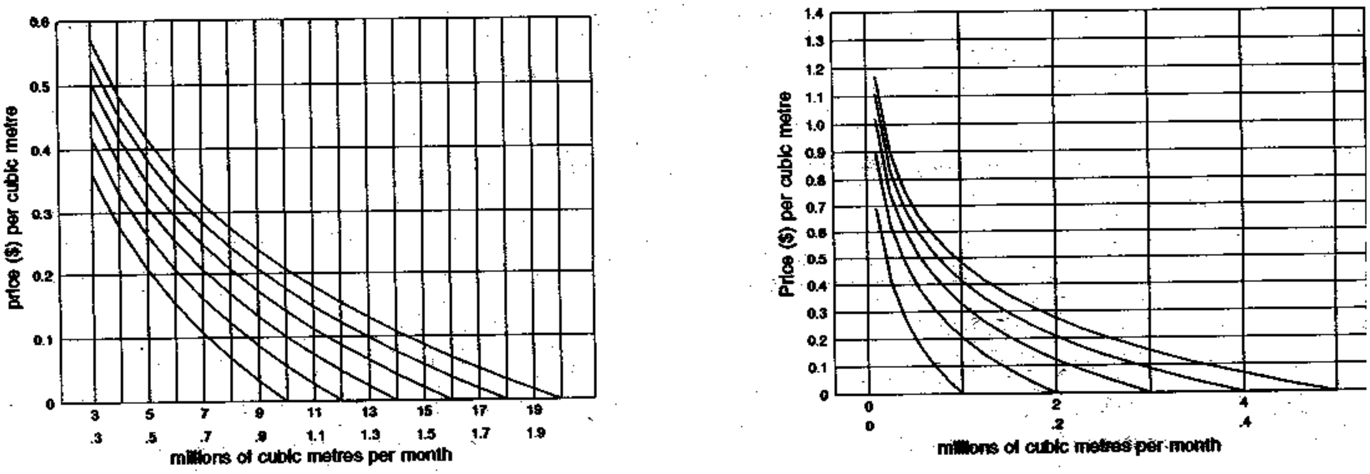


Figure 27. Industrial/commercial water demand, elasticity = -0.50

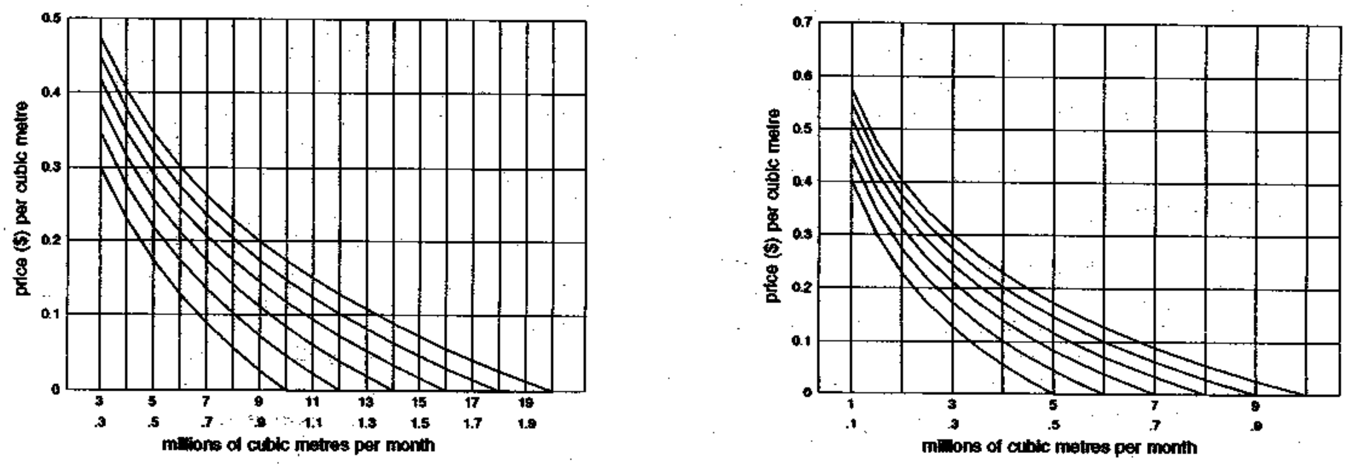


Figure 28. Industrial/commercial water demand, elasticity = -0.60

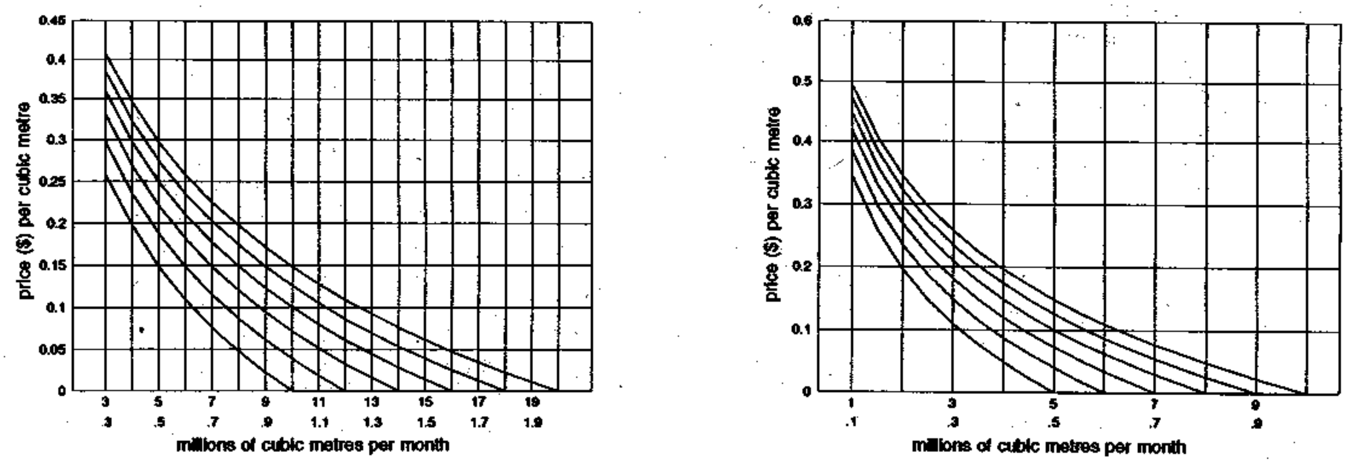


Figure 29. Industrial/commercial water demand, elasticity = -0.70

The analyst should choose the most appropriate scale for the municipality and then select the demand curve that most closely matches the expected elasticity and the consumption at the zero marginal price. As with residential water demand, the analyst should multiply this demand curve by the number of months in each of the peak and off-peak periods to obtain the demand curves for the two periods.

Systems Charging a Non-Zero Price but with No Supplementary Price Data

This category pertains to systems that charge a positive marginal price that has not varied significantly over time or across geographical regions of the service area. In these cases, only one observed point on the demand curve exists, and so the rest of the curve must be extrapolated. The analyst can use the same procedure as was used for flat rate systems above, first deciding on the appropriate elasticity and then selecting the demand curve that most closely reflects the actual quantity demanded at the current marginal price. This procedure applies to both the domestic and commercial categories as well as to the peak and off-peak periods.

For systems that use a declining or increasing block rate system, the marginal price must first be determined. The marginal price can be approximated by the price of the particular consumption block that most households fall under for their last unit of consumption.

Systems with Limited Information on the Effects of Price on Demand

This category includes systems where only a small portion of the demand curve can be estimated from consumption and price data. For example, some municipalities or regions may charge a volume based price in metered areas and a flat rate in unmetered areas. In this case two observed points on the demand curve exist: one at the zero marginal price and the other at the metered price. Drawing a straight line between the two points will give an estimate of the slope of the demand curve at the current consumption level (Fig. 30). In other cases, the utility may have changed its price for water over time, with some corresponding change in consumption. The consumption levels can be plotted against the prices to give a small portion of the demand curve. The slope of this portion of the curve gives a point estimate of slope at current consumption levels.

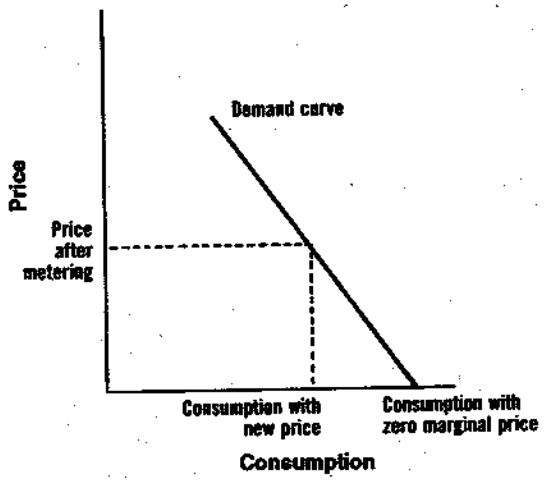


Figure 30. Estimation of demand curve using consumption before and after metering.

Using the slope, the current consumption level, and the current price, the analyst can determine a demand curve with constant elasticity. The general functional form of such a demand curve is represented by equation (12).

$$Q = \alpha P^{\beta} \tag{12}$$

where Q = quantity of water demanded

P = marginal price

α = a constant

β = a constant (less than zero)

The slope of this function at any point is designated by S and is always negative. If the analyst has an estimate of the slope, he can determine the parameter β, which represents the elasticity of demand, using equation (13).

$$\log(-\beta) = \log(-S) - \log(Q) + \log(P) \tag{13}$$

Equation (13) is used to solve for log ($-\beta$). Using a table of logarithms, the value for $-\beta$ and thus β can be determined. Once the value for β is obtained, the value of α can be determined by substituting the values of β, Q, and P back into equation (12).

The procedure outlined above applies to demand curves for both the domestic and industrial/commercial categories in both peak and off-peak periods, provided that the analyst has an initial estimate of the slope.

Systems with a Range of Price and Quantity Data

There may be a few utilities for which significant data exist on the effects of price variation on demand. This could be the case for utilities that serve many different communities, each of which charges a different price. The rate setter may also compare water consumption for several different utilities that charge a range of prices. In other cases, individual utilities may have significantly altered prices over time. Both time series and cross sectional variation in prices may exist for some utilities.

If the corresponding water demand can be matched to the price in each time period or subregion, then a statistical (econometric) estimation can be made of the demand curve for water. Other explanatory variables affecting water demand, such as income and weather, should also be incorporated in the estimation. Although technical, this type of analysis will give accurate estimates of the demand curve if sufficient data exists. Econometric procedures are complex and a detailed study of the methodology is beyond the scope of this paper. If analysts wish to use econometric methods for water demand curve estimation they should refer to studies such as Renzetti (1990) or Shaw (1988).

Econometric estimations usually require a minimum of 15 to 20 observations to obtain statistically significant estimates of the demand curve. A higher number of observations will give more accurate results. If the minimum number of observations cannot be obtained, the analyst may be able to plot the data and make a visual estimate of the demand curve.

Obtaining the Aggregate Water Demand Curve in Each Period

The aggregate demand curve in each of the peak and off-peak periods consists of both the domestic water demand curve and the industrial/commercial water demand curve. A horizontal summation of quantities from both demand curves gives the aggregate demand curve (Fig. 31).

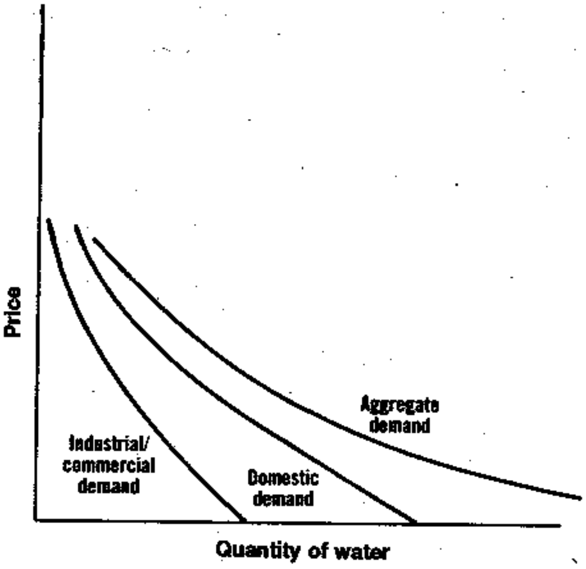


Figure 31. Horizontal summation of demand curves.

DETERMINING PRICE AND TOTAL REVENUE FROM VOLUMETRIC PRICING

At this stage, the analyst can graph the marginal cost curves and demand curves in the peak and non-peak periods to determine the respective prices. The intersection of the marginal cost curve and demand curves determines the optimal price in each period as was shown in Figure 11 at the beginning of this chapter. A projection from the demand curve onto the quantity axis gives the quantity demanded at the optimal prices. Multiplying this quantity by the price gives the total revenue from the volume based price in each period. A summation of the revenues in the peak and off-peak periods gives the total revenue from the volumetric price.

CALCULATION OF THE FIXED CONNECTION CHARGE

As shown in equations (9) and (10), a fixed connection charge paid by each customer is the final element of the proposed price schedule. This charge, which does not vary with the amount of water consumed, aims at covering costs not included in the volumetric portion of the rate. The connection charge is based on the difference between the annualized cost of the water system and the total revenue obtained from the volumetric charge.

The total cost curve in the peak and off-peak periods shows the total costs of water supplied at the optimal price level. If these costs are greater than the total revenues from volumetric pricing, then utilities should apply a fixed connection charge to each customer. This will likely be the case if the utility faces significant fixed costs.

As discussed in Chapter 3, rate setters can use the fixed connection charge to account for the differences in the average costs of supplying different customers. The simplest method of calculating the connection fee per customer, which is to divide the revenue shortfall by the number of connections, results in a lower average price for high volume users. Equation (14) states this calculation mathematically for the individual customer.

$$FC = \frac{TAC - RV}{C} \qquad (14)$$

where FC = the fixed connection charge per customer

TAC = total annualized cost of system operations

RV = revenue received from the volumetric portion of the rate schedule

C = number of connections to the water system

Since the connection charge is the same for all users regardless of the amount of water consumed, high volume users will pay a lower average price than low volume users. The rate setter may consider this to be a fair system if the average costs of supply are lower for the larger connections. However, if the utility serves a mixed market that includes some very high volume users, then this system may result in an unfair burden on the smaller customers.

The rate setter has some leeway to adjust the connection charge in favour of either low volume or high volume customers by dividing customers into classes related to current water demand. The number of classes is arbitrary, but some natural groupings of customers may exist. For example, utilities often serve a few large industrial customers, several light industries, numerous commercial establishments, and a large number of households. Within each of these classes, water demand will be roughly similar, and a common connection charge within each category would be fair. For each class, the utility can calculate the per customer connection charge as in equation (15).

$$FC_{in} = \frac{W_n\,(TAC - RV)}{C_n} \qquad (15)$$

where FC_{in} = the fixed connection charge per customer in class n

W_n = a weighting factor applied to class n

TAC = total annualized cost of system operations

RV = revenue received from the volumetric portion of the rate schedule

C_n = number of connections to the water system in class n

The sum of the weighting factors for all classes should equal one, and the choice of the relative weights between classes is up to the utility. The relative weights will usually relate to average supply costs for each class. For example, the utility may estimate that the class of heaviest water users accounts for 10% of the fixed costs of water supply. The weighting factor, W_n, in equation (15) would thus equal 10%. In other cases, a utility may decide that there are no fixed cost differences in supplying different sized customers. In these cases, the weighting factor for a class of customers should equal the relative proportion of the total water supply consumed by that class. This weighting scheme would result in the same approximate average price for all users.

The determination of the average cost of supply for different classes of customers relies on the judgment of the analyst. For each customer class, the analyst should examine the portion of fixed costs that can be attributed to supplying this class. For many fixed cost items, the amount attributable to various customer classes will simply be proportional to the total water consumed by the customer class. For these items there are no cost advantages that occur for a single large consumer relative to a number of small consumers. For example, the fixed costs of reservoir capacity are related only to total volume of water supply. The costs of the reservoir remain the same whether this capacity is used to supply a few large customers or whether it is used to supply many small customers. Some fixed cost items, however, do relate to the relative size of individual customers. Administrative fixed costs such as meter reading and bill processing will be much higher for a number of small customers than for a few large customers. Thus, the high volume customer classes account for proportionally fewer of these fixed cost items. Adjustment of the weighting factor in the connection charge will account for these cost advantages.

As long as the volumetric portion of the rate schedule reflects marginal costs, the relative weights given to the connection charges will not affect the efficiency of the price system. Therefore, the volumetric portion of the rate structure

should remain invariable between customers. Only the fixed connection charge should be used to account for differences in the average costs of supply between customers.

SUMMARY

This chapter has outlined the basic methods for rate design that use marginal cost pricing principles. The basic rate design involves a volumetric component and a fixed connection charge. In the off-peak period, the volumetric component equals the marginal operating cost plus marginal waste treatment cost; in the peak period, it equals the sum of marginal operating costs, marginal capacity cost, and marginal waste treatment cost. The effect of volume based pricing on demand is accounted for by setting the prices at the intersection of the marginal cost curve with the demand curve in each of the peak and off-peak periods. The fixed connection charge is added to capture any costs not covered by the volumetric charges.

Marginal operating costs can be approximated by the variable costs of water supply. Some costs are easily identifiable as variable, while other costs will require a subjective judgment by the analyst as to whether they are. Estimation of marginal capacity costs is based on the principle that reduced demand can delay requirements for future capacity expansion, thus resulting in cost savings. The slope of the peak period total cost curve for water supply gives the marginal cost curve for water supply. In a similar fashion, the marginal cost curve for waste treatment is derived from the slope of the wastewater treatment total cost curve.

The primary function of the fixed connection charge is to recover any deficits resulting from the volumetric price. It also serves as a means of accounting for the differences in the average cost of supply between customers. Rate setters have the choice of simply dividing revenue shortfalls by the number of connections to give a fixed connection charge per customer or of calculating a separate connection charge for each class of customer. The method used will depend on the mix of customers served and the nature of fixed costs facing the utility.

Using the pricing principles discussed in this chapter, a utility should be able to achieve both economic efficiency and full cost recovery. The implementation of these principles into water rate setting is both practical and straightforward. Examples of applications of these principles are given in the next chapter.

CHAPTER 6

Examples of Marginal Cost Pricing

This chapter examines the application of the marginal cost pricing principles to two hypothetical water supply and wastewater treatment systems. It uses information from standard financial statements, operating plans, and capital expenditure plans to generate the necessary information to estimate marginal costs. The two case studies represent a range of systems, from a large urban waterworks to a smaller system for a mid-size community.

The nature of water supply costs will vary widely between regions and municipalities in Canada. In particular, the relative weights of capacity costs versus operating costs can show substantial variation between systems. For example, utilities that have surface water with significant gravity pressure are likely to have much lower operating costs than groundwater systems. Marginal capacity costs for rapidly growing areas will be much higher than for low-growth areas. Many other factors will affect both marginal and capacity costs. The examples given in this chapter represent a range of water supply systems, and the calculated marginal costs and rates are not meant as baseline figures for specific municipalities. The absolute price level and the relative differences between peak and non-peak prices must be calculated for each system. Analysts should not be surprised if the marginal costs they calculate for their systems are substantially different from the examples shown in this chapter.

Because of the various technologies in use, wastewater treatment costs also show a tremendous variation between municipalities. Geographical factors greatly influence the standards required for effluent discharged. Various levels of treatment — primary, secondary, or tertiary — may be needed to meet the required standards. The level of treatment will usually be the major factor influencing the level of costs. In many cases, particularly when advanced treatment is required, the wastewater treatment costs can be far greater than the costs of water supply. For systems using only basic levels of treatment, the wastewater treatment costs can be less than the costs of water supply. Despite this variability in wastewater treatment costs, the approximation methods for estimating marginal costs should be reasonably accurate in most cases.

Table 10, which is a check list of the procedures for marginal cost pricing, was used as a step-by-step guide for determining the marginal costs and water prices for the case studies.

These steps are undertaken in the two examples that follow.

CASE ONE: LARGE URBAN AREA

General Setting

This water supply utility supplies a major urban area with a population of over two million. It includes 325 000 residential connections to the water system. The utility acts as a wholesaler, supplying water to several member municipalities. The member municipalities incur the retail expenses associated with water servicing, including bill collection, administration, and regulation. In the most recent year of operation, the utility supplied approximately 275 million cubic metres of water. About 60% of this water, or 165 million cubic metres, is supplied during the peak summer months. The remaining 110 million cubic metres are supplied during the off-peak months. The sprawling nature of the area necessitates several secondary reservoirs and a complex system of water mains. Natural water quality is high since primary

Table 10

Steps in Determining Marginal Cost Prices

1. Classify current costs into variable and fixed costs.
2. Calculate the unit variable cost for water supply and for wastewater treatment.
3. Calculate variable costs for water supply and for wastewater treatment over a range of water demand.
4. Calculate expansion costs for water supply and for wastewater treatment over a range of water demand.
5. Determine the total cost curves over a range of demand for peak period water supply, off-peak water supply, and wastewater treatment.
6. Derive the marginal cost curves for peak period water supply, off-peak period water supply, and wastewater treatment.
7. Calculate the combined water supply/wastewater treatment marginal cost curves by summing marginal costs in each of the peak and off-peak periods.
8. Estimate peak and off-peak demand curves.
9. Set peak period prices at the intersection of the combined peak period water supply/wastewater treatment marginal cost curve and the peak period demand curve.
10. Set off-peak period prices at the intersection of the peak period combined water supply/wastewater marginal cost curve and the off-peak demand curve.
11. Calculate fixed connection charge by subtracting total revenues from total costs.

collection takes place in isolated, protected mountain reservoirs, fed by significant rainfall and snowmelt. Treatment costs are thus relatively low. Pumping costs are also fairly low because the primary intakes and reservoirs are at a higher elevation, allowing the use of gravity flow for the most part. Peak period use in May, June, July, and August results in the major demands on system capacity.

Wastewater is processed through a primary treatment system and then pumped to a deep ocean outfall. As a result, costs are relatively low, although energy costs for pumping are significant. Because of the high rate of population growth in the area, the present system is nearing capacity, and expansion will be required within five years. The present volume of wastewater treated is about 250 million cubic metres per year.

The area's population is growing at the very high rate of 2.5% a year, resulting in the need for continual system upgrading and expansion. The utility plans major capital expenditures over a five-year horizon, based on the projected growth rate in consumption. At present, the utility charges only a flat rate based on average cost, with no volume based pricing. The member municipalities also charge a flat rate to residential and industrial customers, with no volume based pricing.

Current Costs of Water Supply

The utility's annual budget provides the total annual costs for water servicing, as shown in Table 11. This budget shows current cash requirements for the utility but does not include a provision for future capacity expansion. The costs of billing and collection are passed on to the municipalities and are included below in the municipal retail expense category.

Table 11

Annual Water Supply Budget, Case 1

Item	Budget
Operation and maintenance	$ 6 590 000
Debt charges	6 500 000
Municipal retail expenses	5 800 000
Total	$18 890 000

Table 12 shows the itemized annual expenditures of the utility on operations and maintenance.

Table 12

Water Supply Costs: Detailed Operations and Maintenance Budget, Case 1

Item	Budget
Salaries	$3 500 000
Electricity	800 000
Chemicals	300 000
Vehicle operation	300 000
Contracted repairs and maintenance	150 000
Equipment replacement	200 000
Provincial water taxes	390 000
Other taxes	300 000
Miscellaneous and indirect costs	600 000
Insurance	50 000
Total	$6 590 000

Classifying Current Costs into Fixed, Variable and Debt Payment

The municipal retail expenses shown in Table 11 can be classified as fixed costs. The operation and maintenance costs, which are a major budget item, present more of a problem for cost classification. Each item in the budget shown in Table 12 should be examined and apportioned between fixed and variable categories.

Some of the operation and maintenance expenditures fall clearly into one category or the other. Insurance, miscellaneous/indirect, non-water taxes, and vehicle operation are considered fixed costs, since they will not be affected by a short-run reduction in demand. Chemical costs are all variable, since the amount added to the water is directly related to the amount delivered. Provincial water taxes in this example are also variable, since the size of the tax varies with the amount of water intake. As electricity costs are primarily for pumping, which also varies with the amount of water delivered, most of this expenditure can be considered as a variable cost. In this particular case, it is calculated that 90% of the electricity costs are due to pumping and are therefore variable costs.

Labour costs, the most significant single O&M cost item, contain both fixed and variable components. The former, which is invariable with the amount of water delivered, occurs because there are major labour intensive functions that must be carried out no matter how much water is consumed. For example, operation of the large number of balancing reservoirs, and regular inspection and maintenance of the supply mains consume 30% of the labour employed. Another 10% of labour is used in operating the primary impounding reservoirs. General administration accounts for another 10% of the labour. Half of the remaining 50% of the labour is engaged in activities dependent on the amount of water delivered, and therefore becomes a variable cost. These activities include some mechanical repairs, system monitoring, quality control, and purification. Thus 25% of the total labour cost is a variable cost.

Equipment replacement costs are partly variable and partly fixed. Although a proportion of the equipment replacement occurs due to obsolescence, wear and tear directly related to the amount of water delivered is also significant. In this example, it is estimated that 25% of the replacement expenditures are variable costs.

Accordingly, variable costs total $2.335 million (Table 13). Fixed costs total $10.055 million and debt payment totals $6.5 million.

Current Costs of Wastewater Treatment

The utility's annual budget shows the total annual costs for wastewater treatment (Table 14). This budget represents current cash requirements for waste treatment, but as for the case of water supply, costs for future capacity expansion are not included.

Table 15 shows the itemized annual expenditures of the utility for operations and maintenance of the wastewater treatment system.

Classifying Wastewater Treatment Costs into Fixed, Variable, and Debt Payment

The debt charges shown in Table 14 can immediately be classified as fixed costs. The operation and maintenance costs detailed in Table 15 should be apportioned between fixed and variable categories as was done for the water supply costs.

Table 13

Annual Variable, Fixed, and Debt Payment Costs ($) for Water Supply, Case 1

Item	Fixed costs	Variable costs	Total costs
Salaries	2 625 000	875 000	3 500 000
Electricity	80 000	720 000	800 000
Chemicals		300 000	300 000
Vehicle operation	300 000		300 000
Contracted repairs and maintenance	150 000		150 000
Equipment replacement	150 000	50 000	200 000
Provincial water taxes		390 000	390 000
Other taxes	300 000		300 000
Miscellaneous costs	600 000		600 000
Insurance	50 000		50 000
Municipal retail expenses	5 800 000		5 800 000
Subtotal	10 055 000	2 335 000	12 390 000
Debt charges	6 500 000		6 500 000
Total	16 555 000	2 335 000	18 890 000

Table 14

Annual Wastewater Treatment Budget, Case 1

Item	Budget
Operation and maintenance	$11 800 000
Debt charges	3 500 000
Total	$15 300 000

Table 15

Wastewater Treatment Costs: Detailed Operations and Maintenance Budget, Case 1

Item	Budget
Salaries	$ 5 500 000
Energy	2 900 000
Chemicals	300 000
Other materials and supplies	1 500 000
Vehicle and equipment operation	400 000
Contracted repairs and maintenance	450 000
Equipment replacement	50 000
Miscellaneous and indirect costs	600 000
Insurance	50 000
Taxes	50 000
Total	$11 800 000

As in the case of water supply, some of the operation and maintenance expenditures fall clearly into the fixed cost category. Insurance, miscellaneous/indirect, non-water taxes, and vehicle operation are considered fixed costs, since they will not be affected by a reduction in the volume of wastewater treatment. Materials and supplies are also considered fixed in the short run.

The other costs cannot be classified as exclusively variable or fixed and must be apportioned between the categories. For example, energy costs are mostly variable as they are related primarily to pumping and aeration, both of which are a function of the volume of wastewater treated. However, a small portion of energy costs are due to lighting and heating, which are independent of the volume of wastewater. About 95% of energy costs are classified as variable, with the remaining 5% classified as fixed.

Because the concentration of solid and dissolved wastes has increased, chemical costs remain largely unaffected, despite the reduced volume of wastewater. Therefore 90% of chemical costs are classified as fixed, and 10% as variable. Contracted repairs and maintenance as well as equipment replacement are also partly fixed and partly variable. The reduced volume of wastewater reduces the annual load on pumps, thereby reducing repair costs. However, some of inspection and maintenance is carried out on a regular annual schedule and can be considered fixed. The utility estimates that about 20% of repairs and maintenance are fixed and 80% are variable.

Labour costs contain both fixed and variable components. As in the case of water supply, there are major labour intensive functions that must be carried out regardless of the volume of wastewater treated. Regularly scheduled monitoring, inspection, and maintenance account for 30% of the labour. Sludge removal and treatment account for an additional 25% of labour costs, and administration accounts for another 15%. The remaining labour engages in activities dependent on the amount of water delivered, and therefore constitutes a variable cost. These activities include some mechanical repairs, system monitoring, quality control, and purification. Thus 30% of the total labour cost constitutes a variable cost.

Accordingly, variable costs total $4.5 million and fixed costs (including payment on debt) total $10.8 million (Table 16).

Table 16

Annual Variable, Fixed, and Debt Payment Costs ($) for Wastewater Treatment, Case 1

Item	Fixed costs	Variable costs	Total costs
Debt payment	3 500 000		3 500 000
Salaries	3 850 000	1 650 000	5 500 000
Energy	145 000	2 755 000	2 900 000
Chemicals	270 000	30 000	300 000
Other materials and supplies	1 500 000		1 500 000
Vehicle and equipment operation	400 000		400 000
Contracted repairs and maintenance	400 000	50 000	450 000
Equipment replacement	35 000	15 000	50 000
Miscellaneous and indirect costs	600 000		600 000
Insurance	50 000		50 000
Taxes	50 000		50 000
Total	10 800 000	4 500 000	15 300 000

Calculating the Unit Variable Cost

The unit variable cost of water supply is found by dividing the total variable costs of water supply by the amount of water delivered during the year. The calculation is thus:

$$\$2.355 \text{ million} / 275\,000\,000 \text{ m}^3 = \$0.008\,56 / \text{m}^3$$

The unit variable cost of wastewater treatment is found in a similar fashion, by dividing the total variable costs of wastewater treatment by the volume of wastewater treated:

$$\$4.5 \text{ million} / 250\,000\,000 \text{ m}^3 = \$0.018/\text{m}^3$$

Calculating Variable Costs over a Range of Water Demand

For any level of water demand or wastewater volume, the variable costs are calculated by multiplying the amount of water delivered or treated by the unit variable cost. This method of calculation is used over the range of water delivery and wastewater volumes specified in the total cost curves of the section on determining the total cost curves.

Calculating Expansion Costs over a Range of Water Demand

Expansion costs were defined as the equivalent annual payment of future expenditures on capacity expansion. Table 17 shows the annual expansion costs based on the capital expenditure plan for the water utility. An interest rate of 12%, which is the current borrowing rate for the utility, is used. The projected capital expenditures include allowances for inflation. The present value and equivalent annual payments were calculated using equations (2) and (3) from Chapter 3.

The annual expansion costs of $6 842 473 for water supply are based on the current peak period water demand of 165 million cubic metres. In order to calculate the costs at lower levels of water use, the effect of a demand reduction on expansion plans must be estimated. By lowering demand, the need for capacity expansion will be delayed. As outlined in Chapter 3, delaying expansion will reduce the equivalent annual costs of financing the expansion.

Table 17

Projected Capital Costs ($) of Capacity Expansion, Case 1

Year	Water supply costs	Wastewater treatment costs
1	4 000 000	0
2	6 000 000	0
3	5 500 000	0
4	5 500 000	0
5	6 000 000	15 000 000
6	6 000 000	25 000 000
7	8 000 000	25 000 000
8	8 000 000	0
9	8 000 000	0
10	8 000 000	0
Present value at 12%	38 661 500	32 485 911
Equivalent annual expansion costs	6 842 473	5 749 492

The current expansion plan for water supply is based on a projected annual increase of 2.5% in water consumption in both peak and non-peak periods. If demand is reduced by the equivalent of one year's growth, then expansion could be delayed for one year, and financial costs reduced accordingly. Table 18 shows the effect on the annual expansion costs of incrementally reducing demand in peak periods by 2.5% from the current level. For each reduction in demand, expansion of the water supply system has been delayed one year, and the present values and equivalent annual payments have been recalculated with the rescheduled expansion.

A short cut to calculating the annual expansion costs at each level of water supply is to calculate annual expansion costs at the current delivery level (165 000 000 m^3) and then apply a discount factor to account for the number of years that capacity expansion would be delayed under each supply scenario.

Table 18

Annual Expansion Costs for Various Levels of Peak Period Water Supply, Case 1

Water supplied (m^3)	Amortized annual payment ($)
165 000 000	6 842 473
160 875 000	6 109 351
156 750 000	5 454 778
152 625 000	4 870 337
148 500 000	4 348 516
144 375 000	3 882 603
140 250 000	3 466 610
136 125 000	3 095 188
132 000 000	2 763 560
127 750 000	2 467 465
123 625 000	2 203 094
119 500 000	1 967 048
115 375 000	1 756 293
111 250 000	1 568 119
107 125 000	1 400 106
103 000 000	1 250 095
98 875 000	1 116 156

Table 19

Annual Expansion Costs for Different Volumes of Wastewater Treatment, Case 1

Wastewater treated (m^3)	Amortized annual payment ($)
250 000 000	5 749 492
243 750 000	5 133 475
237 500 000	4 583 460
231 250 000	4 092 375
225 000 000	3 653 906
218 750 000	3 262 416
212 500 000	2 912 872
206 250 000	2 600 778
200 000 000	2 322 123
193 750 000	2 073 324
187 500 000	1 851 183
181 250 000	1 652 841
175 000 000	1 475 752
168 750 000	1 317 636
162 500 000	1 176 460
156 250 000	1 050 411
150 000 000	937 867

The expansion costs of wastewater treatment over a range of wastewater volumes are calculated in a similar manner. The present annual wastewater expansion costs of $5 749 492 are based on an annual volume of 250 million cubic metres treated. This volume is predicted to grow at a rate of 2.5% per annum. For each long-term reduction in volume of 2.5%, the expansion plans can be delayed by one year, thus reducing the equivalent annual expansion costs (Table 19).

Determining the Total Cost Curves

The analyst should now have sufficient information to calculate three total cost curves: peak period water supply, off-peak water supply, and wastewater treatment. The procedure basically involves adding up the variable, fixed, and expansion costs for each level of water supply or wastewater treatment.

In the peak periods, total costs of water supply include capacity costs plus variable costs (Table 20). In the off-peak period, costs include variable costs only (Table 21). The fixed costs can be included in either category or divided between categories without affecting the price calculations. Following the procedure outlined in Chapter 4, the fixed costs of water supply, including the debt costs, are divided equally between the peak and off-peak periods. The variable costs are calculated by multiplying the amount of water supplied by the unit variable cost of $0.008 56 per cubic metre.

The total costs for wastewater treatment are the sum of the variable, fixed, and expansion costs (Table 22). The variable costs are calculated by multiplying the volume of wastewater treated by the unit variable cost of $0.018 per cubic metre. The fixed costs, taken from Table 16, are invariable over different volumes. The expansion costs are from Table 19.

The total cost curves for peak and off-peak period water supply and for wastewater treatment based on Tables 19 to 21 are shown in Figure 32.

Table 20

Total Costs of Peak Period Water Supply, Case 1

Current demand (m^3)	Expansion costs ($)	Fixed costs ($)	Variable costs ($)	Total costs ($)
165 000 000	6 842 473	8 277 500	1 413 555	16 533 528
160 875 000	6 109 351	8 277 500	1 378 216	15 765 067
156 750 000	5 454 337	8 277 500	1 342 877	15 074 714
152 625 000	4 870 337	8 277 500	1 307 538	14 455 375
148 500 000	4 348 516	8 277 500	1 272 200	13 898 216
144 375 000	3 882 603	8 277 500	1 236 860	13 396 963
140 250 000	3 466 610	8 277 500	1 201 522	12 945 632
136 125 000	3 095 188	8 277 500	1 166 183	12 538 871
132 000 000	2 763 560	8 277 500	1 130 844	12 171 904
127 875 000	2 467 465	8 277 500	1 095 051	11 840 016
123 725 000	2 203 094	8 277 500	1 059 952	11 540 546
119 600 000	1 967 048	8 277 500	1 024 613	11 269 161
115 475 000	1 756 293	8 277 500	989 274	11 023 067
111 350 000	1 568 119	8 277 500	953 935	10 799 554
107 225 000	1 400 106	8 277 500	918 597	10 596 203
103 100 000	1 250 095	8 277 500	883 258	10 410 853
98 975 000	1 116 156	8 277 500	847 919	10 241 566
94 850 000	996 568	8 277 500	812 500	10 015 970
90 725 000	889 793	8 277 500	777 241	9 944 534
86 600 000	794 458	8 277 500	741 902	9 813 860

Table 21

Total Costs of Off-Peak Period Water Supply, Case 1

Current demand (m^3)	Fixed costs ($)	Variable costs ($)	Total costs ($)
110 000 000	8 277 500	941 600	9 219 100
107 250 000	8 277 500	918 060	9 195 560
104 500 000	8 277 500	894 520	9 172 020
101 750 000	8 277 500	870 980	9 148 480
99 000 000	8 277 500	847 440	9 124 940
96 250 000	8 277 500	823 900	9 101 400
93 500 000	8 277 500	800 360	9 077 860
90 750 000	8 277 500	776 820	9 054 320
88 000 000	8 277 500	753 280	9 030 780
85 250 000	8 277 500	729 740	9 007 240
82 500 000	8 277 500	706 200	8 983 700
79 750 000	8 277 500	682 660	8 960 160

Table 22

Total Costs of Wastewater Treatment, Case 1

Volume treated (m³)	Expansion costs ($)	Fixed costs ($)	Variable costs ($)	Total costs ($)
250 000 000	5 749 492	10 800 000	4 500 000	21 049 492
243 750 000	5 133 475	10 800 000	4 387 500	20 320 975
237 500 000	4 583 460	10 800 000	4 275 000	19 658 460
231 250 000	4 092 375	10 800 000	4 162 500	19 054 875
225 000 000	3 653 906	10 800 000	4 050 000	18 503 906
218 750 000	3 262 416	10 800 000	3 937 500	17 999 916
212 500 000	2 912 872	10 800 000	3 825 000	17 537 832
206 250 000	2 600 778	10 800 000	3 712 500	17 113 278
200 000 000	2 322 123	10 800 000	3 600 000	16 722 123
193 750 000	2 073 324	10 800 000	3 487 500	16 360 824
187 500 000	1 851 183	10 800 000	3 375 000	16 026 183
181 250 000	1 652 841	10 800 000	3 262 500	15 715 341
175 000 000	1 475 752	10 800 000	3 150 000	15 425 752
168 750 000	1 317 636	10 800 000	3 037 500	15 155 136
162 500 000	1 176 460	10 800 000	2 925 000	14 901 460
156 250 000	1 050 411	10 800 000	2 812 500	14 662 911
150 000 000	937 867	10 800 000	2 700 000	14 437 867

Determining the Marginal Cost Curves

The analyst can now derive the marginal cost curves for peak period water supply, off-peak period water supply, and wastewater treatment. Given the information contained in the total cost curves, derivation of the marginal cost curves is quite straightforward.

The marginal cost curve of water supply in the peak period, composed of marginal operating costs plus the marginal capacity cost, is found by taking the slope of the peak period water supply total cost curve and plotting the value against the volume of water delivered. This procedure has been carried out in Figure 33. At any point along the x-axis in the right section, the marginal cost is equal to the slope of the total cost function in the left section.

The annual marginal cost curve of wastewater treatment is derived in a similar manner. The slope of the total cost curve for wastewater treatment is taken at a number of points on the x-axis, and plotted against the volume of wastewater treated (Fig. 34). The annual marginal cost curve can be broken down into peak and off-peak periods using the method described in Chapter 4. The basic shape remains the same in each period, but the quantity scale is reduced in each period to reflect the relative amount of wastewater treated. In this case, 35% of the wastewater volume occurs in the peak demand period from May to August and 65% occurs in the off-peak period from

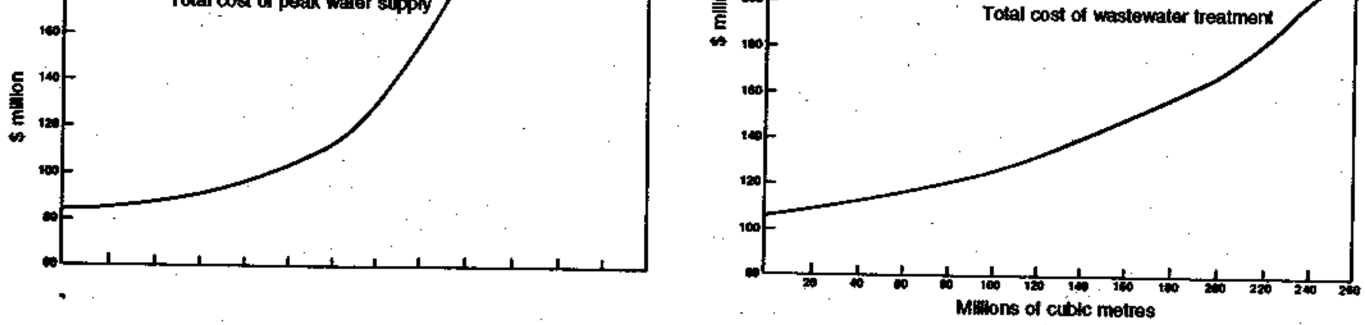


Figure 32. Total cost curves, Case 1.

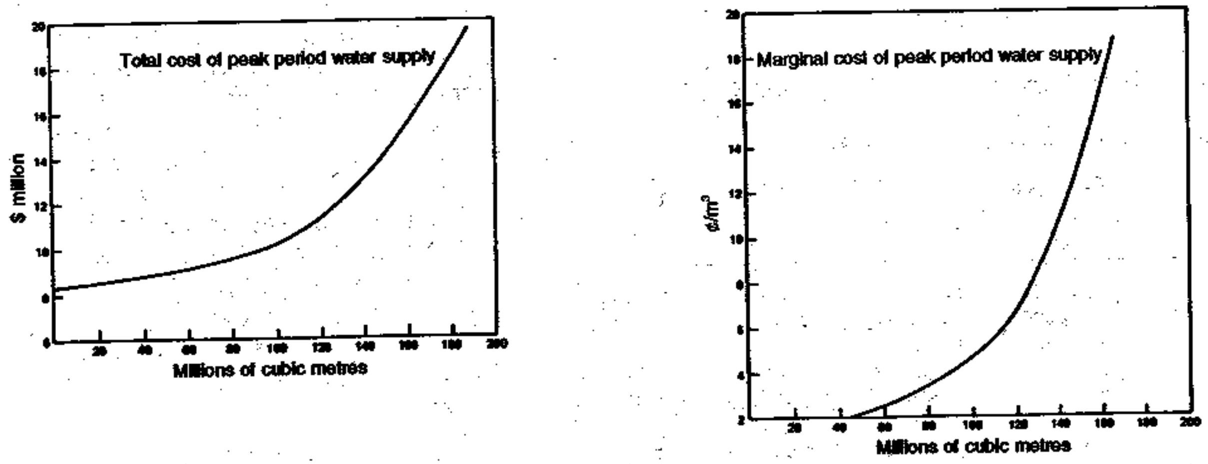


Figure 33. Marginal cost for peak period water supply, derived from total cost curve, Case 1.

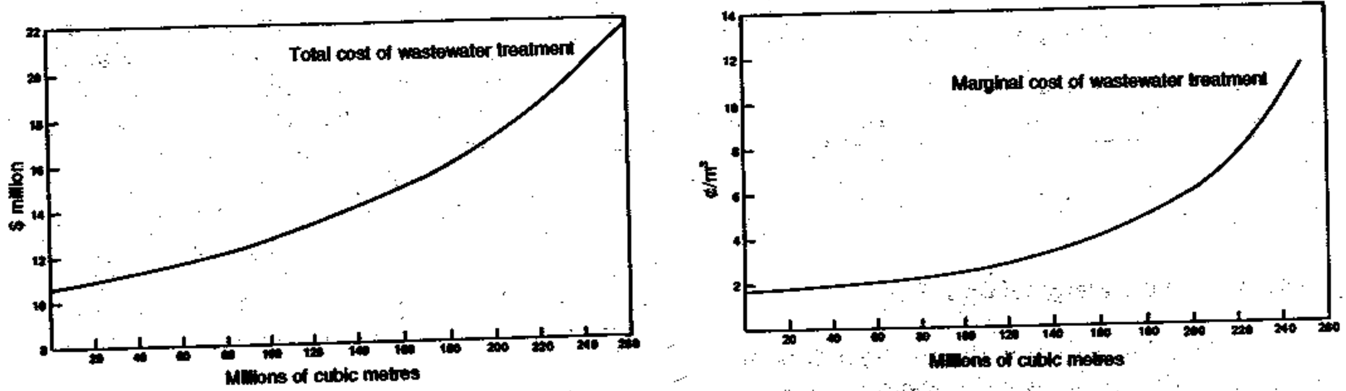


Figure 34. Marginal cost of wastewater treatment, Case 1.

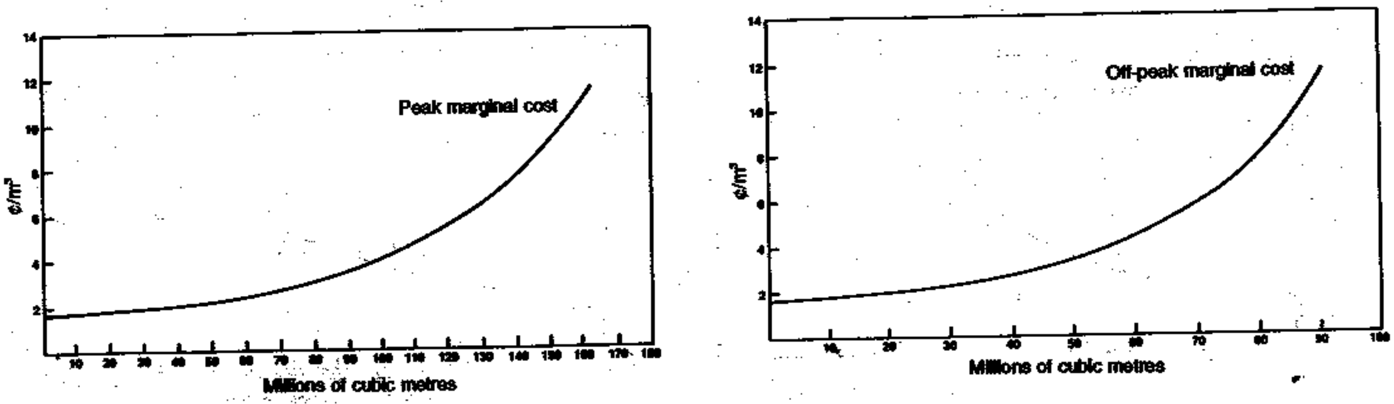


Figure 35. Peak and off-peak marginal costs of wastewater treatment. Case 1.

September to April. Figure 35 shows the breakdown of the annual marginal cost curve into the two periods based on these percentages.

The marginal cost curve for water supply in off-peak periods is simply a straight line equal to the unit variable cost of water supply of $0.008 56 per cubic metre.

Combined Water Supply/Wastewater Treatment Marginal Cost Curves

The combined off-peak marginal cost curve is the summation of the marginal operating cost and the marginal wastewater treatment cost curve. A vertical summation of these components, Figure 36, gives the combined off-peak marginal cost curve. This curve represents the sum of the marginal cost of supplying one additional unit of water and the marginal cost of treating the increase in wastewater associated with the additional unit of supply.

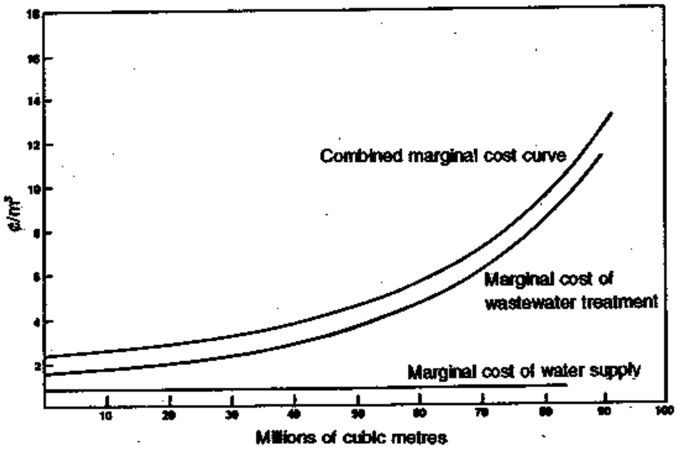


Figure 36. Combined water supply/wastewater treatment marginal cost curve, off-peak period, Case 1.

The combined peak period marginal cost curve is the summation of the marginal cost curve for peak period water supply and the marginal wastewater treatment cost curve. A vertical summation of these two curves gives a graphical representation of the combined marginal cost curve (Fig. 37).

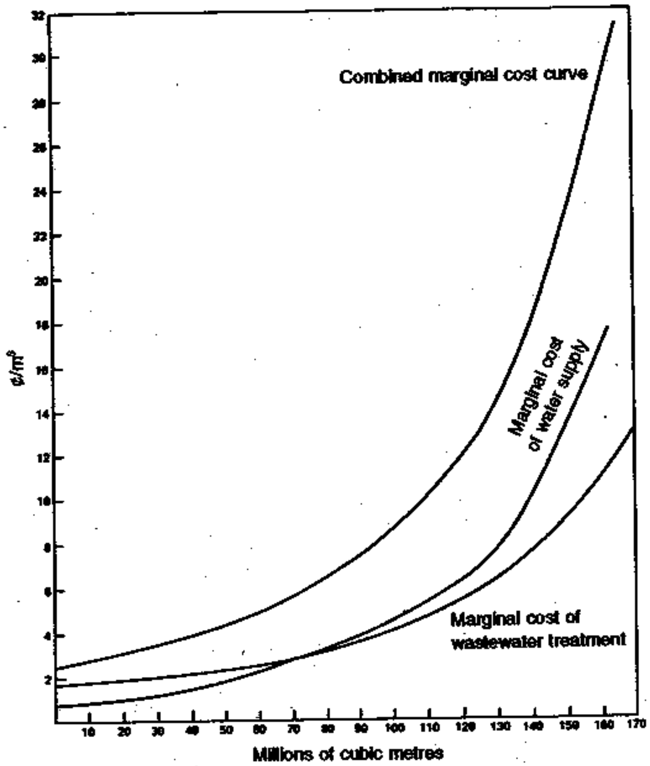


Figure 37. Combined water supply/wastewater treatment marginal cost curve, peak period, Case 1.

Determining the Demand Curves

The utility has been charging a flat rate (zero marginal price) for a number of years, and so there is no record of price variation that can be used in demand curve estimation. This necessitates use of the generic demand curves described in Chapter 5. The most appropriate demand elasticity must first be selected for both the residential and industrial/commercial demand functions. In the absence of more information, the utility selects the mid-value elasticities of -.25 for residential demand and -.7 for industrial demand. The demand curves corresponding to these elasticities are then selected from Chapter 5. The community served is average in its income and has warm but not excessively dry summers, and so the selected elasticities are good first approximations.

During the peak period from mid-May to mid-September, the consumption is 165 million cubic metres. About 60%, or 99 million cubic metres of this total goes towards residential consumption. For 375 000 residential connections, this is equivalent to a monthly demand of about 66 cubic metres per household. This falls between the last two demand curves on the first part of Figure 21. Starting at a value of 66 cubic metres on the lower axis, an approximate demand curve can be drawn by referring to the two adjacent curves. This demand curve is then transformed back into total consumption over the peak period by multiplying monthly consumption per household by the number of months (4) and the number of connections (375 000).

Current industrial demand during the peak period is 66 million cubic metres. The appropriate demand curve lies between the second and third demand curves on the second part of Figure 29, using the lower scale as a reference. Again, an approximate demand curve can be visually drawn, referring to the two adjacent curves. The resulting demand curve represents aggregate peak period industrial demand, and when added to the residential demand curve, the total peak period demand results (Fig. 38).

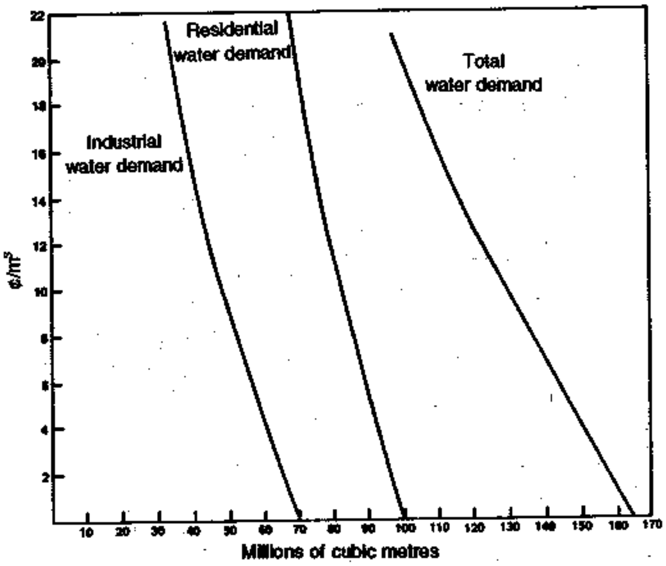


Figure 38. Peak period water demand, Case 1.

In the off-peak season, total consumption is 110 million cubic metres, of which 66 million cubic metres is due to residential demand and 44 million cubic metres is due to industrial/commercial demand. This is equivalent to a monthly demand of 22 cubic metres per household per month. An approximation to this demand curve can be drawn by referring to the adjacent curves that intersect the x-axis at 20 and 25 cubic metres. This demand curve can then be transformed into aggregate residential off-peak demand by multiplying by the number of months (8) and the number of connections (375 000).

The industrial/commercial demand of 44 million cubic metres at an elasticity of -.7 falls below the first demand curve on the second part of Figure 29. The approximate demand curve is determined visually and added horizontally to the off-peak residential demand curve to give the total off-peak demand curve (Fig. 39).

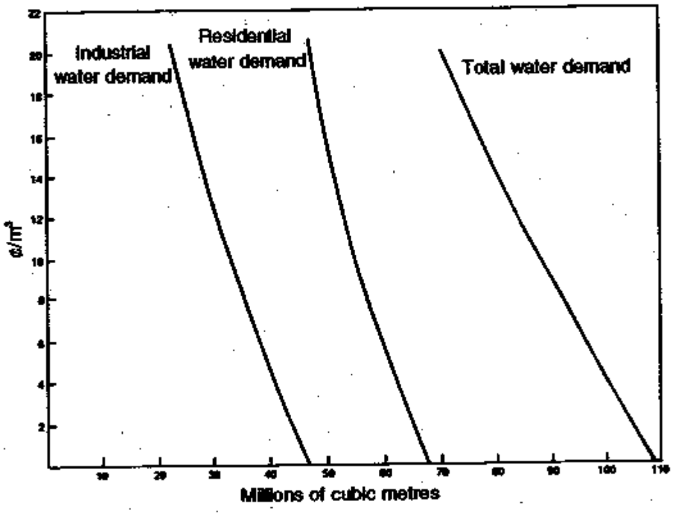


Figure 39. Off-peak period water demand, Case 1.

Setting Peak Period Prices at Intersection of Marginal Cost and Demand Curve

The peak period price should be set at the intersection of the peak period demand curve and the combined water supply and wastewater treatment marginal cost curve for the peak period. Note that the peak period marginal cost curve includes the marginal operating costs and the marginal capacity costs for water supply as well as the marginal wastewater treatment costs.

Figure 40 shows the graph of the peak period demand and combined marginal cost curves with the intersection of the two at the price of \$0.124 per cubic metre. At this price, the demand for peak period water, as can be seen from the figure, would be 122 million cubic metres.

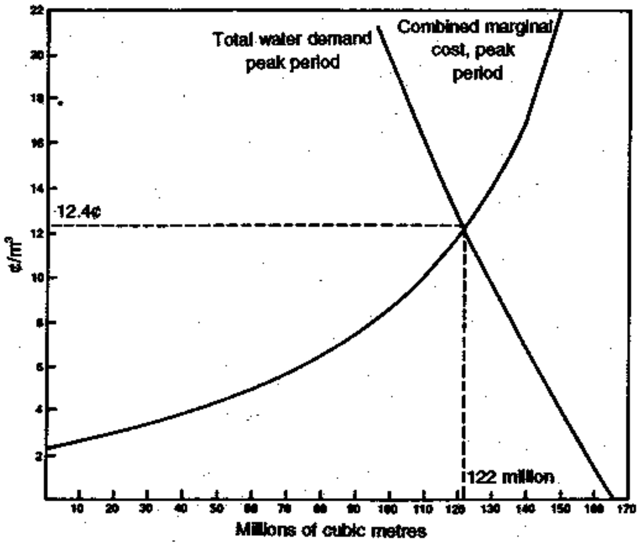


Figure 40. Peak period volumetric price, Case 1.

Setting Off-Peak Prices at Intersection of Marginal Cost and Demand Curve

The intersection of the off-peak demand curve and the combined marginal cost curve determines the off-peak price. (Fig. 41). The combined marginal cost curve for the off-peak period includes the marginal operating costs for the water supply and the marginal waste treatment costs. The equilibrium price is 10.9 cents per cubic metre, resulting in an off-peak consumption of 87 million cubic metres.

Calculating the Fixed Connection Charge

The connection charge aims at generating sufficient revenue to recover any remaining costs not covered by the volumetric charges. The total revenue from volumetric pricing equals:

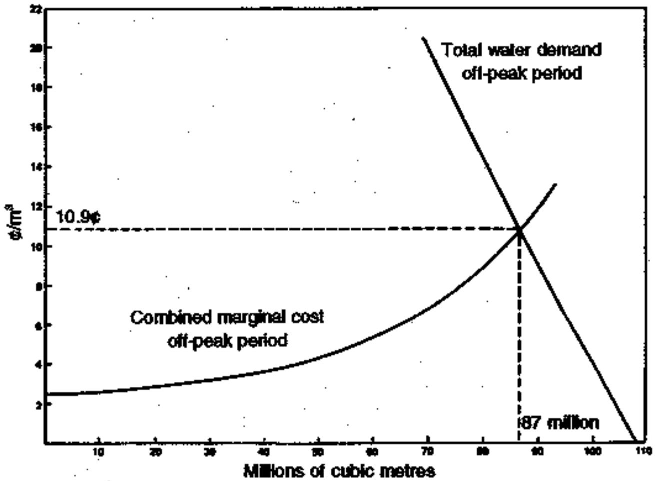


Figure 41. Off-peak period volumetric price, Case 1.

Peak period revenue 122 000 000 m^3 x \$0.124
= \$15 128 000

Off-peak revenue 87 000 000 m^3 x \$0.109
= \$9 483 000

Total......\$24 611 000

The costs can be read from the total cost curves (Fig. 32) for the corresponding water consumption. The total costs equal:

Peak period water supply 122 000 000 m^3
at a cost of \$11 427 000

Off-peak period water supply 87 000 000m^3
at a cost of \$9 022 200

Annual wastewater treatment 209 000 000 m^3
at a cost of \$17 300 100

Total......\$37 749 300

The fixed connection charge recovers the difference between the total revenue and the total costs. Thus, the shortfall equals:

\$37 749 300	total annual costs
- 24 611 000	revenue from volumetric pricing
\$13 138 300	shortfall recovered through connection charge

curve includes the marginal operating costs and the marginal capacity costs for water supply as well as the marginal wastewater treatment costs. Figure 50 shows the graph of the peak period demand and combined marginal cost curves with the intersection of the two at the price of 13.5 cents per cubic metre. At this price, the demand for peak period water, as can be seen from the figure, would be 9.4 million cubic metres.

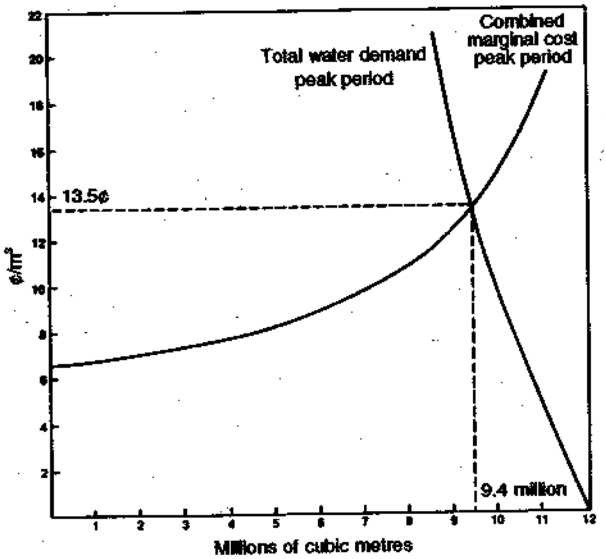


Figure 50. Peak period volumetric price, Case 2.

Setting Off-Peak Prices at Intersection of Marginal Cost and Demand Curve

The intersection of the off-peak demand curve and the combined marginal cost curve determines the off-peak price (Fig. 51). The combined marginal cost curve for the off-peak period includes the marginal operating costs for water supply and the marginal waste treatment costs. The equilibrium price is 9.6 cents per cubic metre, resulting in an off-peak consumption of 10.8 million cubic metres.

Calculating the Fixed Connection Charge

The connection charge aims at generating sufficient revenue to recover any remaining costs not covered by the volumetric charges.

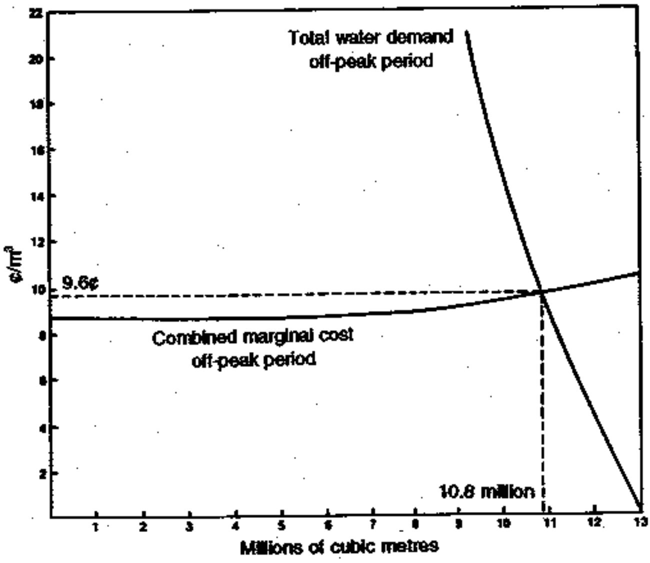


Figure 51. Off-peak period volumetric price, Case 2.

The total revenue from volumetric pricing equals:

Peak period revenue 9 400 000 m^3 x $0.135
= $1 269 000

Off-peak revenue 10 800 000 m^3 x $0.096
= $1 036 800

Total.......$2 305 800

The costs can be read from the total cost curves (Fig. 42) for the corresponding water consumption. The total costs equal:

Peak period water supply 9 400 000 m^3
at a cost of $1 562 000

Off-peak period water supply 10 800 000 m^3
at a cost of $1 519 000

Annual wastewater treatment 20 200 000 m^3
at a cost of $3 190 000

Total.......$ 6 271 000

The fixed connection charge recovers the difference between the total revenue and the total costs. Thus, the shortfall equals:

Table 36

Summary of Rate Schedule, Case 2

	Off-Peak charge	Peak charge	Fixed connection charge
Amount	$0.104/m^3 for all customers	$0.122/m^3 for all customers	$106 per household or industrial/commercial connection
Period	Sept. 15 to May 15	May 15 to Sept. 15	Single annual charge
Basis	Marginal operating cost of water supply *plus* Marginal cost of wastewater treatment	Marginal capacity cost of water supply *plus* Marginal operating cost of water supply *plus* Marginal cost of wastewater treatment	Covers all other costs

$6 271 000	total annual costs
-2 305 800	revenue from volumetric pricing
$3 965 200	shortfall recovered through connection charge

Because the industrial/commercial users are mostly quite small, the utility decides to apportion the shortfall equally among all connections.

The fixed connection charge per customer works out to be:

$3 965 200 / 37 500 connections = $106 per connection

Summary

The pricing schedule for Case 2 is given in Table 36.

This rate schedule is quite different from the Case 1 example, having higher fixed connection charges but lower volumetric charges. The reason for these differences is that in the second case, fixed costs in the form of current debt charges result in a major portion of the current costs. The fixed costs affect only the fixed connection charge and not the volumetric charge. Furthermore, since the utility has recently expanded its wastewater treatment system, no further expansion will be required for several years. Therefore, the marginal cost of future expansion for this system is relatively low, and this is reflected in the lower volumetric prices.

This rate schedule results in an annual cost savings of $649 916 for the utility from current levels and enables expansion to be delayed by several years. Peak period use declines by 21% and off-peak use by 13%. With the addition of a fixed connection charge, revenues are sufficient to recover total annual costs.

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